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Nile Economist Forum – Proceedings

Laico Lake Victoria Hotel, Entebbe, 16-17 May 2017

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1. Background to Forum: scope, objectives, format

The first Nile Economist Forum took place in Entebbe – Uganda on the 16th and 17th of May of 2017, and gathered a total of 44 participants – including representatives from all ten Nile Basin riparian states, the NBI regional centres, as well as a large number of national, regional and international economists. The overarching objective of the Forum has been to generate 'sound economic analyses which is considered to be required to guide decision-making processes, and the development and assessment of policy options and continue to build the case for cooperative management and development of the Nile water resources'. Ultimately, the Forum aims to support the Nile Basin cooperation by broadening the deliberations and thus the solution space of alternative, sustainable management and development options through the inclusion of economic perspectives. This includes analyses and quantification of options beyond the physical volumes of water to include economic valuation of water in alternative uses, so that a broader range of management, development and investment options can be generated.

This Economist Forum represented a first step to establish a sounding board to further the riparian dialogue, sparking new ideas for cooperation, co-development of solutions, and an economic analysis of alternative development options. It has already contribute to enrich the basin-wide discourse on options for cooperative management and development with an economic perspective. Further, it will give place to regular "think tank" of influential economics from across the Nile region to jointly reflect on ongoing economic research on the basin and provide ideas to the Nile Basin cooperation process from the perspective of economic policy-making. This report is an attempt to capture the main discussions and recommendations from the forum, which can be used as a tool to communicate more broadly to decision-makers and the public to add economic perspectives to the basin-wide dialogue.

Scope and Specific Objectives of the First Nile Economist Forum

The First Economist Forum has focused on two perspectives:

1. Scenarios that affect future economic development in the Nile region, including energy and agricultural water demand development, virtual water trade, climate change impacts , all of which impinge on and are affected by changing water availability and use.
2. Policy options for management and development of the scarce basin resources, focusing on the nexus between water energy and food security, the benefits of cooperative water resources management and the contributions a regional integration agenda in energy and agricultural trade and investments can make to resolving water related basin trade-offs.

And the specific objectives were:

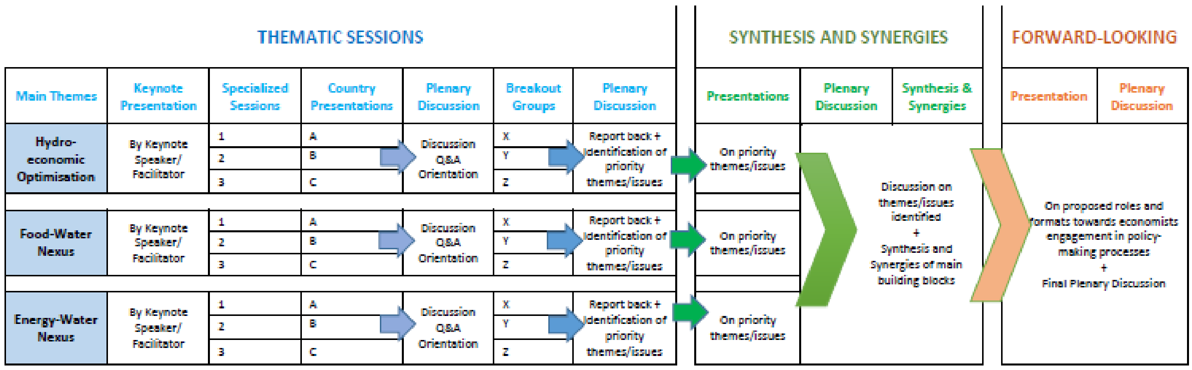
1. To discuss and review the status of analyses and economic thinking on water-related cooperation in the Nile Basin;
2. Get an overview of available tools to assess:
   (a) Hydro-economic optimization to assess policy options for management of shared resources and infrastructure
   (b) Basin-wide trade and economy modelling (CGE, SAM, etc.) to asses sector-wide impacts of various cooperation trajectories
3. To chart out and make recommendations on emerging key policy options for the countries that should be explored as part of the Nile Cooperation process moving forward;
4. Identify the key policy choice variables that can be used as potential building blocks (key policy/ management choices) to develop scenarios for improved cooperative management of the basin under the NBI collaborative water resources assessment process;

5. To identify and build a relationship with economists from the basin who can make a contribution to this;
6. To establish a modus operandi and roadmap for the future of the Nile Economist Forum.

Forum format

The forum has focus on three themes, namely 1) hydro-economic modeling/optimization for efficient water resources management; 2) food-water nexus focusing on integrated and coordinated options for meeting rising food demand in the Nile Basin; and 3) enhancing regional integration of energy systems to leverage the region's considerable untapped hydropower potential. As shown in Figure xxxx below, **for each of these topics a keynote speaker and three specialised speakers were invited to present on very specific topics**, and according to specific ToRs. During the preparation phase, dialogue between the different presenters have been incentivised in order to foster a common thread among the three themes focuses on how options that integrate economic aspects help in addressing the rising water, food and energy demands in the Nile Basin in a more sustainable and cooperative manner.

Figure 1 - Schematic Building blocks of Forum's agenda



The three thematic sessions corresponded to the three themes described above. Each session begins with a keynote/background presentation canvassing main issues of the theme, overview of past and ongoing studies on the Nile and beyond and culminating in a set of key economic-policy issues that are relevant to the ongoing deliberations on cooperative management and development of the Nile Basin water resources. Similar patterns were be followed for the other two themes.

Besides the specialised sessions, there has been **two presentations by national representatives** (economists working directly with the Ministries of Water Resources) from Nile Basin countries, for each of the thematic blocks. These presentations have focused on the experiences, challenges and lessons from member countries on issues relevant to the specific theme of the session. These keynote/specialised/country presentations were followed by plenary discussion moderated by the facilitator.

Finally, the thematic session also included **interactive and constructive breakout groups** that were organised in a way to allow detailed deliberations on selected issues, that have been captured in this document and that can be used later in the strategic processes. Finally, a guided exercise on synergies/synthesis took place with the double goal of **Identifying Building Blocks and Key Options,** that can later be used to promote further engagement of economists on Nile cooperation issues.

In the Annexes, the detailed agenda can be consulted – which includes information about the topics, the presenters, the structure, etc. Bios for all the keynote and specialised presenters is also included at the end.

2. Thematic Session 1 – Hydro-Economic optimisation for efficient water resources management in the Nile Basin

The first thematic was dedicated to the topic of Hydro-Economic optimisation for efficient water resources management in the Nile Basin, and followed the format described above: A keynote address setting the scene, Three specialised topics on key related topics, Two presentations by senior economists of the Nile countries, and Breakout sessions where main priority issues/messages on the first thematic block were identified collectively. This section aims at summarising the main points of the several presentations, the discussions and the main forward-looking messages commonly identified by the participants.

"Hydro-economic Modeling for efficient water resources management in the Nile Basin, Keynote Address by Prof. Marc Jeuland

The keynote presentation has focused on three main axes: 1) Brief review of hydro-economic modelling approaches; 2) Examples from the Nile (mix of traditional and non-traditional); and 3) Interdependence and trade-offs: looking at the example from the Ganges River Basin; 4) Back to the Nile: analysing infrastructure options under uncertainty.

A first guiding question posed by the speaker focused on**: "What is hydro-economic modeling?".** Hydro-economic models represent regional scale hydrologic, engineering, environmental and economic aspects of water resources systems within a coherent framework (Harou et al., 2009). Hydro-economic models are solution-oriented tools (not descriptive) for discovering new strategies to advance efficiency in water use. They are also entail a shift away from prescribed quantity-based "targets", and reliance on a single metric – the economic value of water (and away from multiple objectives). A follow-up question focused on **How can hydro-economics can and have been applied**. A review of applications by Bekchanov et al. (*forthcoming*) shows that: much work was been done on economic sensitivities, trade-offs, water efficiency, water pricing and trade; but relatively less on ecosystems, feedbacks, water-energy-food nexus.

A traditional deterministic approach to hydro-economic model is usually based on: An Optimization model that helps planner choose infrastructure (e.g. where, how big and wherein Economics enter the objective function, which is in $ and the typical objectives include market output valuation and/or penalty functions). This traditional approach relies on historical flows (stationarity). The exploration of future changes by: a) Specifying changes as decision variables controlled by planner; or b) Creating scenarios of development for factors outside planner's control. The typical misconception: hydro-economic modelling is usually for planning purposes, not for operations. Some of the limitations of the traditional approach have been identified, such as: 1) Assumption of perfect foresight (deterministic flows); 2) Water planners are generally risk averse ; 3) Water planning challenges optimization (even stochastic); 4) May not account well for option value (irreversibility, learning). But these limitations can be overcome through some advances such as: Various methods extensions to simple deterministic optimization (for example combining Optimization with sensitivity analysis; utilisation of Stochastic methods, Robust optimization and robust decision making, etc.

What are the hydro-economic model to design and apply? There are several basic design choices, summarised in Table 1 below. The choice between the different options depends on: the final objective of the deploying the model, for example if it to inform policy, promote uptake, or work at the cutting edge of methods. The deployment of multiple models is also a possibility and it has some advantages: such as replication and convergent validity; although ultimately it might lead to problems of inefficiency. And **which models have been already applied to the Nile Basin**? Tables provide a summary of main eight hydro-economic studies on the Nile (conducted/published between 2005 and 2017), and the specifics on the model type, flows, uncertainty and integration being used by the different studies. It also refers to the main topics covered by them: if it economy-wide, or if they cover specific sectors or issues such as irrigation, hydropower, flood control and siltation. Table 3 provides more specific information regarding the 8 studies on issues addressed (infrastructure, specific dams, cooperation, etc.), as well the key findings and main policy messages of each of the studies.

Table 1. Basic design choices in hydro-economic models

Options	Description	Comments
Model type: Optimization Simulation	-What strategy is best? -How does strategy perform if…?	-Flexible solution space, but may be unconvincing or challenge solvers -Computational advantages, realistic rule representation, but may underperform
Flows: Single series Stochastic series'	-Historical or synthetic series -Sampling from stochastic series'	-Intuitive comparisons for managers / decision makers, but future may not be like the past -More thorough incorporation of variability, but less intuitive, may also misrepresent future
Uncertainty: Scenarios Risk-based Other	-Best-worst / ranges -Well-specified prob. distributions -No or partial prob. distributions	-Deterministic and simple, but asking a lot -Amenable to standard methods in decision analysis, but assume away "deep" uncertainty -Perhaps most relevant, but may challenge decision-making
Integration: Modular Holistic	-Linked models run separately -Single integrated platform	-Well adapted to disciplinary realities, but clunky to use and hard for interdependencies -Allow modeling of feedbacks; but solutions are hard, may require simplification

Table 2 and Table 3. Hydro-economic examples from the Nile

Author(s)	Year	Model type	Flows	Uncertainty	Integration
Wu et al. (NEOM)	2005; 2006; 2016; 2017	Optimization	Deterministic	Flow, dams, energy value	Holistic (Full basin)
Strzepek et al.*	2007	Optimization (CGE)	Deterministic	Capital shocks	Holistic (Egypt)
Block (IMPEND)	2010	Optimization	Deterministic	Climate scenarios	Holistic (Eastern Nile)
Jeuland (3 linked models)	2010a, b; 2014	Simulation	Stochastic	Flow; development	Modular (Full basin)
Halleux; Goor; Arjoon et al. (Nile SDDP)	2009; 2010; 2014	Optimization	Stochastic	Infrastructure	Holistic (East. Nile)
Dinar	2013; 2015	Optimization	Deterministic	Initial rights	Holistic (East. Nile)
Geressu et al.*	2015	Optimization	Deterministic	Weights for decision vars.	Holistic (East. Nile)
Satti et al. (SHOM)	2015	Optimization	Deterministic	Flow; prices; development	Holistic (Nile in Sudan)

Irrigation; Hydropower | Economy-wide | Irrigation; Hydropower; Flood control | Irrigation; Hydropower; Siltation

Author(s)	Year	Issues addressed	Key findings / policy messages
Wu (NEOM)	2005; 2006 2016; 2017	Upstream infrastructure Politics & water rights	*Cooperation: Much potential for benefits *Distribution of benefits strongly depends on institutions (degree of cooperation) *Power trade really important
Strzepek	2007	Aswan Dam	*HAD has had large multi-sectoral impacts
Block (IMPEND)	2010	Blue Nile dams	*Accounting for reservoir filling & El Nino-like climate decreases net benefits
Jeuland models	2010a, b 2014	Blue Nile dams	*Climate change affects dams' benefits via several pathways *Large benefits; more & smaller dams are best; cost of investment delays is high
Nile SDDP	2010 2014	Downstream risks post GERD	*Evaporative savings from coordination *Large benefits; Downstream externalities could be positive, even in dry years
Dinar	2013; 2015	Cooperation on the Blue Nile	*Fragile basis for cooperation; GERD adds benefits; results sensitive to rights distribution
Geressu et al.	2015	Blue Nile dams	*Significant tradeoffs across objectives
Shom et al.	2015	Sudan tradeoffs	*Ag-power tradeoff limits irrigation in Sudan

Next, the keynote speaker used the example of the Ganges River Basin to provide a **critical discussion on issues of Interdependence and Trade-offs**. The Ganges case was one of very first international case studies for hydro-economic optimization. One of the main observations was that past hydro-economic might have overhyped interdependence, namely by reflecting perhaps India's hegemony perhaps, and the fact that negotiations over developing the Ganges have largely proceeded along bilateral lines. The main question raised was: can misconceptions and misplaced belief in interdependence raise barriers to pragmatic development? The story of interdependence has also been determinant in the understanding of trade-offs in the Ganges Basin, namely by emphasising: no meaningful trade-off between hydro and other objectives in this system; and that trade-off hinges on water consumption for upstream irrigation versus downstream ecosystem services. On the other hand, there is the belief in interdependence may be obstructing development. Another possibility is that uncertainty and risk impede cooperation. The example of the Ganges served as a good introduction to understand the potential and limitations of hydro-economic models to understand the real options (and assess their robustness) in the Nile Basin, in particular the Blue Nile Basin.

How to assess the robustness of real options for the (Blue) Nile and the **role of vulnerability – in particular climate vulnerability - plays in the hydro-economic models** were central pieces of the last part of the presentation. The main highlights are that: 1) vulnerability is also a function of development and adaptive capacity; 2) dealing with climate change is a new manifestation of a much older planning problem with uncertainty. And how can **issues of variability and vulnerability be incorporated in the choices of design in hydro-economic models**? Table 4 provides a summary of the design options and respective description. An application of a Modular Approach for example links different modules - Streamflow generation model, Hydrological simulation model, Economic simulation model – together with **Climate Scenarios** (and respective Economic climate linkages, such as value of water in agriculture and energy, etc.).

Table 4. Nile Modeling Framework Choices

Options	Description	Comments
Model type: Optimization	-What strategy is best?	-Flexible solution space, but may be unconvincing or challenge solvers
Simulation	-How does strategy perform if…?	-Computational advantages, realistic rule representation, but may underperform
Flows: Single series	-Historical or synthetic series	-Intuitive comparisons for managers / decision makers, but future may not be like the past
Stochastic series'	-Sampling from stochastic series'	-More thorough incorporation of variability, but less intuitive, may also misrepresent future
Uncertainty: Scenarios	-Best-worst / ranges	-Deterministic and simple, but asking a lot
Risk-based	-Well-specified prob. distributions	-Amenable to standard methods in decision analysis, but assume away "deep" uncertainty
Other	-No or partial prob. distributions	-More like the real world, but may challenge decision-making
Integration: Modular	-Linked models run separately	-Well adapted to disciplinary realities, but clunky to use, may ignore interdependencies
Holistic	-Single integrated platform	-Allow modeling of feedbacks; but solutions are hard, may require simplification

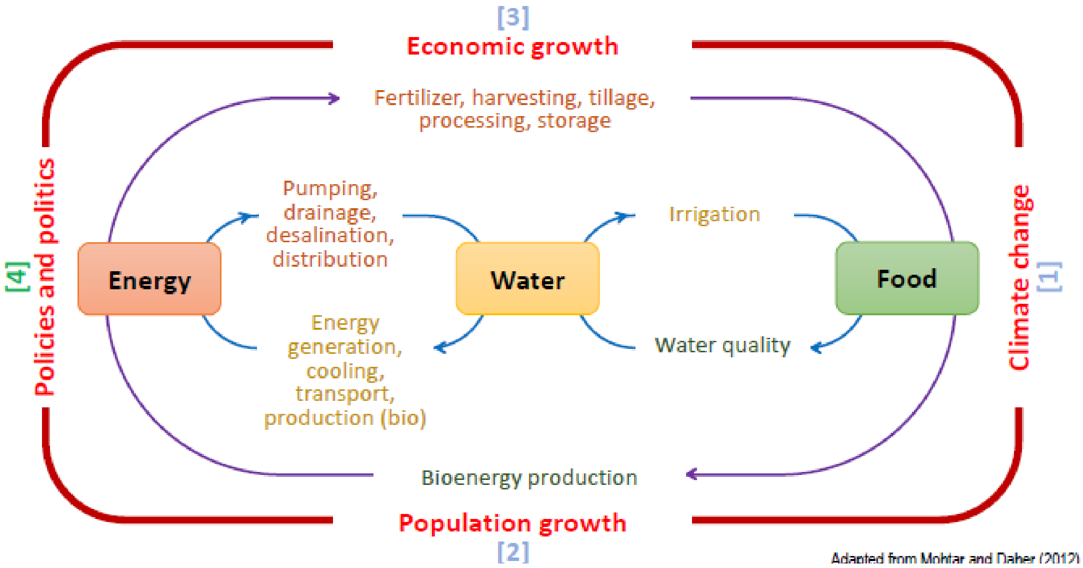
One of the main difficulties associated with decision analytic framework is that it might be unwise to assign probabilities to climate change (and development) predictions, because of: the uncertainty of future mitigation; the model uncertainty and proliferation; and technical climate-hydrology issues. The approach suggested – and applied specifically to hydraulic projects in the Ethiopian Blue Nile – consists of: 1. Study the relative a) downside risk, b) expected NPV, and c) upside potential of **planning alternatives** across model experiments; 2. Build in flexibility: "Real options" (Oversizing, site selection); and, 3.Compare each with outcome of "best option", identify alternatives that balance risks and rewards across conditions (robustness).

The final discussion was the **value of using this approach**. Firstly, one can see which factors contribute most to variation in outcomes – for example to assess if they are mainly physical, or economic? (one of the conclusions is that they are mainly economic). Second, one can better understand the relative performance of options (one of the conclusions is that more and smaller dams limit risk and capture upside). Third, one can assess the "relative" cost of building specific projects. And, fourth, one can assess the cost of delay, in terms of lost net present value (and a main conclusion is that building without delay is very valuable).

"Water in National Economies: Utilization, Challenges, Valuation" - Specialised presentation by Dr. Khalid Siddig

The presentation started by looking at the role of water in an interconnected economy, namely on how it is intimately interlinked with the energy and food sectors, and how the three sectors are interconnected in a system where challenges such as Climate Change, Population Growth, Economic Growth and Policies and politics frame the decision-making process. Figure 2 provides a simplified representation of the several interlinkages.

Figure 2 – Water in an interconnected economy



How do the **four common challenges influence the economic value of water in the national economies of Nile Basin** countries? We hereby provided a brief summary of the main highlights.

1. **Climate Change.** The annual flow is limited to 84 billion cubic meters (commonly accepted natural average), but recent studies show a standard deviation describing that the interannual variability is increasing by 50% in the 21st century (Siam and Eltahir, 2017). This is expected to have severe impacts in agricultural productivity in the next decades – based on the IMPACT model, the presenter gave examples impacts under different climate scenarios for several crops, such as Wheat, sorghum, vegetables, sugarcane and groundnuts.

2. **Population growth:** Nile Basin countries make 487 million (Akolet al., 2016). Expected to double by 2050 (1 billion) (Siam and Eltahir, 2017). Basin population is 257 million (53%of total Basin countries population). This is expected to exceed 300 million in 2025 (Salman, 2016).

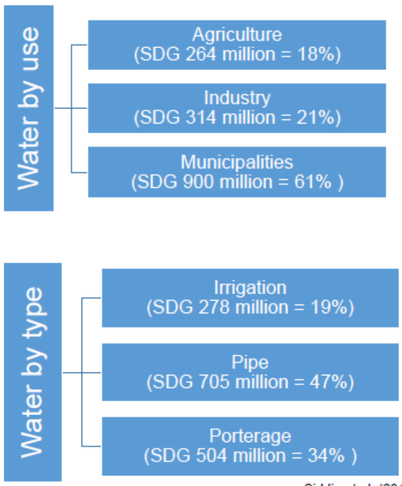
3. **Economic growth.** Asymmetries of economic growth among (Eastern) Nile Basin countries were presented, as well as figures regarding the agriculture-based growth for the same countries. And although the trend is a declining one, the fact is that the value added of the agriculture sector to the GDP of the countries is still a very significant one. This also includes irrigation-based agriculture, with its respective high demands for water.

4. **Policies.** It looks on how much freshwater withdrawals and how this water is being utilised per economic sector, and concludes that Water productivity (constant 2010 US$ GDP per cm of freshwater withdrawal) is 3.0%, 2.6%, 4.2%, and 14.4% in Egypt, the Sudan, Ethiopia and South Sudan, respectively.

By looking at the current policy oriented assessments it is possible to calculate the value of water. The presenter gives an example of Sudan. Figure 3 summarises what is the value of water per sector (agriculture, industry, municipalities) and the type of water (agriculture, pipe, porterage).

Figure 3 – Value of water per sector

Agriculture	SDG m	Industry	SDG m	Households	SDG m
Cotton	14.6	Crude petroleum	5.2	Rural hhs Q1	9.5
Csorghum	24.5	Mining and quarrying	0.6	Rural hhs Q2	19.6
Wheat	11.2	Food and beverages	14.8	Rural hhs Q3	29.3
Maize	2.0	Textile and paper	0.9	Rural hhs Q4	40.1
Groundnuts	13.5	Wood	0.1	Rural hhsQ5	54.5
Millet	2.0	Reined petroleum	0.6	Urban hhs Q1	123.1
Sesame	15.2	Non-metallic products	15.9	Urban hhs Q2	152.4
Sugar	18.5	Basic metal	17.1	Urban hhs Q3	153.6
Fruits	28.8	Fabricated metal	2.4	Urban hhs Q4	162.2
Vegetables	28.3	Other manufacturing	0.2	Urban hhs Q5	155.4
Beans	23.1	Hydro electricity	0.5		
Sunflower	3.1	Thermal electricity	0.6		
Other crops	17.0	Irrigation water	23.7		
Cattle	11.2	Pipe water	6.2		
Sheep	14.1	Porterage water	13.6		
Goats	11.8	Construction	53.0		
Poultry	1.7	Trade	37.8		
Other livestock	9.2	Restaurants & hotels	19.6		
Milk	13.6	Air transport	16.3		
Eggs	0.3	Road transport	34.5		
		Rail transport	1.8		
		Water transport	5.4		
		communication	5.0		
		insurance	0.2		
		Business service	18.1		
		Public administration	17.4		
Total SDG m	**264**	**Total SDG m**	**414**	**Total SDG m**	**900**
% of total	**18%**	**% of total**	**21%**	**% of total**	**61%**



Siddig et al. (2016).

"Investing in infrastructure considering Nexus and transboundary dimensions" -Specialised presentation by Prof. Julien Harou

The presentation have shed light on **Trade-off Analysis and its role in seeking efficiency across multiple criteria**. And then discussed how this analysis can be applied to the Nile, namely when discussing and deciding over: 1. Efficient new dam portfolios; 2. Scheduling new reservoirs; and, 3.Adaptive filling of new reservoirs.

As an initial step for the discussion, the 'Pareto-optimal' was defined in order to understand what the trade-off curve is (based on defined criteria). And then applied to water systems: link river basin simulation to **multi-criteria search to identify efficient trade-offs**. Using the example of the London water supply, and having reliability and capital cost as criteria, it is possible to calculate the "least cost solution" or "perfect reliability solution". Taking the analysis further, it is possible to **analyse the trade-offs in large systems**, such as country level or even larger systems such as river basins. Ultimately this analysis can inform processes of **negotiations of trade-offs** between the different parties involved.

The initial discussion about Trade-off Analysis informed the rest of the presentation on how to apply to the Nile context, having in mind a series of key features: a) Seasonal and inter-annual variability of flows; b) Downstream impact of any new upstream dams (especially during filling); c) Development potential. The initial point of departure were the plans including some of the proposed dams in the Blue Nile in Ethiopia, wherein the three main questions were addressed:

1. Efficient portfolios of new Nile dams. Figure 4 below indicates a number of portfolios having in mind cost and energy production as criteria. Each shape is an efficient portfolio of dams, their sizes, and operating rules. This is part of a larger analytical piece that aimed at screening reservoir systems by considering the efficient trade-offs and that ultimately can inform infrastructure investment decisions on the Nile Basin. An extension of this analysis is that it can be used in processes of negotiating new dams by exploring trade-offs, for example not just taking into account costs and energy production, but as well annual irrigation surplus/deficit, as exemplified in Figure 5.

Figure 4 – Portfolios of new dams in the Blue Nile

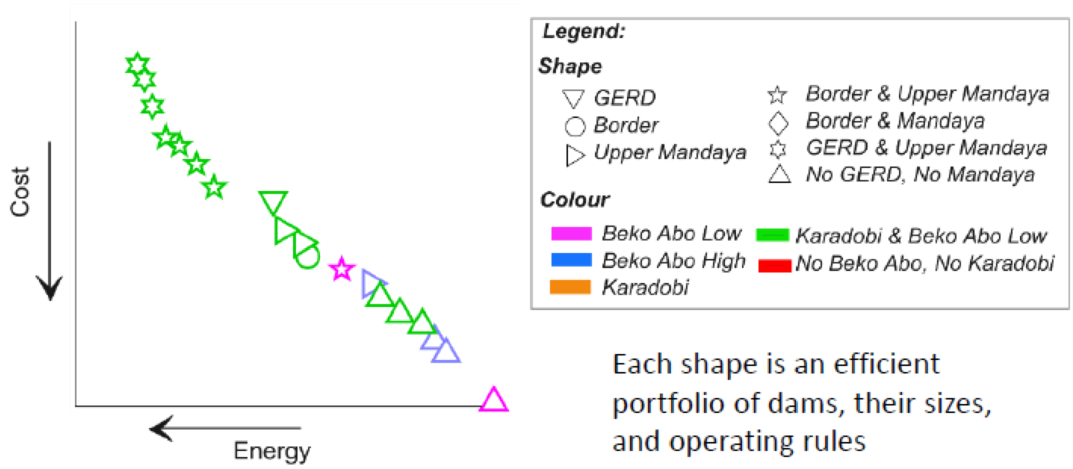
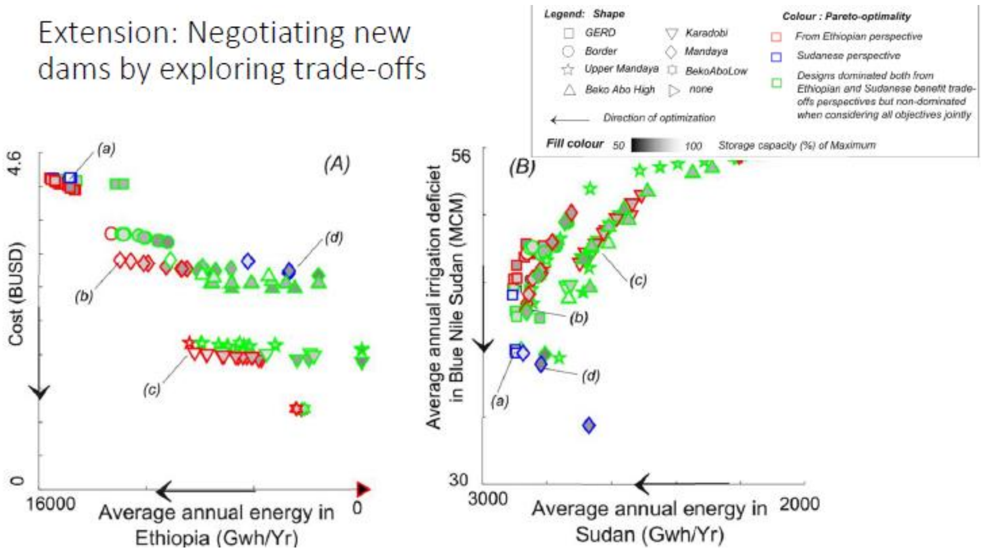
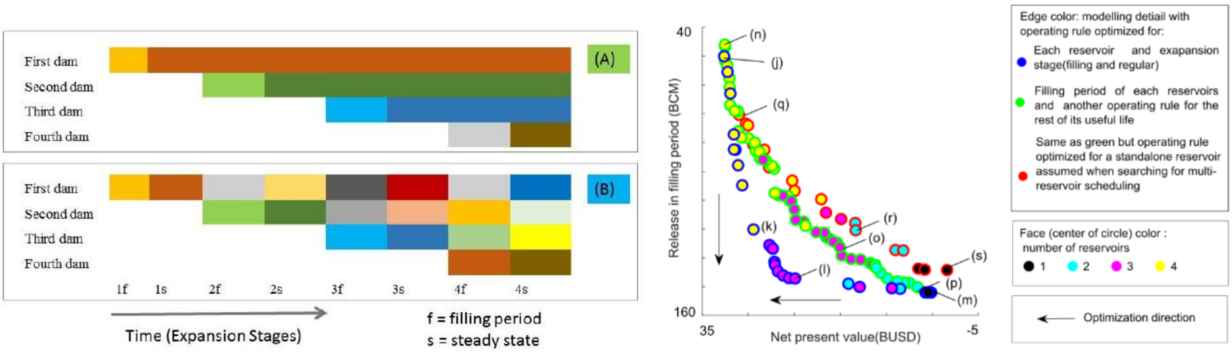


Figure 5 - New dams and trade-offs



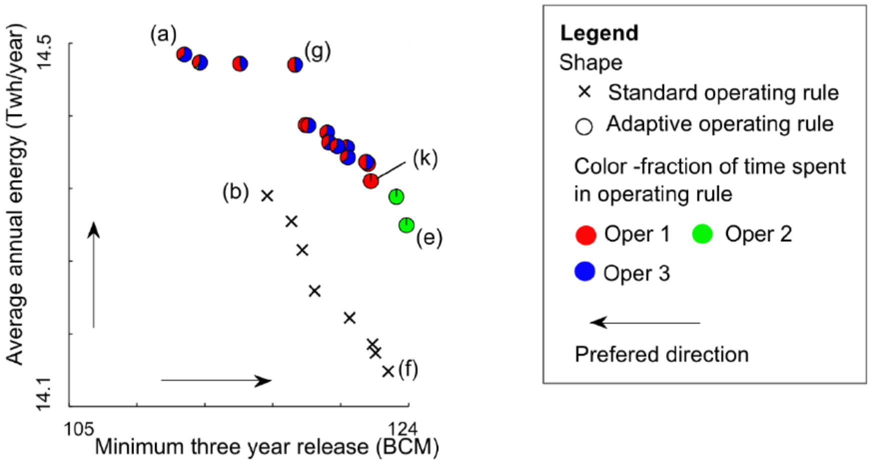
2. Scheduling new reservoirs. In this section it was discussed on how better stage and prioritize new dams if the operating rules are optimized during the successive filling phases of new reservoirs, as represented in Figures 6 and 7.

Figure 6 and 7 – Filling phases



3. **Adaptive management of new reservoirs.** The third section discussed on how to optimise new dams assuming that release rules adapt to recent conditions.

Figure 8 – Adaptive operation



Some of the conclusions regarding the application of the **Trade-off Analysis** to the Nile Basin are:

1. Efficient portfolios of new dams & their operation can be designed to carefully weigh the many different benefits;

2. Scheduling new reservoirs should consider that operating rules can change during filling;

3. Filling of new reservoirs should adapt to available water to minimise negative downstream impacts;

And ultimately:

• Economic (efficient) system planning and management benefits from representing many competing criteria of success;

• Trade-offs show opportunity costs, but without requiring the monetization of all metrics;

• Trade-off analysis is visual, intuitive and interactive – it is helpful to build understanding and trust for complex negotiations.

“Hydro-economic optimization- Economic-based solutions for Nile Challenges”- specialised presentation by Prof. Amaury Tilmant

As a starter, the fundamental questions of **what is and why to use a Hydro-economic modelling**? was addressed. A Hydro-economic model can be understood as an analysis of the water economy of a regional water system (e.g. river basin, country), wherein the model integrates essential hydrologic, institutional and economic processes in the system. Eventually (or ideally) it can provide decision-makers with information about fundamental issues such as: Optimal flow allocation between competing uses, Economic information (shadow prices, marginal values), etc. The presenter also mentioned why **applying an hydro-economic model can be challenging in the Nile Basin context**. It was mentioned that there are several obstacles to moving closer to the system-wide optimality, namely: a) Presence of multi-dimensional trade-offs (space, time, economic sectors, countries); b) Investment planning; c) Operational management of the system.

A second set of discussion have looked at the **Benefits of cooperation and coordination in transboundary river basins.** An example of Cooperation can be Strategic (investment) planning. An example of Coordination would be join Operational management. Finally, it is considered that there are different levels of cooperation that can range from ‘No cooperation/coordination’ to “Full cooperation/coordination. Having this in mind, one can consider have a Hydro-economic modelling of three possible levels of coordination/cooperation

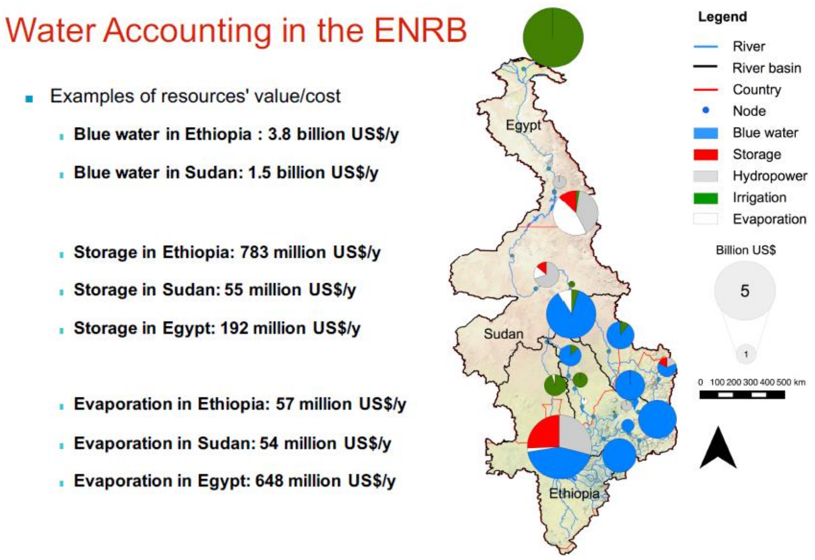
1. Centralized hydro-eco optimization Maximize expected basin-wide net benefits across sectors

2. Decentralized hydro-eco optimization Maximize expected benefits in the upstream riparian country, then move to the downstream riparian, and so on.

3. Decentralized hydro-eco optimization BUT with customized SDDP formulations for the downstream riparian to account for the availability of data in the upstream countries.

Using the GERD & irrigation expansion in the Eastern Nile River basin as examples is possible what are: 1) the **advantages of a coordination/cooperation** (the coordinated operation of GERD with the Sudanese and Egyptian reservoirs (S2) yields a 4% increase in power output from the Sudanese generators with negligible gains and losses in Ethiopia and in Egypt respectively), and, 2) **Cost of non-cooperation** in the Eastern Nile River Basin, namely the associated Basin-wide impacts of unilateral irrigation developments in Sudan and Ethiopia. The presentation also introduced the participants to **Water Accounting applied to the Eastern Nile Basin**, as seen in Figure 9 below.

Figure 9 – Water Accounting in the Eastern Nile River Basin



As conclusion, it was highlighted that in order to operationalise the benefit-sharing in the EN Basin there is a need for an institutional arrangement in order to: maximize basin-wide economic welfare and equally share generated benefits using bankruptcy methods.

Hydro-Economic Modelling and Optimisation: Reflections by countries

Before the Forum took place, the organisers have invited the Nile riparians to provide a first set of reflections regarding the three thematic blocks, based on guiding questions. Below some of reflections on the first theme – by Ethiopia and Kenya – as presented during the Forum.

1. How are water-related **economic aspects** (economic value of water; economic efficiency for guiding inter-sectoral water allocation and trade-offs, etc.) integrated in your **national development planning**?

2. Do you have any **specific study** of best practices from your country regarding the aspects above? If yes, please share the main **highlights**. If not, please explain what are the **obstacles/challenges**?

ETHIOPIA	KENYA
1. Water-related economic aspects in national planning • Water-related economic aspects are considered through the application of economic modelling procedures in water resource development projects. • Water resource development programs are essentially assessed based on hydro-economic models • Hydro-economic models that integrate hydrologic and economic issues are best-suited and commonly applied for evaluating water resource development programs • Hydro-economic optimization models are applied in two major cases (Basin resources development master plan studies; and Assessing basin-wide water resource allocation options in the Eastern Nile Basin) **The first case: Masterplan studies** •The major objective: ensure optimum use of resources with minimum environmental impact •The method: Economic Resource Optimisation and Allocation Model (EROAM) - The model maximizes the economic value of the use of resources under constraints of water, land and labour availability **The second case: Assessing basin-wide water allocation options** • The objectives: Analyse Nile water treaties in the light of international water laws; Devise mechanisms on more equitable allocation of Eastern Nile water resources among the riparians; Assess the benefits of cooperation on the Eastern Nile basin • The method: cooperative game theoretic model based on hydro-economic model – 1) Hydro-economic model maximizes the economic value of water for agricultural production and hydropower generation subject to water balance equation and environmental flow constraints; 2) Cooperative game theoretic model devises cooperative water allocation mechanisms based on the Hydro-economic model	**1. Water-related economic aspects in national planning** •Kenya's water policies had recognized water as a social good until the National Water Policy of 1999 which recognized water as an economic good. •Water Services Providers were created and mandated to provide water on commercial basis for cost recovery. •There is however a lot of government subsidy in the provision of water in Kenya especially under the water infrastructure. •The 3 main water uses in Kenya are; □ Domestic water use □Irrigation water use □Industrial water use •Out of these uses, water is an economic input in sectors like agriculture, tourism etc •Water abstraction surveys are carried out regularly in Kenya in order to establish the demand against the available water. •Clean and safe water in adequate quantities is a basic human right as per the Constitution of Kenya hence domestic water takes precedence therefore trading off some economic benefits that would have been realized.
2. Best Practices studies – main highlights/challenges •Hydro-economic optimization models have attractive features: encompass hydrologic and economic details •Several studies applied hydro-economic optimization models to analyse the economic effects of infrastructure development on the Ethiopian part of the Blue Nile River •The findings of the studies reveal that: 1) Water development for hydropower generation in Ethiopia will not have significant adverse effect on downstream countries; 2) Cooperative water resource development generates significant basin-wide economic benefits in the Nile basin •Main challenges: Partial equilibrium nature of the model; Limited national capacity in designing and implementing state of the art hydro-economic optimization models; Implementation of results from basin-scale hydro-economic models are hindered by institutional problems	**2. Best Practices studies – main highlights/challenges** •No specific study. •However, the Government of Kenya is constructing both large and medium sized dams in order to increase the water storage capacity in the country.

Outcomes of Breakout Sessions, Plenary Discussion and Synthesis of Theme 1

After the several different presentations, all the participants (both international and national economists, as well as the official technical representatives from the countries – the Nile-TAC members) had the opportunity of joining productive and constructive working groups. The small group discussions aimed at the **identification of the key priority issues/themes** that need to be further explored, and that can be used as **building blocks to develop scenarios for more efficient water management under the NBI collaborative water resources assessment process**. These two goals have served as a prior orientations for the breakout sessions. Below is a summary/synthesis of the main questions identified by the four groups:

GROUP A

- In a hydro-economic analysis, it is important to consider multiple objectives and address the trade-offs involved rather than basing our decision on a single objective, including environmental sustainability (ecological integrity; sustenance of the aquatic systems)
- Often decisions in WR are made to minimize conflicts. How do you quantify conflicts and integrate this as a factor in hydro-economic analysis?
- How do you strike a balance in meeting your policy objectives and ensuring that water is used in most efficient ways?
- How do we integrate economic aspects in our national water resources planning? And transboundary levels?
- How can the economic analysis can help us in analyzing the tradeoffs (and decisions) between local production vs imports in a water scarce condition? (food , energy)
- How can the (hydro) economic analysis help to determine the proper scale of our interventions (small or big) in view of the uncertainty on economic variables? (spatial, temporal scales as well taking into account costs and benefits)
- What kinds of metrics can be used in hydro-economic analysis in tradeoff given that the economies of countries are highly varying and concept of benefits and impacts are different?
- How can NBI raise the awareness of the stakeholder on value of water (rational use of water), value of cooperation; and institutional capacity?

GROUP B

1) Benefits
- Aggregate benefit: how can we maximize the aggregate economic benefits from the Nile under any cooperative or non-cooperative intervention in the Nile basin measured in GDP growth-related indicators and/or welfare measures?
- Benefit sharing: what mechanisms can be adopted to assure a fair sharing of the accumulated benefits?

2) Water value: how can associate value with water use in the entire basin?
- There should be a unified water prices across sectors and regions of the basin.
- Prices for the different sectors are needed: Agriculture, Industry, Municipalities, Energy, and Ecosystem services
- If that became strictly difficult, countries my tax or subsidize certain sectors and/or uses of water

3) Starting values for estimating the benefits:
- What starting values are to be used against which the economic benefits are calculated?
- Countries and sectors vary in their use of water. Therefore, the starting value hugely influences the calculation of the benefits.
- This question could initially benefit from what have be adopted by NBI, in which NBI used the master plans of the individual countries as starting point.

GROUP C

- Choice of performance measures is important e.g. land versus water productivity.
- Accommodate multiple visions of economic benefits e.g. considering total hydropower production versus firm energy production (high reliability energy)
- Does using economic analysis imply market driven management? It is important that different countries and sectors have a say on how economic performance is evaluated.
- Including performance measures that represent negative effects, e.g. floods
- Is the economic evaluation of impacts useful? Yes, both in the basin-wide and economy wide context
- Location specific or economy wide model? (Both are valuable but may become more useful when integrated)
- Evaluation of infrastructure portfolios also includes their institutional arrangements.
- Is economic analysis useful to study water shortages? Yes, because economics management is particularly useful under scarcity.
- How can economic models inform decision making in national policy with regard to sustainability?
- Can the tools accommodate long term structural economic changes?

GROUP D

- How does CC affect the economy or the way you do business (CC affects power generation, food production)?
- Does it make economic sense to practice water-intensive agriculture in areas of high-evapotranspiration? (relative comparative advantage); How do you diversify agriculture based on relative water shortages? Too expensive for upstream countries to buy expensive produce from downstream countries
- What is the economic value of ecosystem services?
- What is the economic value of watershed management (avoided sedimentation)?—There have been a number of studies on the cost of siltation. Reservoirs have to be increased. Cost of siltation in Gezira is included. Not yet included in Hydro Economic modeling studies.
- Focus on comparative advantage—some countries have potential for HP, others for irrigation, what kind of allocation would generate maximum value and still benefit everyone. [F.ex. ETH and EGY to produce HP and send to UGA, UGA to send food Downstream]
- What is the economic value 1 cubic meter of water?
- Need to know economic policies affecting profitability of agriculture (tariffs differ by country)
- Marginal value of water and how to estimate it—is it close to zero?
- What is the full economic value of water?
- In the end, not even economic realities often convince policymakers, politics matters more
- What is the economic value of groundwater?
- What is the economic cost of pollution? What is the cost of remedial measures?
- What is the economics around wastewater reuse?
- Competition between agriculture and hydropower is growing (Hydropower more profitable but agricultural more important from social aspects)

3. Thematic Session 2 – Food-Water Nexus: Leveraging basin-wide opportunities for addressing food security challenges in the Nile Basin

The second thematic was dedicated to the topic of Food-Water Nexus, and followed the same format as the previous session:

- A keynote address setting the scene
- Three specialised topics on key related topics
- Two presentations by senior economists of the Nile countries
- Breakout sessions where main priority issues/messages on the first thematic block were identified collectively

This section summarises the main points of the several presentations, the discussions and the main forward-looking messages commonly identified by the participants.

"Water & Food in the Nile Basin", Keynote Address by Dr. Bart Hillhorst

The presentation started by reminding the audience of the **connections between Water and Food**, namely that worldwide, 70% of freshwater use is for crop production, hence the water challenges are closely tied to food provision. It was highlighted that the **Agriculture sector is the dominant component of the water demand function**. This takes us to the Concept of Water Footprint, and an estimation of what are the typical water requirements of several agricultural products, as exemplified in Figure 10 below.

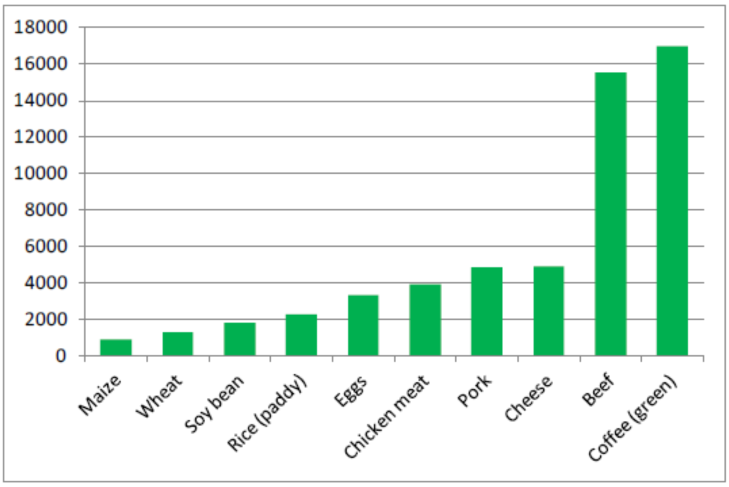


Figure 10 – Water Footprint of agricultural products

The understanding of the concept of Food Security, and its several dimensions, is central to discussion about the Water Food Nexus. In the Nile Basin, food for human consumption is the main element of the agricultural demand function. Two citations were used to exemplify the centrality of food and water in the socio-economic and political dimensions of a society: "Civilization and anarchy are only seven meals apart" (Spanish proverb); and, "It is costly to achieve water and food security….., but not nearly as costly as failing to achieve them" (Julian Cribs).

Demand for food in the Nile Basin depends on combination of different drivers. First and foremost, the Population growth factor (53% growth from 2010 to 2030, according to medium projection). Besides, as an outcome of Economic growth/development, there is an increasing calorie intake that comes along with rising income (from <2,000 to 3,000 kcal/caput/d) and also a changing diet - from cereals to meat. Other drivers associated with food exports and imports dynamics within the Basin and with outside the region also have an impact on the changing food demand levels. According to studies, the typical evolution of nutrition fast-growing economies, shows that there is an initial fast growth that comes with rising incomes, and that level off at around 3,000 kcal/person/day. As the Figure 11 below highlights, there are four different scenarios for the nutrition requirements in 2030, which depend on two main variables: a) the international trade regime, and b) governance issues. Those will have an impact on the increase demands in the near future.

Figure 11 - Nutrition requirements in 2030: Four Scenarios

The presentation also recalled the rural dimension of food security in the Nile Basin, taking into account that rural populations are dominant in all upstream Nile countries. And even by 2050, it expected that rural population will remain dominant in 6 of the Nile countries. And if the urban sectors of society can rely on food imports, the rural population cannot. Thus, most food needs to be produced in close vicinity to its actual consumers; hence a significant part of the production increase will have to take place locally. In any of the scenarios, it is expected that rainfed agriculture remains important.

The challenges to meet food security - and required water resources - in the Nile Basin region are large and in its genesis there is a problem of resource scarcity. The Nile flows are modest, and the region is experiencing unprecedented pressure on natural resources, socio-economic systems, and managerial capacity. There is a rapidly rising demand for water and food; and the Climate Change factor is increasing these challenges. Thus, pressure on all elements of the water-food nexus will continue to rise. All in all, what we can observe is that there increasingly more connections across space and time; while at the same time smaller buffers and a rapidly increasing complexity.

A close look at the current status of the agriculture sector in the Nile Basin shows a number of trends. 1) Close to 90% of the land is currently under rainfed farming systems. And around 5.6m ha under irrigation, mostly in Egypt and Sudan. 2) Productivity and water use efficiency are generally low – with some few exceptions. 3) Potential of the agricultural sector is large, but held back by constraints in the natural resource base, and in the policy, economic, and institutional environment. 4) Trade volumes are low, and most of the Nile countries are net-importers.

In general, water (for agriculture) is a constraint. In areas subject to high temporal rainfall variability, rainfed crop yields are adversely affected by occasional moisture deficits. This is a reality, but is this necessary? The presentation called the attention for the fact that a lot of answers might be found in the current water management and agricultural practices in the different Nile Basin countries, namely in terms of water management, land management, appropriate agricultural system and practices. Non-biophysical constraints are also very relevant, such as land tenure, rural infrastructure (roads, electricity, etc.), Low farm-gate prices, and absence of value chain infrastructure.

Some of the insights of the Study were highlighted:

- The natural resources base was **not** considered the principal constraint to improving agricultural productivity; institutional aspects were considered more critical;
- Addressing constrains in isolation does not lead to meaningful improvements; constraints – biophysical & non-biophysical - have to be addressed in concert; further, the sequence & timing of policy measures matter;
- At presence, small-holder agriculture simply does not make sense from a financial perspective;
- Thus, under the current conditions, farmers often cannot respond to a price incentive;
- Inevitable crisis? No, we will just have to do "less with more"; i.e. increase resource efficiency. For instance, post-harvest losses amount to 40% ;
- It is economic systems, and not hydrological and water engineering systems, which achieve water security for economies in water scarce regions.

The last item included in the presentation focused on the issue of food security at national level versus food security at the basin-wide level. For the speaker, addressing the institutional and economic constraints in the agricultural system is predominantly a national issue. Therefore, while water is the apparent cause of the 'Nile issue', a critical component of its solution is outside the water domain and the basin-perspective. The issue would be later debated widely.

"Water for Food in the Nile River Basin: Potential of irrigation to address cereal import dependency" – specialised presentation by Dr. Claudia Ringler

This specialised presentation included a discussion of a recent study carried out by IFPRI called IMPACT (2017). Among other things, the study looks at the **impact of population growth on Food Demand**, as both are growing very rapidly in almost all the Nile Basin countries. It is expected that the demands between 2010 and 2050 will double for a number of different agricultural products, but in particular for cereals and fruits and vegetables. **The Hydro-economic model driven by 2050 Food Demand** shows that the Irrigation investment potential in the Nile River Basin (not counting with Egypt) might more or less double the current area of 3.6 million ha, including both large-scale and small-scale irrigation. According to the study prepared by IFPRI to the World Bank there is potential for a total of around 2.7 million ha (of each 2.1 million are small-scale and 0.6 large-scale). The distribution and localization of this potential can be seen in the Figure 12 below. The associated costs of the irrigation investment potential are represented in Table 5.

Figure 12 – Irrigation investment potential in the Nile River Basin

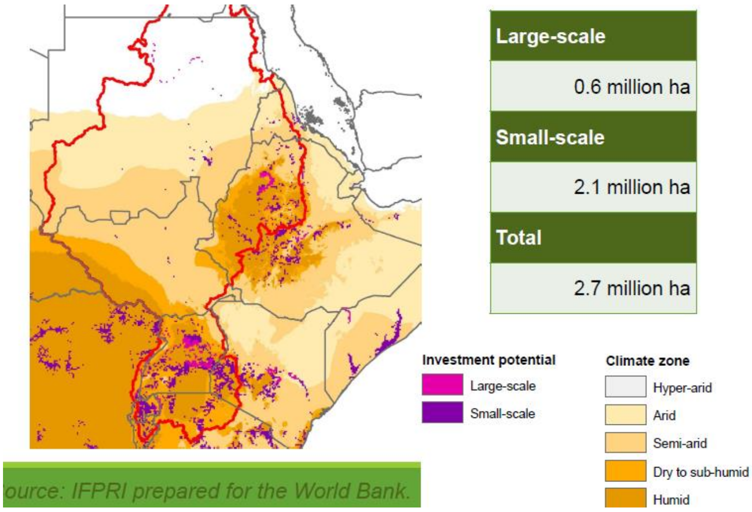
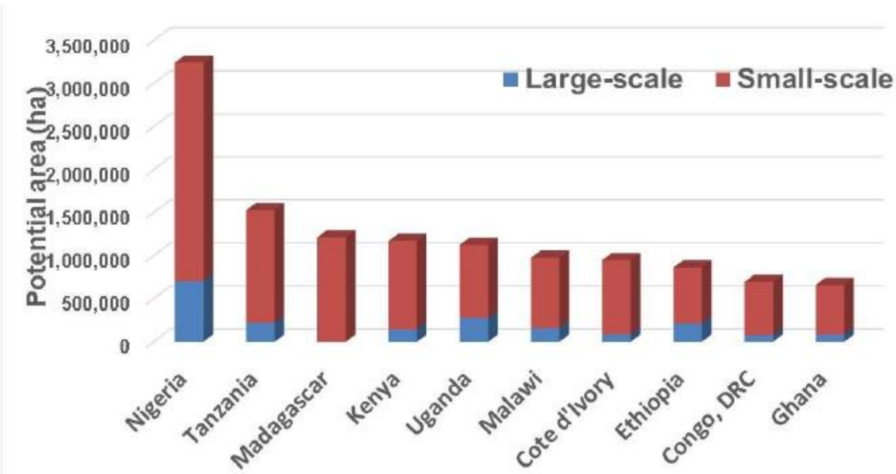


Table 5 – Costs of the irrigation investment potential in the Nile Basin (without Egypt)

	High cost		Medium cost		Low cost	
	IRR>5%	IRR>12%	IRR>5%	IRR>12%	IRR>5%	IRR>12%
Large-scale	0.3	0.2	0.6	0.3	0.9	0.5
Small-scale	1.6	1.4	2.1	2.0	2.7	2.7
Total	1.9	1.6	2.7	2.3	3.6	3.2

The same study also reveals that among the top 10 countries with largest irrigation development potential (at medium irrigation costs and IRR>5%) in Sub-Saharan region one can find 5 of the 10 Nile riparian countries – Tanzania, Kenya, Uganda, Ethiopia and DRC. Figure 13 shows how much of this potential is large-scale and small-scale irrigation.

Figure 13 - Irrigation development potential in select countries



The study also takes a close look at the impact of expanded irrigation investment on net trade in the case of cereals (wheat, maize and rice) and sugar. Figures 14 and 15 below shows what is the expected impact – with and without irrigation development – for different African regions. And how this same investment could change (and to what extent the number of people at risk of hunger as a result of the irrigation investment scenario. Figure 16 shows that for the different costs scenarios.

Figure 14 and 15 – Impact of expanded irrigation investment on net trade for cereals and sugar

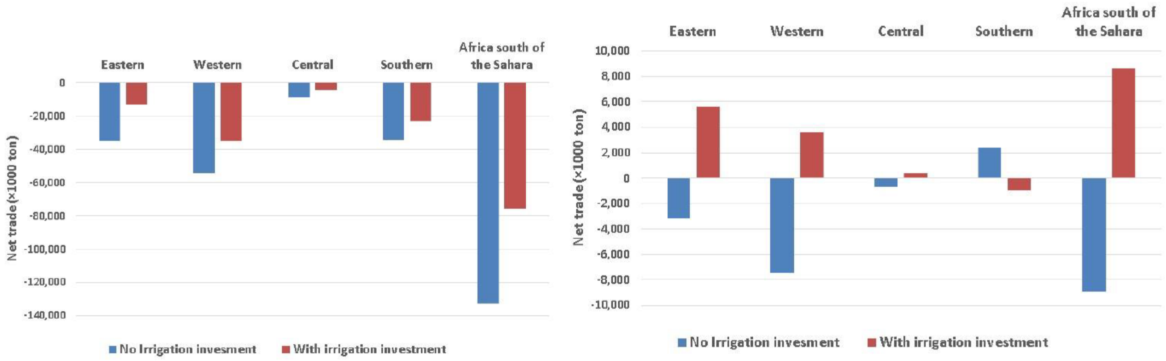
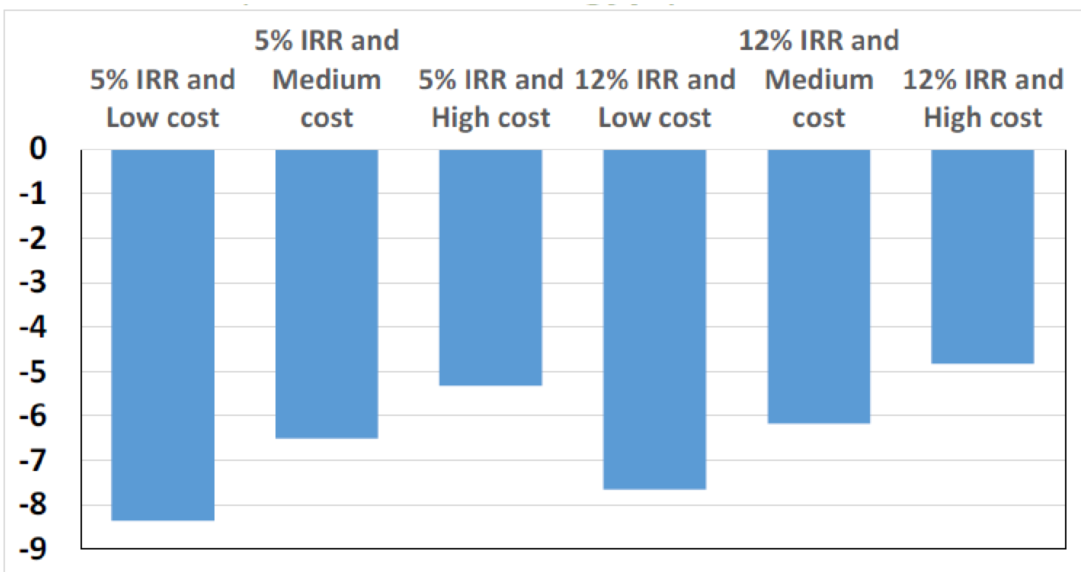


Figure 16 – Impact on hunger as a result of expanded irrigation investment



The main conclusions of this presentation have been:

- Goal: Convergence in water, energy and food security across the Nile countries without making more-well off countries worse-off
- Upstream Nile countries will increase irrigation but will remain largely rainfed ag economies while downstream countries will continue to rely increasingly on irrigation
- Sustainable irrigation potential can increase irrigated area growth from 1.6%/yr to 2.7%/yr; most additional irrigation will be small-scale (i.e. no large reservoirs)
- Large additional energy demands associated with irrigation expansion: fertilizers, machinery, electricity, pollution
- Large potential to increase food security without significant increase in water use (hybrids, input and output price policies)
- Solar groundwater will drive a lot of irrigation development in the region demand for grid-based electrification will decline, impact on water, energy, food security?

“Agricultural water demands in the Nile Basin” - Specialised presentation by Dr. Rashid Hassan

This presentation focused specifically in the identified **projected trends and challenges in order to meet the agricultural water demands in the Nile Basin**. As mentioned already in almost all previous presentations, the pressure on water resources in the Nile Basin is projected to increase sharply in the short- and long-term future. Some of the **main drivers for increasing demands** are:

1) Growth in food demand due to several factors such as population growth, urbanization, diet transition, etc.) – It is expected that more water will be required for projected expansions in production in both dryland and irrigated systems.
2) Climate change will have impacts on both supply/availability & agricultural demands. Three factors of particular relevance: a) direction of precipitation trends uncertain –implications for vulnerability & suitable adaptation policies; b) More frequent episodes of extreme events likely, particularly drought in arid & semi-arid areas; and, c) Warming is certain with direct implications for agricultural water demands (for example Higher basin-wide evapotranspiration and plants demand for water and Lower yields and hence need for more production expansions.
3) Increased competition from non-agricultural uses with economic growth, due to current trends in expansion of impoundments / damming for supply of energy & municipal water, etc.
4) Changes in transboundary water sharing and governance regimes/ arrangements, including expected changes in the current politics of water sharing agreements.

Having in mind these challenges: the questions arising is **what are the opportunities/options available for addressing these challenges**? The presentation look at the different sides of the coin: what are the opportunities and options in the demand side, and also at the possible opportunities in the supply side. The presentation highlights three different and complementary **options for water demands management policies**, as mentioned below:

1. Potential for substantial gains from more rational & improved efficiency of water use, particularly in irrigation, for example by reducing the substantial losses from the huge surface canal irrigation systems-downstream. However, the presenter calls the attention for the fact that currently the structure of economic incentives is distorted (for example, the agriculture users highly subsidized in most countries). In order to address these challenges, there is the suggestion that countries might need to start with charging for water as an economic input into production (i.e. remove subsidies) to provide incentive for (even subsidies) switching to more efficient irrigation methods and discourage wasteful use. Some other market-based instruments are also available, such as the creation of water markets to move water to its most efficient and highest value uses through trade, which have worked well in many places. However, the application of the measure above would require critical revision & harmonization of water use and allocation policies in all countries.

2. Focus on gains from increasing agriculture productivity rather than area expansions: in order to exploit the current big yield gap, especially among low input smallholder subsistence farmers, e.g. through promotion of green revolution technologies and practices (e.g. intensifying use of external inputs). Besides, the promotion of Climate smart agriculture (drought & heat tolerance, terracing, agroforestry, irrigation, etc.).

3. Exploit the huge potential for savings through better management of food waste, through innovative policy, institutional, educational, technological interventions to reduce the substantial losses of food from the production side (harvest and post-harvest handling) to the consumption end (good examples of managing food waste exist to adapt and adopt, e.g. food bank in Egypt, other).
Besides the demand management options identified above, are there still **options and opportunities on the supply side**? Although alternative supply sources are nowadays already limited, one can say

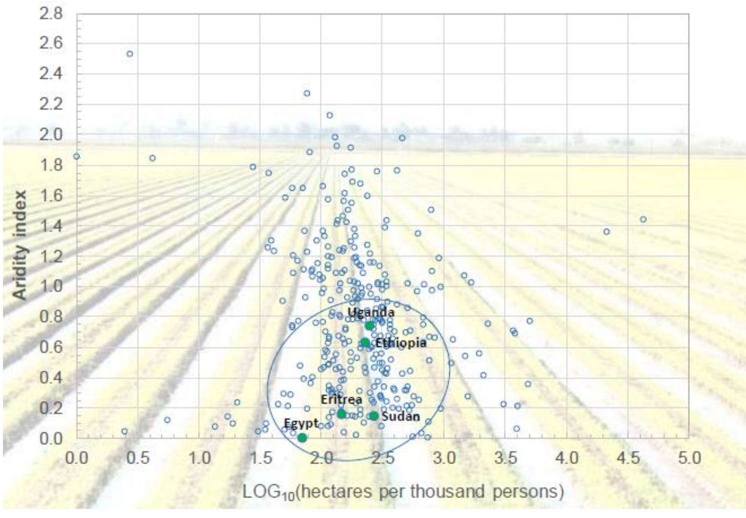
that some potential exists still exists for: a) Water harvesting for supplemental irrigation by smallholders in dryland systems; b) Tapping of existing ground water resources in some areas, especially for municipal users (household, industrial, services, etc. sectors) at a reasonable economic cost / charges and sustainable exploitation regimes; 3) Further exploit potentials for water storage in high rainfall areas. However, the presenter calls the attention to the fact that countries need to be Careful with the impacts of these supply-side options might have on the hydrological cycle & sustainability of use. For example, water harvesting through small or large scale (storage in dams) have hydrological and other implications that need to be carefully managed and avoided. And groundwater resources are exhaustible resources and hence prudent exploitation is necessary.

Last but not the least, the presentation analysed the the need to include Regional economic cooperation and trade in the discussions regarding agricultural water demands in the Nile Basin. One of the suggestions is that there is a need to exploit the principles of comparative economic advantage (CEA) to guide land and water use and allocation in agriculture. Currently all countries are trying to produce domestically as much as they can of main food staples and export cash crops, regardless of the optimality of using domestic resources to produce water intensive goods in water stressed areas. Allowing free movement of and trade in agricultural goods, for example, through well designed regional economic cooperation and integration policies promotes specialization based on the CEA principles, i.e. water intensive goods are produced in water abundant areas and hence water moves to its highest value user –leading to basin-wide efficient allocation of scarce domestic resources. Then trade distributes the total agric. output that is efficiently produced (efficient use of domestic water resources) among the Nile Basin countries participating in the regional common market for agricultural commodities, for instance. Ultimately, it will also help easing current tension between upstream and downstream states, and promote cooperative transboundary water sharing arrangements.

"Water Infrastructure and Agricultural Development: Perspectives on the Nile River Basin" – Specialised presentation by Tingju Zhu

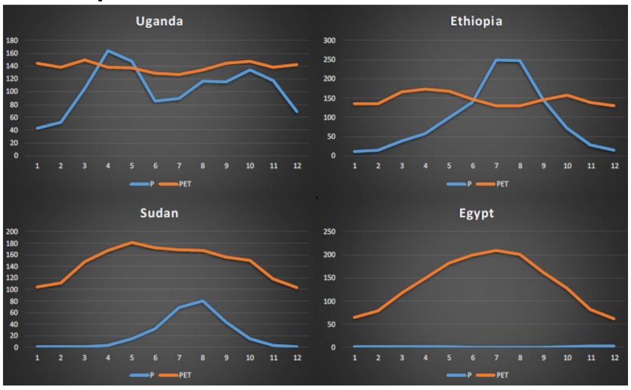
The presentation started by displaying a **worldwide comparison regarding climate and land availability** (also part of the IMPACT 2017 study referred above), where one can see some of the Nile Basin amongst the highest levels of aridity and limited land availability (see Figure 17 below).

Figure 17 – Aridity and land available



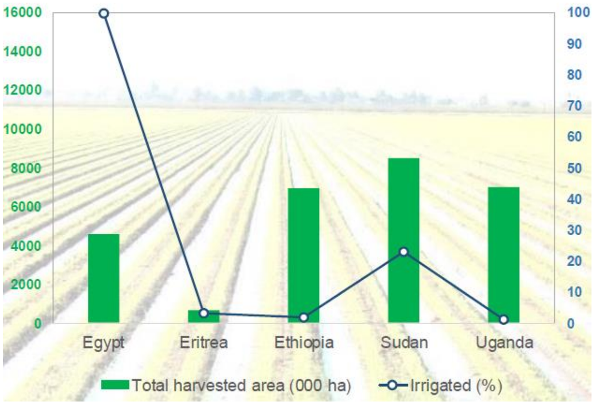
However, the **irrigation requirements of the Nile countries** are high, in particular in countries such as Egypt and Sudan. The diagram below (Figure 18) shows the irrigation requirements throughout the year for a selection of four Nile riparian countries.

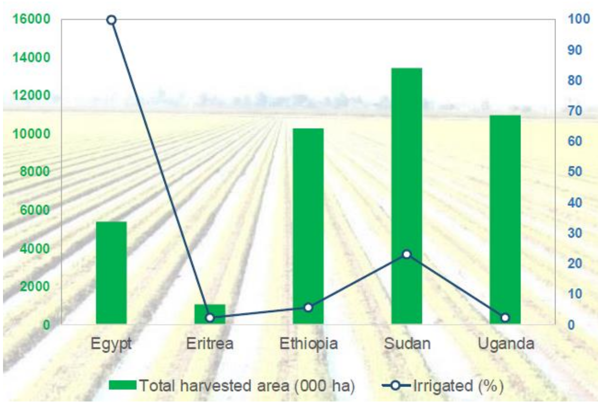
Figure 18 – Annual irrigation requirements



The two next diagrams shows the harvested crop area and irrigation share in percentage – in 2005 and for forecasting for 2050. The first diagram confirms the total dependence of Egypt on irrigated agriculture, and to a certain extent also Sudan. The second diagram shows the expected trends for 2050 – where total harvested areas are expected to increase for all countries – but in particular Sudan, Ethiopia and Uganda, with irrigation also showing increasing trends in the these countries.

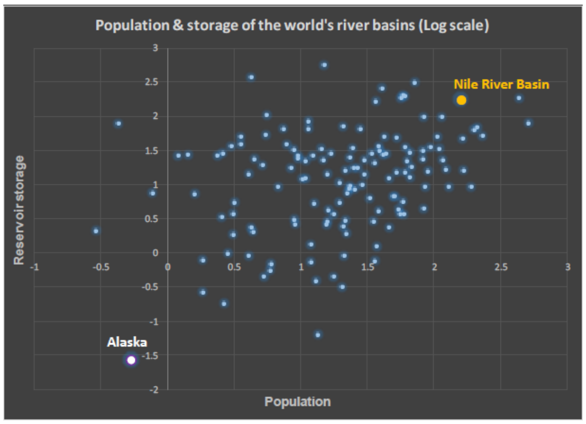
Figures 19 and 20 - The harvested crop area and irrigation share (2005 and 2050)





IFRPI'S Impact Model (2017) also looks at the storage capacity of for specific river basins, and the Figure below shows that storage capacity is high but also population is high.

Figure 21 – Population and storage of the world's river basins (Log scale)



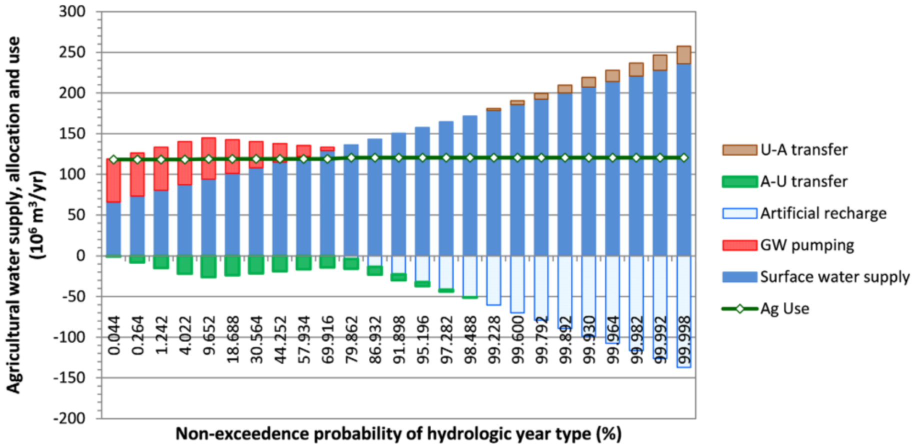
Another important comparison between the current scenario and the future trends (again for 2050) is related to **crop productivity in the Nile Basin countries**, and its effects of water and other inputs – both in the rainfed and irrigated sectors. Figure 21 shows the current levels for a specific crop (maize), and puts in evidence the large asymmetries in terms of productivity between Egypt and the other Nile countries. Figures for 2050 show significant increases in the level of crop productivity for both rainfed and irrigated agriculture for all the countries being observed, but in particular for Ethiopia and Uganda.

Figures 22 and 23 – Crop productivity (2005 and 2050, respectively)

One of the ways of **coping with water scarcity if to adopt new irrigation technology**, but this does not come without challenges. Three main challenges can be identified. The first related to challenges in financing water infrastructure for the building, maintenance, and expansion of irrigation infrastructure; Adoption of advanced technologies – drip and sprinkler (for small farmers); and Associated rural infrastructure – road, rural electrification. The second set of challenges relates to lack of Incentives: Farmers concerns on economic return and production risks, not necessarily irrigation water-saving – which can lead to inflexible water allocation and Ineffective water governance. The third challenge is related to lack of information (for example about technologies, scheduling). And the fourth challenges relates to how to deal with farmers perceptions of risk.

Finally, the presentation reflect upon on how to optimise value and reliability in the agricultural water supply portfolio. As the water infrastructure system improves water managers will have a greater level of flexibility to optimize the value and reliability of water supply and reduce agricultural production risks, as Figure 24 below shows.

Figure 24 – Optimising water supply



Food-Water Nexus: Reflections by countries

Before the Forum took place, the organisers have invited the Nile riparians to provide a first set of reflections regarding the three thematic blocks, based on guiding questions. Below some of reflections on the first theme – by Ethiopia and Kenya – as presented during the Forum.

1. How are **regional perspectives** reflected or integrated in your national **Water Resources/Agricultural planning**?

2. Do you have any **specific study** of best practices from your country regarding the aspects above? If yes, please share the main **highlights**. If not, please explain what are the **obstacles/challenges**?

BURUNDI	SOUTH SUDAN
1. Regional perspective in WR/Agricultural planning • The regional Project of the Agricultural Trade (**ARTP)** which was based in Burundi had made much studies in the sector • The documents are available, but no step ahead because of the lack of finance; • The regional Project of **LVMP II**, is making some activities in land management and protection by installing the catchments and set out some techniques for irrigation	**1. Regional perspective in WR/Agricultural planning** • Water resources and agricultural planning don't reflect or integrate regional perspectives; • Plans are inward-looking focusing on ecological zones and administrative areas (e.g. green belt, states, counties, urban vs. urban, etc.); • The trans-boundary nature of the Nile waters necessitates the development of effective measures for regional and international cooperation.
2. Challenges • There is in Burundi Periods of overproduction and periods of under-production for some foods like tomatoes and fruits • Need of the safe managing of production • Irrigations technical are not very developped in Burundi • Many projects are not implemented after preliminary studies according to problems of budget • Political and Social crises impact on countries collaboration on transboundary projects	**2. Best Practices studies – main highlights/challenges** • Currently, there are no best practice studies; • Obstacles/challenges include: • poor policy and legal frameworks, • inadequate human resource capacity, • Lack of strategic focus, and insufficient funding. • Concerned institutions in the Republic of South Sudan (e.g. Ministry of Water Resources & Irrigation, Ministry of Agriculture and Food Security and Ministry of Energy and Dams) would require technical support from the NBI and its partners to (i) undertake such studies, (ii) incorporate the regional perspectives and (iii) streamline the water-energy-food nexuses in their plans.

Outcomes of Breakout Sessions, Plenary Discussion and Synthesis of Theme 2

After the several different presentations, all the participants (both international and national economists, as well as the official technical representatives from the countries – the Nile-TAC members) had the opportunity of joining productive and constructive working groups. The small group discussions aimed at the **identification of the key priority issues/themes** that need to be further explored, and that can be used as **building blocks to develop scenarios for more efficient water management under the NBI collaborative water resources assessment process**. These two goals have served as a prior orientations for the breakout sessions. Below is a summary/synthesis of the main questions identified by the four groups:

GROUP A

- How can the NBI tap on the existing regional trade ; institutional arrangements and agreements (EAC, SADC, COMESA) to promote preferential trade arrangements in food in the Nile basin

- How to exploit the potential for increasing protein food from inland fisheries and acquaculture

GROUP B

- Make sure that we are able to distinguish between basin-wide and national level strategies and objectives. At the basin level, visions, strategies and objectives need to be consistent. Implementation needs to happen at the national level. How can we ensure sustainability? We need to incorporate environmental sustainability as well as social sustainability

- How can we ensure that factor, input and product markets are efficient in order to ensure efficient allocation of water (Opportunity costs need to play an important role in allocating resources in the food sector)? For instance, pricing of water is important. It is a scarce resource, need to price it so its allocation is efficient going to the activity of the most return. This will come out in the crop mix. How can we put in place the correct incentive structure for the food sector?

- How can we ensure that markets basin-wide are well developed to ensure win-win scenarios for food trade and consequently resource allocation?

- How can we plan such that food self-sufficiency at the national level is not the way to go? Specifically, drawing upon comparative advantages across the basin in order to achieve the most efficient food relationships?

GROUP C

- How do we identify synergies for multipurpose water infrastructure?
- How do we integrate commodity price variability into the concept of water productivity?
- Is there a comparative advantage in crop production in the basin from both a physical and trade perspective?
- Can the basin produce enough food for the entire population?

GROUP D

- What are the comparative advantages in food production across countries and across commodities in the Nile Basin?
- What is the potential for inter-basin food trade, considering the nature of the global food market? How are trade barriers creating challenges for meeting this potential?
- What are the implications of changing preferences (e.g. taste, convenience) for water use and food production in the Nile?
- What are the implications of changing climate for water use and food production in the Nile? What technologies can effectively enhance robustness to climate variability and change?

4. Thematic Session 3 – Energy-Water Nexus: Leveraging basin-wide opportunities for regional power trade for sustainable economic growth in the Nile Basin

The third and last thematic was dedicated to the topic of Energy-Water Nexus, and followed the same format as the previous sessions.

- A keynote address setting the scene
- Three specialised topics on key related topics
- Two presentations by senior economists of the Nile countries
- Breakout sessions where main priority issues/messages on the first thematic block were identified collectively

This section summarises the main points of the several presentations, the discussions and the main forward-looking messages/issues commonly identified by the participants.

"Leveraging basin-wide opportunities for regional power trade for sustainable economic growth in the Nile Basin", Keynote address by Prof. Kenneth Strzepek

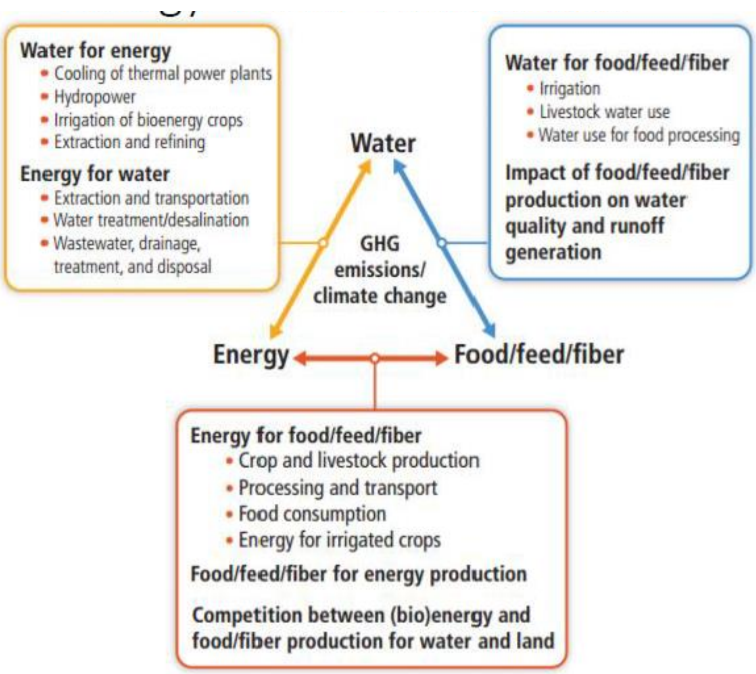
This keynote address started by questioning the **dichotomy of Engineer versus Economist** and a citation that reflects on the different perspectives that both can bring to the discussion about water/resources management and infrastructure development. *"If I am going to live below a dam I would much rather have it built by an engineer than an economist. Nevertheless, the economist comes into the picture perhaps by asking the awkward question as to whether the dam should have been built in the first place"* (Boulding, 1964). A main guiding concept for the discussion is that one of **Opportunity Cost**, i.e. the benefit that could have gained from an alternative use of the same resource. This introduction was used to deliver a message: **We need to think about things differently.**

An example about a new way of looking at things is the discussion and adoption of SDGs. In brief, **t**he Sustainable Development Goals (SDGs) are intended to embody a universally shared common global vision of progress towards a safe, just and sustainable space for all human beings to thrive on the planet. They reflect the moral principles that no-one and no country should be left behind, and that everyone and every country should be regarded as having a common responsibility for playing their part in delivering the global vision. Therefore, 1hile poverty-reduction is central to both human development and sustainable development, and while both view economic growth as a means rather than an end of development **– thereby providing an alternative to mainstream, economistic perspectives that tend to treat economic growth synonymously with development** – sustainable development places emphasis on meeting the needs of future generations by preserving the earth's natural systems.

How can this **'thinking differently' can be reflected in our water sector – in particular in the its infrastructure and development dimensions**? In principle, the role of infrastructure is to enhance economic growth, and how to finance it has resurfaced as a major topic among development economists. Nobel laureate Amarty Sen has made two key observations related to this "even the feasibility of high economic growth is threatened by the underdevelopment of social and physical infrastructure (Dreze and Sen ,2013); and "the challenge of sustainable and injustice-reducing development … are complicated by …climate change" (Sen, 2015).

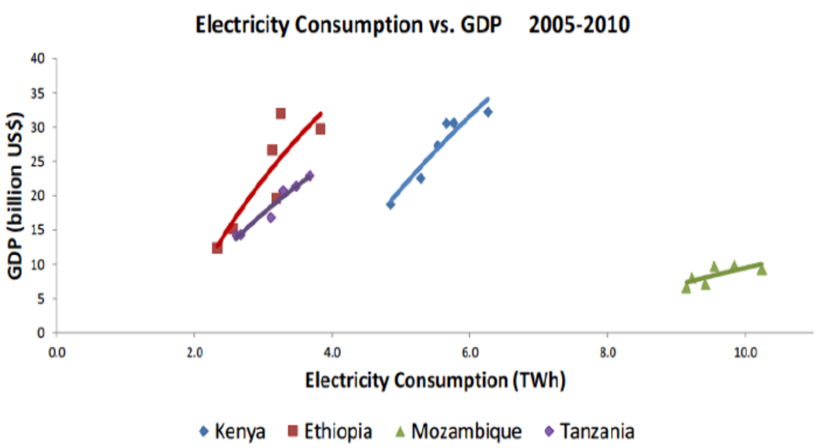
Next, the presentation has included an innovative schematic presentation (see Figure 25 below) on the **Energy-Water-Food Nexus** – on how the three sectors are interlinked and contribute to each other, as well as the impacts. But it also takes into account Climate Change and GHG emissions into account.

Figure 25 – The Energy-Food-Nexus



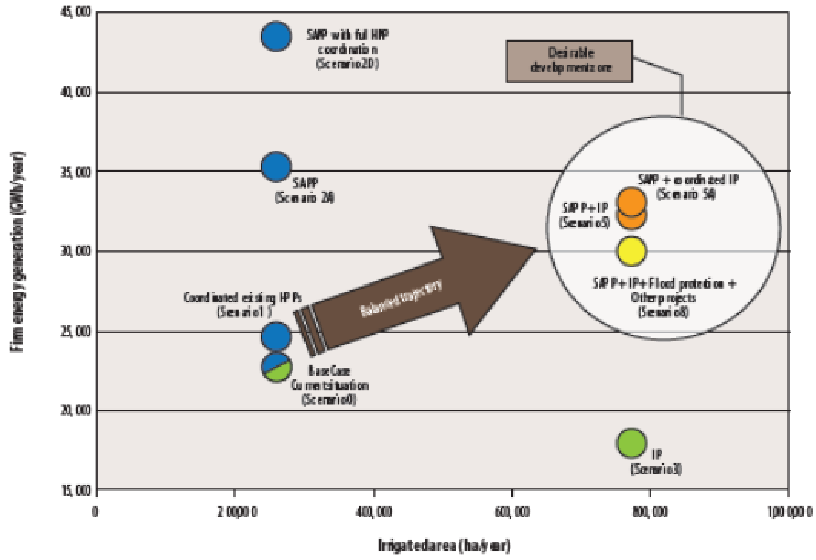
Looking closer into the "Energy" box, the presenter called the attention to the fact that there is no road to development that does not greatly improve access to energy services. Actually there is a **correlation between Electricity and Economic Development**, as visible in Figure 26 below. Expanded access to energy services for pro-poor development implies an increase in CO2 emissions that is entirely incompatible with the precautionary climate policy.

Figure 26 – Electricity Consumption vs GDP



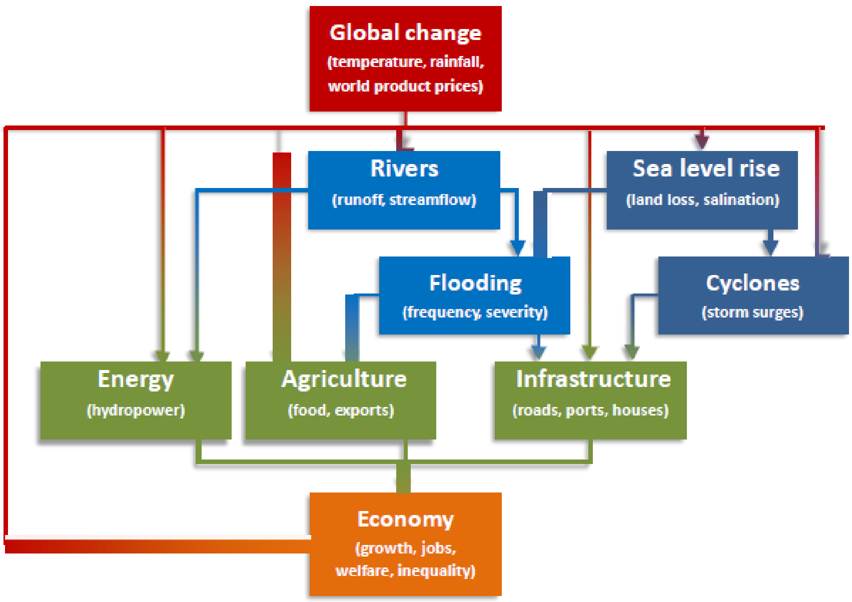
These assumptions about the key role of energy in development of political economies (at national and regional level) is already being adopted as part of the vision, analysis studies and programmes/projects of river basin organisations. For example, in the Multi-Sector Investment Opportunities Analysis (MSIOA) for the Zambezi River Basin, the centrality of the energy sector (side by side with the food sector) is recognised. Figure 27 included in the MSIOA report is self-explanatory.

Figure 27 – Potential for Energy generation and Irrigation by development scenario



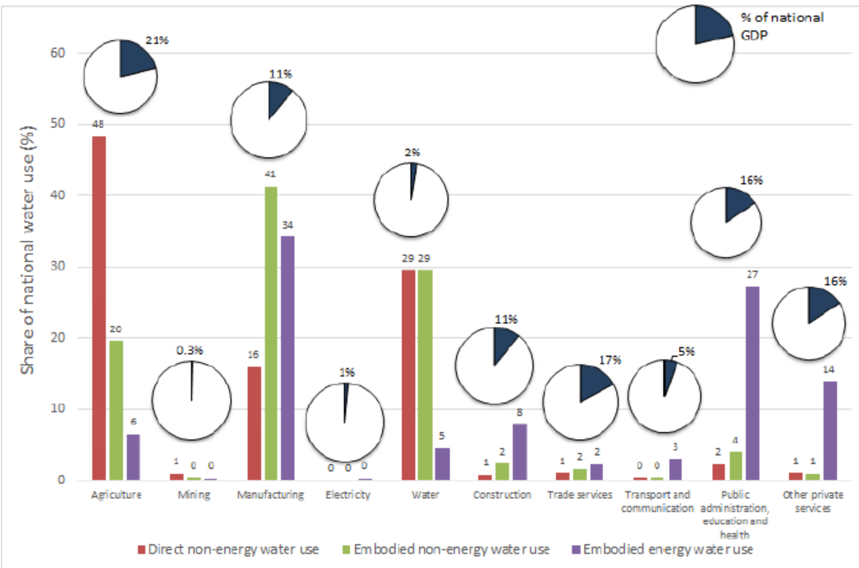
How do we analyse the effects on development, for example on in terms of employment? The development of irrigation has another important aspect: direct employment. Building and operating irrigation systems demands a lot of labour and thus creates job opportunities. Hydropower generation also produces direct jobs, of course, but except in the relatively short construction period, employment opportunities are limited to those with necessary skills. The strongest employment effects from hydropower development arise as the increased quantity and reliability of power production turn the wheels of the economy and creates new jobs. This indirect effect need to be further study. Under the UNU-World Institute for Development Economics Research SACRED, it was developed a Multi-sector Modeling Framework (see Figure 28 below) which aims at capturing the complex nexus between different issues/sectors.

Figure 28 - Multi-sector Modeling Framework



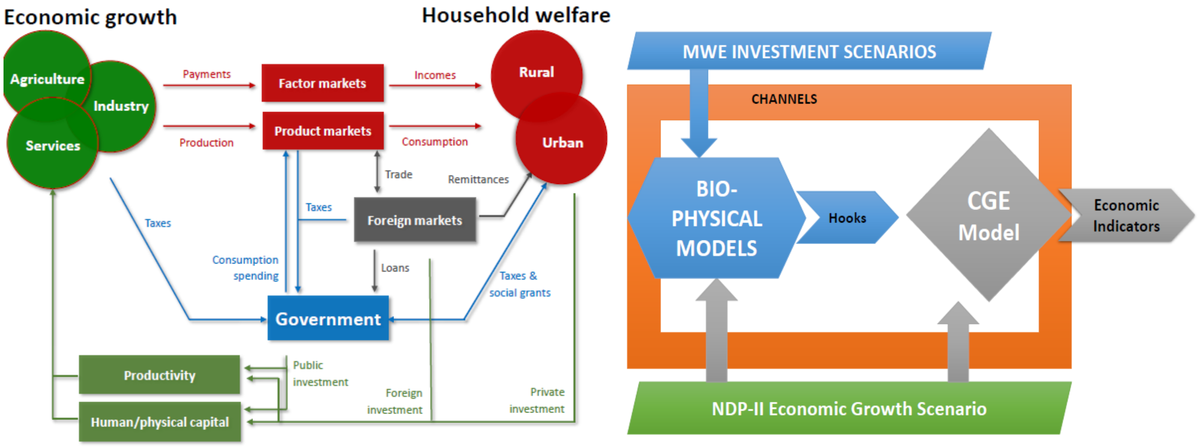
Applications of this framework for example to the case of Uganda allows us to understand what is the role of water in the current economy. Figure 29 below allows to understand not only where water/energy is being allocated, but as well the contribution for the different economic sectors (example: agriculture, manufacturing, public administration, etc.) for the national economy.

Figure 29 – Role of Water in the Ugandan Economy



Two additional questions of importance for this thematic block addressed were: **What is a CGE Model** and **how does this fit in the Analytical Framework?** The diagrams below show how complexity can be caputred by these models.

Figure 30 and 31 – CGE Model (left) and CGE Model input in the Analytical Framework (right)



How can these models help to examine the energy policies for countries/regions? An example from South Africa was given, wherein an **economy-wide modelling exercise was developed exactly to examine the available policy options**. Several factors were taken into account, for example: Energy Resources, Imports and Exports, Supply Technology, Demand sectors, Economic Analysis, etc. Figure 32 provides an overview of the Full Sector model.

An additional factor to be incorporated in the models relates to Climate Change with the goal of Enhacing the Climate Resilience of Africa's Infrastructure (ECRAI), which was applied to seven Major African River Basins (Nile, Congo, Niger, Zambezi, Orange, Senegal and Volta) and Four Power Pools (Central, Eastern, Southern, and West African). The study looked at the hydropower capacity enhancements and projected irrigation - additions based on the Program for Infrastructure Development in Africa (PIDA). What was done in ECRAI power planning? It included a state of the art modeling of all SSA power pools, including: a) an explicit representation of hydro; b) Economic damage evaluation; c) With and without adaptation. Figure 33 shows which data and tools used in the ECRAI.

Figure 32 – Overview of the Full Sector Model

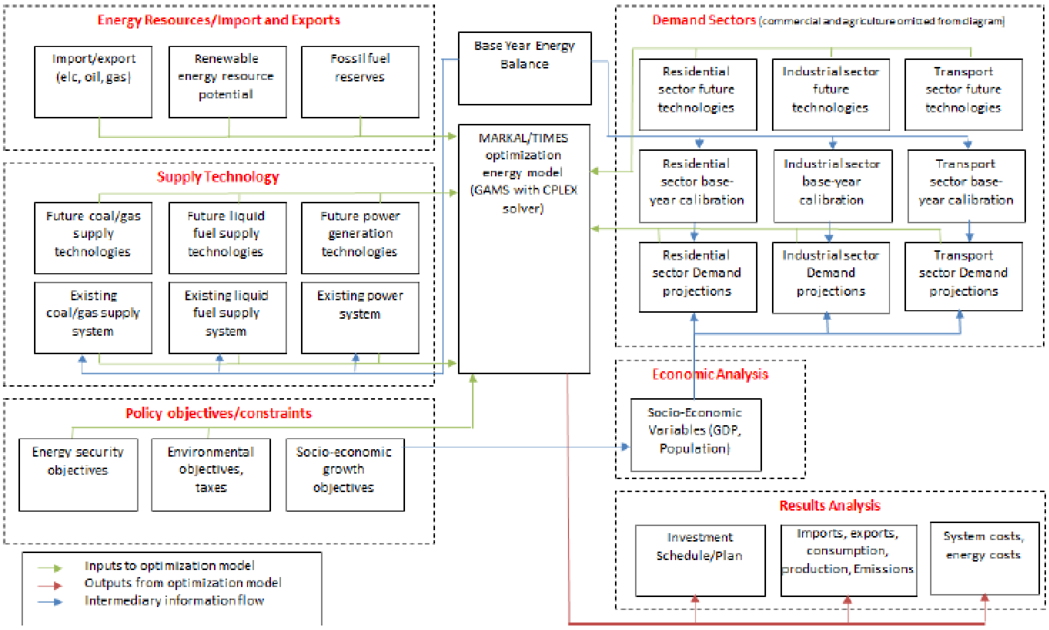
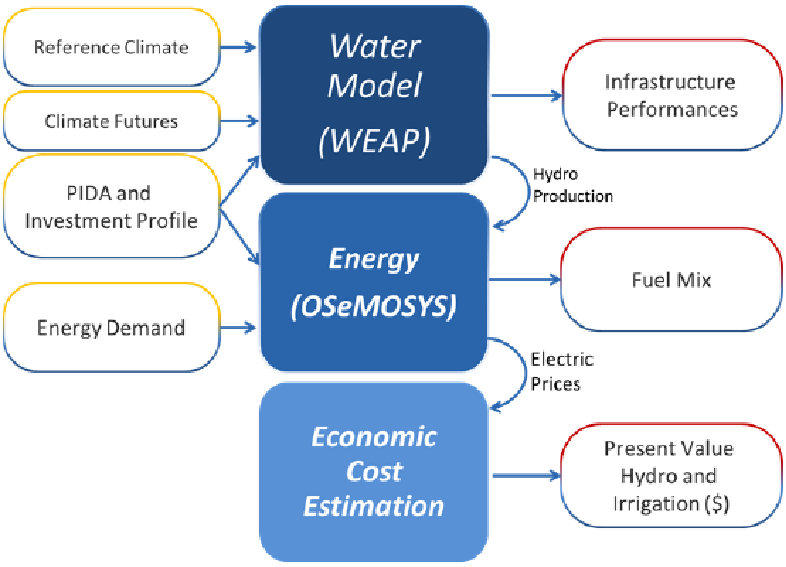


Figure 33 – ECRAI: Modeling the interaction of climate, hydrology, energy and irrigation systems

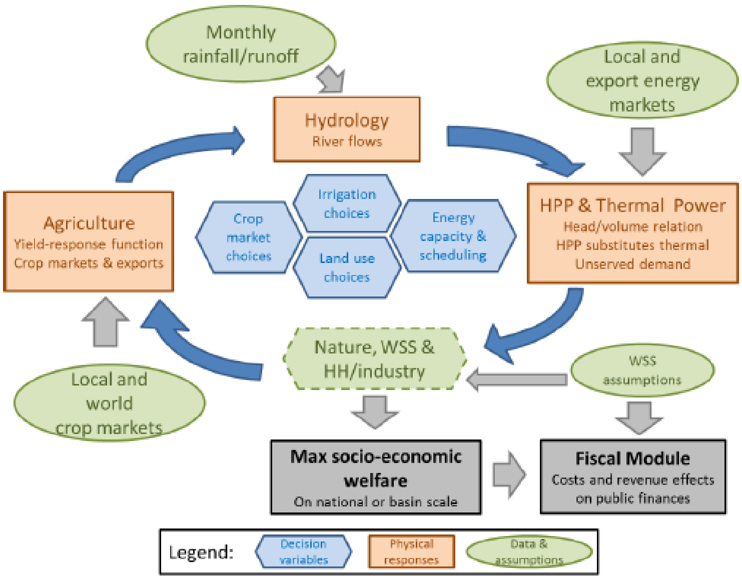


The ECRAI Study provides important key messages regarding **Power Pool Modelling important** for the energy/modelling-related discussion in the Nile Economist Forum, namely:

- Hydro Power is significant because of its Capacity, Investment and Generation. Because it will underpin trade, competitiveness and cooperation. Therefore needs to be accurately appraised
- A changing climate (has and) will affect: a) Investment in all generation capacity; b) The running of that capacity; c) Levels of trade; d) Energy prices; e) it will require smart adaptation; f) it affects countries differently
- A toolkit has been developed that can help ensure robust investment

The keynote speaker have also introduced A Fully Integrated Water – Agricultural – Energy System Hydro-economic Model (The WHAT-IF Model) – see Figure 34 below. The WHAT-IF simulates decisions in land use, irrigation, crop markets, and energy production. For example it looks at: 1) Land use: Which crops are most profitable?; 2) Irrigation: Is there enough water for the most profitable crops?; 3)Crop markets: How does crop production changes affect local crop market prices and crop profits; 4) Energy: How does altered hydro power scheduling and potential affect other power demand, production and investments? In WHAT-IF Models the Decision variables are kept within bounds and constraints that reflect physical realities (Water balance, energy balance, agricultural constraints, crop market equilibrium; and Priority use for households, industry and nature).

Figure 34 – WHAT-IF Model - A Fully Integrated Water – Agricultural – Energy System Hydro-economic Model



In brief, some of the results of the model. WHAT-IF provides indicators on economic welfare, for example the farmer income (i.e. crop revenue minus cultivation costs), the "Consumer Surplus" (i.e. the value to consumer net of the price paid), and the how Crop price changes affect consumers and producers in opposite ways. Surpluses are calculated for both power and crop markets. The WHAT-IF Hydro-Economic Model has been used in the Zambezi Strategic Plan to analyse the Development and Policy Options. Below a short summary of main blocks of the analysis.

Figure 35 – WHAT-IF Model for the Zambezi Strategic Plan

- Small scale investments
  - Smaller irrigation canals
  - On-farm equipment
  - Drainage (?)
  - Rural water supply and sanitation (?)
- Large scale investments
  - Larger canals
  - Large reservoir hydro power
  - Run-of-river hydro power
  - Urban water supply and sanitation
- Water policies
  - Transboundary water sharing
  - Scarcity prices / water tax (?)
- Agricultural policies
  - Subsidies and taxation (?)
  - Information / education
- Energy policies
  - Subsidies and taxation
- Effects of transport policies
  - Lower transport costs/losses through improved roads and cooling chains (to improve economic water productivity)
- Environmental policies
  - Minimum discharges to selected eco-systems
  - Minimum flow rates
  - Maximum flow rates
  - Greenhouse gas emissions
- Other policies (wish list)
  - … ?

The main conclusions for the Nile Basin – and in particular its Energy-Water Nexus - after the extensive discussion on models and its applications were:

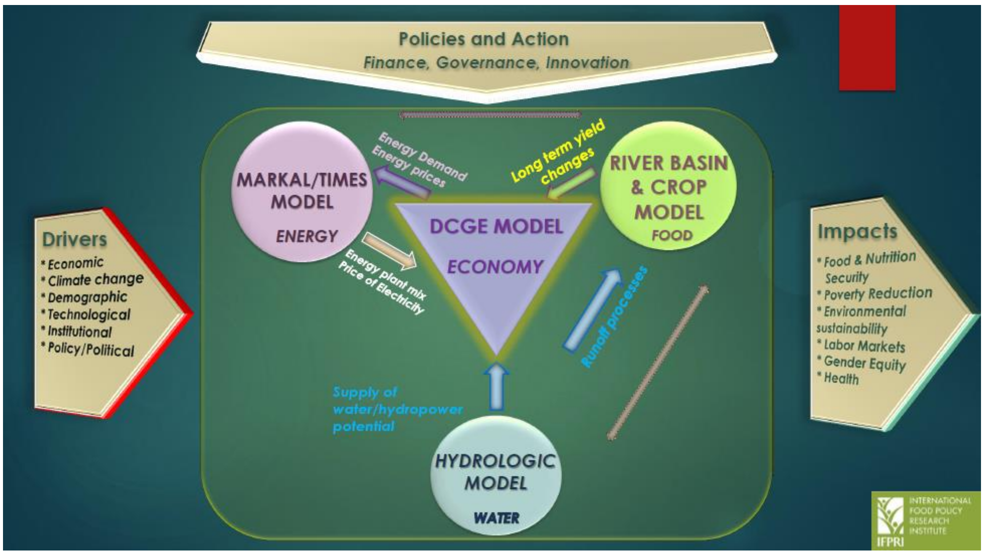
- Electricity is an important ingredient to Economic development
- In light of Capital Costs and growing discovery of fossil fuel resources: Fossil Electricity Generation for Africa is a financial option unless Carbon Emissions are taken into account;
- Seasonal to Decadal Variability of Streamflow provides reliability issues for large scale hydropower;
- Hydropower can play a key role within an mixed based national and regional Electricity GRIDs;
- Regional Power Pools are mechanism to increase reliability of hydropower and other renewables;
- Africa-wide power trade among Power Pools can help to provide an increased reliability of Africa's hydropower systems.

"Water, Energy, Food Nexus: Climate Change Socioeconomic Impacts" – Specialised presentation by Dr. Perrihan Al-Riffai

This presentation started with an introduction on the **debate between economists and water/energy specialists**. In brief ***Economists***: Tend to emphasize the connection between resource scarcity in the sector of focus and the rest of the economy and model these interlinkages in stylized general equilibrium models. These models use general equilibrium theory and the neoclassical theory of economic growth as their economic underpinnings. The problem with the *General equilibrium models* (CGE models) is that they are unable to fully capture the technological intricacies of partial equilibrium models. On the other hand, ***Water and energy specialists***: tend to provide highly detailed and specific water and energy partial equilibrium models that emphasize the technological intricacies of these resources within the sector(s) of focus. The limitation of the *Partial equilibrium models* is that they do not have the capacity to asses and analyse the impact of policy changes on the rest of the economy.

Therefore, "stylizing" water & energy in CGE models is inadequate for water and energy modellers and "stylizing" economics in water and energy models is inadequate for economists. And therefore the best option is to use **hybrid modelling frameworks that make use of the comparative advantage of both types of models in order to explore the Water, Energy, Food Nexus.** The figure 36 below show the full hybrid model, with its diverse drivers, modules, and impacts.

Figure 36 – A hybrid model



For the specific module on Energy it was suggested to use the MARKAL/TIMES Model, which mainly consists of a large set of energy technologies, linked together by energy flows, jointly forming a reference energy system. It is driven by a set of the economy's demand for energy. The feasible solutions are obtained only if all specified end-use demands for energy for all the periods are satisfied. Has a clearly defined objective, usually chosen to be the long-term discounted costs of the energy system. In this process, the model computes a partial equilibrium of the energy system for each period, i.e., *a set of quantities and prices of all energy forms, such that supply equals demand in each period*. A variety of constraints can be supplied to MARKAL/TIMES for making the solution more realistic.

Based on the outcomes of the the hybrid model – what are the possible interventions? The study provides several possible **sectoral interventions, and its links to water security, energy security, and food security**. Below is one example, using the example of a policy intervention in the Energy sector and its multiple impacts in the other sectors.

Table 6: Water, Energy and Food Nexus Interventions: Energy intervention

Scenario	Policy Intervention	Water Security	Energy Security	Food Security
Energy Sector	Change in energy mix: Relying more on renewables in energy generation	*Direct*: Greater use of water in the process of electricity generation	*Direct*: More energy available for use by consumers through a more efficient energy mix and less reliance on fossil fuels	*Direct*: More electricity is available for consumption, but not clear if output price of electricity will fall because some of the renewable sectors will depend on subsidies to operate efficiently. Consequently, price of electricity for intermediate demand is indeterminate at this point. *Indirect*: Potentially higher employment in electricity generating sectors contributing to higher incomes and greater food access

"Regional Power Pools – the Example of the Eastern Nile Power Pool (EAPP)" – Specialised presentation by Ephrem Tesfaye

This specialised presentation has been dedicated to the specific case of an **example of regional power pool, to which some of the Nile Basin countries are members**. The presentation has provided background information about the history and developments at EAPP, and discuss the current power production and interconnections and the status of regional power market. In brief, the EAPP Establishment was established in 2005, and adopted as a Specialized Institution for Energy by COMESA in 2006. It involves 11 member countries and it has 15 power utilities as members; and there are three potential additional countries. There are two kind fundamental documents that set EAPP direction and priorities are: 1) EAPP 10 year Strategic Plan (2016–2025) and 2) the EAPP Regional Power System Master Plan (RPSMP), which was first prepared in 2011 and updated in 2014. The EAPP Objectives are:

- Secure power supply for the Region's countries;
- Optimize the usage of energy resources available in the Region by working out regional investment schemes in Power Generation, Transmission and Distribution, taking into account the socio-economic and environmental aspects;

- Increase Power supply in the Region in order to increase the access rate of the population to electricity.
- Reduce electricity cost in the Region by using power systems interconnection and increasing power exchanges between countries;
- Provide efficient co-ordination between various initiatives taken in the fields of power production, transmission as well as exchanges in the Region;
- Facilitate financing of integration projects in the fields of power generation and transmission in the Region
- Facilitate, in the long-term, development of electricity market in the Region
- Contribute to Goal 7 of the UN SDGs –Ensure access to Affordable, Reliable, Sustainable & modern Energy for all by 2030.

The presenter also provided an update on the current status of EAPP Power Production and Interconnections. It started by referring that the hydro potential in the region is large (e.g. the DRC, Ethiopia, Uganda and South Sudan (in the or-der of 40,000 MW from one river Grand Inga, 45,000 MW, 3,000 MW and 1,500-3,000 MW). It was also mentioned that Ethiopia, Kenya, the DRC and Tanzania have significant potential for using geothermal energy. The total capacity of Kenya is expected to reach 4,000 MW by 2025. Egypt, Libya and Tanzania have the potential of Natural gas in the region. On the side of demand, the electricity demand is expected to increase from 315 TWh in 2015, to 675 TWh in 2025, corresponding to an annual growth rate of 7.6%. So far, the access to electricity is in the range of 10-30%. This means that **large investments in new generation and transmission are necessary**. The tables 7 and 8 below provide information about the Existing and Committed Generation (MW) of EAPP countries (including South Sudan). Table 9 provides information about the existing and committed Crossborder Transmission Capacity (as per 2015) – which shows the ambitious objectives in terms of future interconnections. Figure 37 shows the existing and committed crossborder transmission capacity, and its different connections between the member countries. In regards to recommended new capacity for 2020/2025, it is particularly interesting to highlight that the major connections are the Sudan-Ethiopia one (capacity of 1,600MW) and the Egypt-Sudan one (2,000 Mw). The key recommendations – main scenario – can be seen in Figure 38.

Tables 7 and 8 - Existing and Committed Generation (MW) of EAPP countries

Year	Natural gas	Coal	Hydro	Geothermal	Oil	Wind	Solar PV	Other	Total (MW)
2015	32,750	-	11,033	691	5,847	2,366	188	421	53,296
2020	32605	3,154	21,290	2,496	4,839	3,836	763	1,181	70,164
2025	28,021	3,154	21,290	2,496	4,099	3,836	763	1,181	64,840

Year	Natural gas	Coal	Hydro	Geothermal	Oil	Overall Total with the above(MW)
2015						53,296
2020	31,038	1,521	2,598	200	313	105,834
2025	54,153	2,657	15,193	1,879	313	139,035

Table 9 - Existing and Committed Crossborder Transmission Capacity 2015

No	To/From	From/ To	Existing (MW)	Committed (MW)
1	DRC	Burundi	16	49
2	DRC	Rwanda	100	300
3	DRC South	DRC East	-	500
4	DRC West	DRC South	560	1,000
5	Egypt	Sudan	-	200
6	Ethiopia	Djibouti	180	
7	Ethiopia	Kenya	-	2,000
8	Kenya	Tanzania	-	1,300
9	Libya	Egypt	180	
10	Rwanda	Burundi	12	100
11	Rwanda	Tanzania		27
12	Sudan	Ethiopia	200	
13	Ethiopia	South Sudan		200
14	Sudan	South Sudan	300	
15	Tanzania	Burundi		
16	Uganda	Kenya	145	300
17	Uganda	Rwanda	5	300
18	Uganda	Tanzania	70	

Figure 37 – Existing and committed crossborder transmission capacity

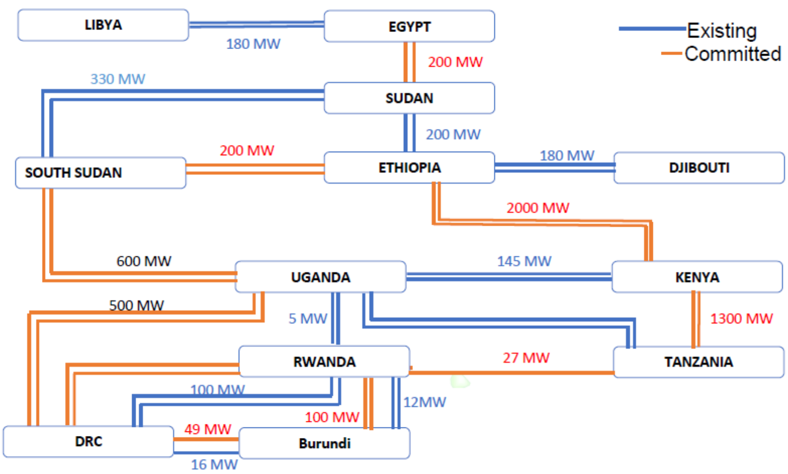
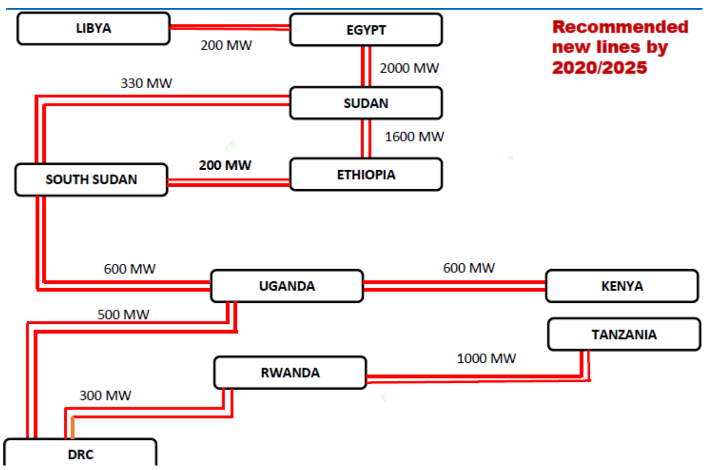


Figure 38 - Recommend new lines 2020/2025



The last part of the presentation focused on the **current status of the Regional Power Market Development**. At this stage there are two pilot projects of short-term trade (Uganda-Kneya and Ethiopia-Sudan). EAPP is also working on the 1) Draft Market Rules, Market Road Map and Interconnection Code; 2) Wheeling Agreement and Tariff under preparation; 3) Operations Committee established and performed as interim Market Committee; 4) Barriers to short term-trade have been identified and discussed by Operations Committee; 5) And the Independent Regulatory Board is created to regulate the Regional Power Trade. The **economic rationale of investment in Transmission/Interconnectors between countries** is based in three main pillars:

- Savings in operational costs: Reduction of fuel costs by more efficient dispatch across countries and technologies
- Investment in generation: More hydro and geothermal, along with less investment in expensive coal-fired generation
- Without new Interconnectors - the total system cost will increase - for example in 2020, the total annual system cost is estimated to be 412 million USD/year

"NBI/NELSAP experience in Regional Power Trade" – Specialised presentation by Eng. Alloyce Oduor

This presentation focused on the role/portfolio that NELSAP – one of the NBI centers established in 1999 – has in the field of Energy. (NELSAP), is one of the investment programs under the Nile Basin Initiative (NBI, within its role and mandate facilitates jointly agreed transformative Regional transboundary cooperative projects or in-country projects with regional impact/significance related to the common use of the Nile Basin water resources. NELSAP-CU renders support to national initiatives and focuses on two investment areas of: **(i) power development and trade;** and (ii) natural resources management and development. NELSAP is dominant player in the regional context with respect to: **1) the nexus between Water and Energy**; **2) Power Development Tools** developed to date (CBWS, Strategic/Sectoral, Social, and Environment, Assessment of Power Development options in NEL Region, NEL Power Trade etc.); 3) Method of work – with the countries and for the countries; 4) Regional Projects prepared; and, 5) Coordination of Projects under implementation. The main achievements so far – in the field of Energy, but not only have been: a) Promote Project and mobilize funding for Regional Projects and/or; b) National Projects of regional impact; 3) Coordinate project activities and stakeholders and ensure needed modalities for realization of project objectives are met; 4) Render technical assistance to countries with; 5) Professionalism to ensure best practices.

Table 10 – NELSAP Energy Prepared projects – feasibility studies completed

		Funds Mobilized			
No	Project Name	Funding source	Currency	Amount ($ Million)	Period
1.	Interconnection of Electric Girds of the Nile Equatorial Lakes Countries: Burundi, DRC, Kenya, Rwanda and Uganda	AfDB	UA 1,990,540	3.00	2007-2008
2.	Nile Equatorial Lakes Power Trade Project	WB-NBTF	USD	3.80	2010 – 2012
3.	Kenya–Tanzania Power Interconnection Project	Royal Norwegian Government	NOK24.0M	4.00	2009 – 2012
4.	Uganda (Nkenda) - DR Congo (Beni-Bunia-Butembo) Power Transmission Line Study	Royal Norwegian Government	NOK18.0 M	3.00	2012 – 2013

Table 11 – NELSAP Energy Projects Under Implementation

PROJECTS UNDER PREPARATION			
	Project Name	**Currency**	**Period**
1.		NOK18.612M	Nov 2013 - Mar 2015
	Tanzania (Mbeya)- Zambia (Kabwe) power interconnection Feasibility studies.	€2.26 Million	Mar 2015 - Dec 2017
2.	Power Interconnection studies	€2.0 Million	Feb 2016 - March 2017
3.	Uganda-South Sudan Interconnection	USD 2.8 Million	Oct 2016 – June 2018
4.	**Plus about 30 approved projects in the pipeline**		

Table 12 - Projects under implementation under NELSAP's Coordination

	Projects Under Implementation Under NELSAP's Coordination				
	Project Name	**Funding source**	**Currency**	**Amount ($ Million)**	**Period**
1.	Interconnection of Electric Grids of the Nile Equatorial Lakes Countries Project: Burundi, DRC, Kenya, Rwanda and Uganda	AfDB (UA127.81M); JICA (JPY5,406.0B); Government of Germany (GOG)/KfW (€56.0M); Government of the Netherlands (€23.75M), EU€18.0M	USD/€/JPY	414.53	Jan 2010 - Dec 2017
2.	Regional Rusumo Falls Hydroelectric Project _ Power Plant	World Bank	USD	340.00	2014 - 2019
3.	Regional Project Coordination Unit for the Interconnection Project	SIDA	SEK 5.0 Million	0.57	Sept 2015 – June 2017

he tables above summarise the **main prepared NELSAP projects in the field of Energy**. The rationale is that Interconnection of Electric Grids of NEL Region will result in Cost Effective Exchange of Energy, Reliability and Security of Power Supply and above all is a driver for Regional Integration.

Energy-Water Nexus: Reflections by countries

Before the Forum took place, the organisers have invited the Nile riparians to provide a first set of reflections regarding the three thematic blocks, based on guiding questions. Below some of reflections on the first theme – by Ethiopia and Kenya – as presented during the Forum.

1. How are **regional perspectives** reflected or integrated in your national **Water Resources/Energy planning**?

2. Do you have any **specific study** of best practices from your country regarding the aspects above? If yes, please share the main **highlights**. If not, please explain what are the **obstacles/challenges**?

D.R.Congo	UGANDA
1. Regional perspective in WR/Energy planning -Water for Hydro power: Estimation capacity of DR CONGO 100,000 MW, that represent 13% of world potential. -Real production estimated 44,000 MW •Ruzizi 1, 2 and 3: hydro power, estimated capacity 147 MW (DRC, Rwanda and Burundi) •Kivu lake: exploitation of Methane gas in Kivu lake between DRC and RWANDA •SEMLIKI: Hydro power between RDC and Egypt	**1. Regional perspective in WR/Energy planning** • Installed HP capacity is 382 with potential capacity of 2,000 MW on the nile • The Electricity access stands at less than 20% • Uganda has the high power tariff in the Nile basin of 1=$10kwh • There are several integrated planning initiatives however to a small extent. This has been mainly engineered by NBI. This is very important since the water resources are cutting across different riparian countries • This is highly practiced as all major hydropower projects being implemented are based on integrated regional approach
2. Best Practices studies – main highlights/challenges Many projects under the common vision are being implemented in DRC and many others are studying. - National analysis of GAPs: country capacity and Atlas of energy. - Provincial diagnostic studies: to determine the capacity of each province. - "NB DSS, as water resources management tool in Congo river downstream" (Serge PANGU, PhD topic): water and hydro power modelling.	**2. Best Practices studies – main highlights/challenges** • Examples here are the Kagera-Kikagati hydro power plant • 30 MW contract between Uganda and Kenya and the exchanges between DR Congo, Burundi and Rwanda associated with Ruzizi II (36 MW). • Nile Equatorial Lakes Interconnector Project construction and upgrading of 769 km of 110 kV and 220 kV lines connecting Burundi, DR Congo, Kenya, Rwanda and Uganda. • River Nile allocation tool for optimizing the water requirements for power plants along the Nile river in Uganda • Power export and production agreements that are signed between the state in that the power producing states share the power supply with those where the water comes from • Most of the urban areas and semi-urban areas are not connected • There is need for intensive planning to address the power shortage and access despite the many energy potentials in the country • Inadequate and inefficient power supply system, arising from stunted generation capacity growth, a poor transmission and distribution infrastructure and poor utility commercial practices, has been prevalent. • Integrated planning not practiced as talked about, a case in point is the exploitation of R. Nyamugasani (power supply, urban water supply and rural water supply implemented at different times)

Outcomes of Breakout Sessions, Plenary Discussion and Synthesis of Theme 3

After the several different presentations, all the participants (both international and national economists, as well as the official technical representatives from the countries – the Nile-TAC members) had the opportunity of joining productive and constructive working groups. The small group discussions aimed at the **identification of the key priority issues/themes** that need to be further explored, and that can be used as **building blocks to develop scenarios for more efficient water management under the NBI collaborative water resources assessment process**. These two goals have served as a prior orientations for the breakout sessions. Below is a summary/synthesis of the main questions identified by the four groups:

GROUP A

- How can basin wide energy policies be translated into national level policies and plans

- What institutional, political and economic structures should be in place to secure Trans boundary energy agreements and avoid vulnerability in case of political changes

- How does institutional arrangements at national level impact implementation of the water-energy-food nexus

- How do we build the water and energy models to capture different spatial and temporal scales between the two

GROUP B

- What are the options for energy markets in the basin?
- How much water could be saved by moving to solar, wind and other energy sources, keeping in mind the SDGs?
- What role can NBI play in the energy sector? [ensure that national energy policies and EAPP strategies are consistent with NBI goals or more]
- How costly will alternative energy sources be?

GROUP C

- What is the cost of water in the overall cost of HPP development projects? (incl. cost incurred by evaporation etc.)
- What is the opportunity cost of greening the national energy portfolio?
- What economic factors need to be in place to make HP projects attractive to stakeholders?

GROUP D

- How can and should investment for various *already identified* energy generation and transmission projects be mobilized? What are the barriers to investment and how can they be overcome (e.g., specific political and security risks, lack of agreements)?

- How should electricity tariffs be set, also considering transboundary trade in electricity (need for guarantees), and links to other interdependencies?

- How can energy generation be diversified to be more robust? (perception of too much hydro, with climate and hydropolitical risks) Should it include more solar / wind?

- What are the tradeoffs between energy generation and environmental quality / protection of ecosystems?

5. Synthesis/Synergies Exercise: Identifying Building Blocks and Key Options

The four tables presented in the next pages are the outcome of the Synthesis/Synergies Exercise, in which four different groups were required to use the knowledge and discussions of the previous sessions and work together to capture the main 'building blocks' and/or key options specific to the Nile Basin – Looking at 'Water Systems', 'Food systems' and 'Energy' Systems.

A Matrix/Template was provided beforehand – and the participants were requested to think in terms of Infrastructure Investments and Management Options for three different (general) scenarios – no-cooperation, medium level of cooperation and full cooperation.

<table>
<tr><th colspan="5">Water/Food/Energy systems</th></tr>
<tr><th rowspan="2">Category</th><th rowspan="2">Options (Building blocks)</th><th colspan="3">Possibilities in the no-cooperation/Cooperation scale</th></tr>
<tr><th>No cooperation</th><th>Medium level cooperation</th><th>Full cooperation</th></tr>
<tr><td rowspan="2">Infrastructure investments</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Management Options</td><td></td><td></td><td></td><td></td></tr>
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Water systems [GROUP 1]				
Category	Options (Building blocks)	Possibilities in the no-cooperation/Cooperation scale		
		No cooperation	Medium level cooperation	Full cooperation
Infrastructure investments	**New large dam (Purpose, Size, Safety, Siting, Timing)**	**Unilateral** *Unilateral planning and design* *Safety – only consider national safety issues*	**Consultation** *Information sharing and limited consideration of feedbacks from other countries* *Safety – consultation on dam safety issues*	**Co-design** *Safety – review on full consultation; co-funding security*
	Large scale irrigation schemes	**Unilateral**	**Consultation**	**Co-design**
Management Options	**Filling strategies for new reservoirs**	**Unilateral** *Maximizing national interest*	**Limited consultation** *Share data and policy with other parties about current reservoir water levels and release*	**Joint operation** *Jointly design rules to optimize benefits*
	Normal operations	**Unilateral** *Maximizing national interest*	**Limited consultation** *Share data and policy with other parties about current reservoir water levels and release*	**Joint operation** *Jointly design rules to optimize benefits*
	Benefit sharing	**Unilateral** *Maximize a narrow defined national interest that reflect absolute sovereignty*	**Limited consultation** *Given information in advances including infarction on benefits out of the country*	*Sharing the full benefits Work together to optimize the benefits for everyone*
	Cost sharing	**Unilateral** *Minimize cost to occur in own country*	**Limited consultation** *Given information in advances including information on costs out of the country*	**Effective coordination** *Co-design release rules under situations of drought and flood; avoid significant harm to anyone*
	Environmental flow	*No consideration of downstream ecological benefits*	*Environmental flow*	*ESIA*

Water systems [GROUP 2]				
Category	**Options (Building blocks)**	**Possibilities in the no-cooperation/Cooperation scale**		
		No cooperation	**Medium level cooperation**	**Full cooperation**
Infrastructure investments	Dam development	Unilateral investment and operation, no information sharing	Many possibilities: Regional optimization (some countries) Information sharing only Coordinated operations only	Fully coordinated investment and operating rules (basin optimization), full information sharing
	Irrigation efficiency improvements (technology, demand mgmt., etc.)	National decisions on irrigation efficiency (political incentives against improving efficiency)	Some options for transboundary investment in irrigation efficiency improvements	Fully coordinated investment and management program in irrigation efficiency
	Managing flows for ecosystem services	National decisions on protecting ecosystems	Notification of ecosystems threats	Basin coordination to protect ecosystems
	Management of extreme events (forecasting, hard/soft measures)	Try (perhaps not successfully) to protect national populations and assets	Information sharing	Try to protect all people and assets in the basin
Management Options	Supply enhancement (desalination, reuse, new infrastructure to reduce losses, groundwater)	Individual country supply enhancement programs to meet national objectives	Some options for transboundary investment in irrigation efficiency improvements	Basin-wide supply enhancement program
	Water trading	None	Trading of raw water with high transactions costs, or with limits and constraints on trade	Full trading of raw water is possible
	Water tariff reform (use of price instruments)	Use prices to optimize national net benefits		Use prices to optimize basin-wide net benefits
	Sediment control (watershed protection)	No substantive sediment control (low incentives)	Some bilateral payment for environmental services	Multilateral payment for environmental services

Food Systems (Food - Water Nexus)				
Category	**Options (Building blocks)**	**Possibilities in the no-cooperation/Cooperation scale**		
		No cooperation	**Medium level cooperation**	**Full cooperation**
Infrastructure investments	Irrigation expansion		Sharing irrigation plans	Basin wide irrigation plan based on biophysical potential and socioeconomic needs, expand based on comparative biophysical and economic advantage
	Small-scale groundwater exploitation			Basin-wide assessment,
	Improving performance and productivity of rainfed agriculture			Basin wide agricultural research system network, sharing of rainfed technologies, exchange extension staff! Basin-wide plan for water harvesting for crops
	Agro-industry development			Develop based on basin-wide comparative advantage (energy-intensive)
	Transportation to support movement of food and inputs			Basin wide transport infrastructure
	Advanced irrigation technologies			Remove tariffs on irrigation technologies, train people
	Water policy reforms			Basin wide water conservation plan, Nile Basin council comes together and says: there is no free water for productive use
Management Options	Trade		Crop zoning in basin based on comparative advantage	Nile Basin Preferential trading zone for food, no tariffs on any crops, standardize food safety standards,
	Water pollution			Basin-wide water quality monitoring, wastewater treatment, use of recycled wastewater for irrigation
	Increase yield per ha	Fertilizer policies to support increased application (note—this impacts pollution)		Improved seeds and Fertilizer policy as part of a basin-level food security strategy, remove subsidies Seed markets, harmonized seed labeling, etc. etc.

	Sustainable land management		Watershed management	Implementation of basin-wide watershed management plan
	Climate change adaptation and mitigation	Unilateral actions	Sharing of national plans	Basin program on climate change adaptation and mitigation for food security (crops, etc.); improve basin-wide science to predict rainfall
	Increase fish production	National plans to increase production		Implementation of basin-wide plans and sharing of additional fish production
	Addressing price variability	National measures (large physical stocks, trade agreements with non-basin countries, self-sufficiency plans)		Market information system for food prices across the basin; strategic food reserve and physical food reserve
	Make sure the most food insecure have access to food	National strategies		Basin-wide priority for allocation of water to food (food crops, livestock, and fish) over other crops, basin wide food safety nets,
	Managing food demand			Part of basin-wide strategy (focus on reducing obesity and undernutrition, various policy measures available, including food safety nets), technologies to process indigenous food faster
	Value Chains			Basin-wide identification of optimal value chains
	Virtual Water			Understand how much water is exported outside the basin through trade in agricultural commodities Basin-wide moratorium for land grabbing

Energy Systems (Energy – Water nexus)				
Category	**Options (Building blocks)**	**Possibilities in the no-cooperation/Cooperation scale**		
		No cooperation	**Medium level cooperation**	**Full cooperation**
Infrastructure investments	**Run of the river power plants**	No Impact	No impact	Peaking: Control is under a central control centre that operates the power plant and the dam.
Infrastructure investments	**Storage/reservoir power plants**	No exchange of information	Coordinated operation: Countries will develop joint operational rules and share real time data. However, the countries will make unilateral operating decisions.	Joint ownership and operation of hydro: Centralized operation body formed by the member countries, e.g., Ruzzi III and Rusumo Falls
Infrastructure investments	**Transboundary transmission (interconnectedness)**	None	Wheeling power: One standard methodology for wheeling agreement and tariff Coordinated operation: Monitor the system and intervene in the event of problems/challenges that may arise	Joint operation of the portfolio: Dispatch and control of the interconnected network and generation resources
Infrastructure investments	**Off grid community level energy supply**	No Impact	Economic, R&D, Technological cooperation	Cross border trading: A country supplies the communities of neighbouring countries.
Management Options	**Regional energy policy**	N/A	Sharing of information	National plans conform to the regional level energy policy
Management Options	**Power trade**	No trade	Bilateral power trade: Countries sign a bilateral agreement for energy trade (PPA)	Competitive power trade: Any country can bid on spot markets for energy
Management Options	**Updating development plans**	Isolated National development plans	Regional energy plan approved and accepted by some countries	Regional energy plan approved and accepted by all countries
Management Options	**Coordinated operation of reservoirs**	Each reservoir is operated independently	They may share operational rules	Full coordinated operation: Countries will develop joint operational rules

ANNEXES

Annex 1 – Annotated Agenda

Nile Economist Forum
Laico Lake Victoria Hotel
Entebbe, 16-17 May 2017

Evening of 15 May

Welcoming of Participants at Laico Lake Victoria Hotel
Informal gathering of organisers, facilitators and participants for a brief introduction to the Forum

Day 1 (16 May)

Registration of Participants *(08:00-09:00)*

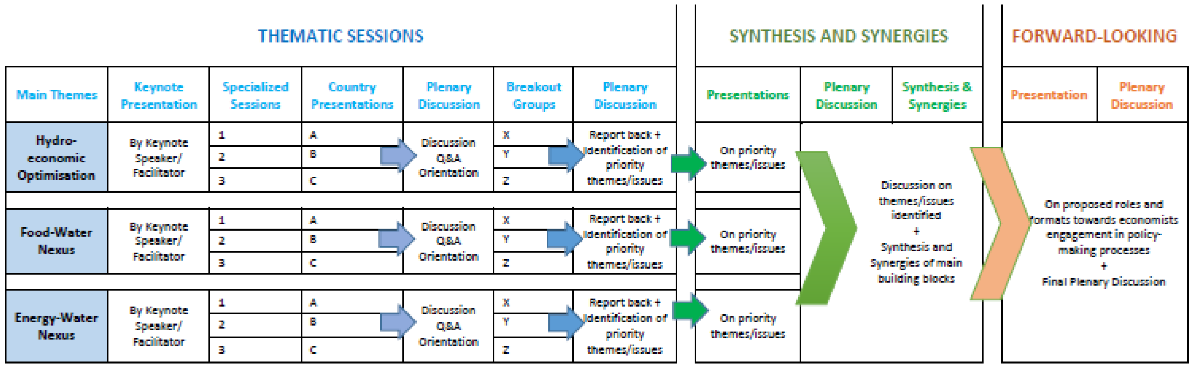
Session 0. Opening and introduction *(09:00-09:30)*

Welcome remarks, *by Innocent Ntabana – Nile-Sec Executive Director*
Welcome remarks, *by Malte Grossman – GIZ Head of Projects, Transboundary Water Cooperation*
Opening remarks (and official opening), *by Nile-TAC Chair*
Introduction of Organisers, Facilitators and Participants

Session 1. Setting the scene *(09:30-10:30)*

- Cooperative development and management of the Nile Basin water resources: experiences and prospects, *presentation, by Abdulkarim Seid, Head of NBI WR Management Department (09:30-09:50)*
- Forum background, objectives and expectations, and how it fits into the regional context, *by Abdulkarim Seid* (*09:50-10:00*)
- Q & A (*10:00-10:15*)

Schematic building blocks of Forum's agenda



10:15-10:45 Coffee Break

Session 2. Hydro-economic optimisation for efficient water resources management in the Nile Basin *(10:45-13:30)*

Time Breakouts		Format	Facilitator/ Presenter	Title / Contents	Specific objectives
10:45-13:30	10:45-11:15	**Keynote, by main facilitator of Topic 1 (30min)**	Marc Jeuland	**Keynote Address on 'Hydro-economic modelling for efficient water resources management in the Nile Basin"** Discussion and review the status of analyses and economic thinking on water related cooperation in the Nile Basin. Get an overview of available tools to assess: a) Hydro-economic optimisation to assess policy options for management of the shared resource and infrastructure; and b) Basin-wide trade and economy modelling to asses sector-wide impacts of various cooperation trajectories	• Provide Background and state-of-the-art • Provide summary of main concepts, methodologies, approaches, etc. • Provide main pointers for the discussion(s) under Topic 1
	11:15-11:45	**Three short specialised presentations (10mn each)**	Khalid Siddig	**Water in national economies: utilisation, valuation and challenges**	• Engage with Keynote speech • Provide insights on selected (and complementary) key/ specialised issues • Provide additional pointers for the discussion(s) under Topic 1
			Julien Harou	**Investing in infrastructure considering Nexus and transboundary dimensions**	
			Amaury Tilmant	**Hydro-economic optimisation: Economic-based solutions for Nile challenges**	
	11:45-12:00	**Country presentations (5min each)**	Country a Country b	Reflections on how at national level (in different Nile riparian countries) hydro-economic optimisation is being (or not) addressed, how and why	• Reflections on country experiences • Get policy-makers engaged from the very beginning of the workshop
	12:00-12:20	**Q&A + Plenary Discussion (20min)**	*Ana Cascão*		• Promote collective discussion about topics presented • Pre-identification of main issues at stake
	12:20-13:00	**Breakout session (maximum 3 groups) (40min)**	Each group should select a rapporteur	**Orientation for Breakout Session** (12:20-12:30) **What are the main priority issues?** Identification of the key policy/management choices that can be used as potential building blocks to develop scenarios for more efficient water management under NBI collaborative water resources assessment process	• Small group discussions aimed at identification of the priority issues/themes (max 3) that need to be further explored • Develop building blocks
	13:00-13:30	**Report from breakout sessions and Plenary Discussion/Synthesis**		Short report back and Guided Discussion	• Collective synthesis and agreement on main issues • This information will be used in Session 5 (next day)

13:30-14:30 Lunch

Session 3. Food-Water Nexus: Leveraging basin-wide opportunities for addressing food security challenges in the Nile Basin *(14:30-18:00)*

Time Breakouts		Format	Facilitator/ Presenter	Title /Contents	Specific objectives
14:30-18:00	14:30-15:00	**Keynote, by main facilitator of Topic 1 (30min)**	Bart Hilhorst	**Keynote Address on "Food-Water Nexus: Leveraging basin-wide opportunities for addressing food security challenges in the Nile Basin"** In-depth discussion about policy options for management and development of basin resources, focusing on the nexus Food-Water security, and the benefits of cooperative management regarding agricultural production, trade and investments can make to resolving water-related trade-offs (between sectors/ between countries/etc.); Introduction to scenarios that affect future agricultural water demands, virtual water trade, approaches to food security	• Provide Background and state-of-the-art • Provide summary of main concepts, methodologies, approaches, etc. • Provide main pointers for the discussion(s) under Topic 1
	15:00-15:40	**Three short specialised presentations (10mn each)**	Claudia Ringler	**Water for Food in the Nile River Basin: Potential of irrigation to address cereal import dependency**	• Engage with Keynote speech • Provide insights on selected (and complementary) key/ specialised issues • Provide additional pointers for the discussion(s) under Topic 1
			Rashid Hassan	**Agricultural water demands in the Nile Basin**	
			Tingju Zhu	**Role of infrastructure in agriculture projects**	
			Hellen Natu	**Virtual Water Trade in the Nile Basin**	
	15:40-16:00	**Country Presentations (5min each)**	Country a	Reflections on how at national level (in different countries) food security issues are being (or not) addressed, how and why	• Reflections on country experiences • Get policy-makers engaged in the discussions
			Country b		
			Country c		
	16:00-16:20	**Q&A + Plenary Discussion (20 min)**	*Ana Cascão*		• Promote collective discussion about topics presented • Pre-identification of main issues at stake
	16:30-17:00 Coffee break				
	17:00-17:40	**Breakout session (maximum 3 groups) (40min)**	Each group should select a rapporteur	**Orientation for Breakout Session** (17:00-17:10) **What are the priority themes of Food-Water Nexus for ensuring regional food security?** Identification of the key policy/management choices (specific to Food-Water Nexus) that can be used as potential building blocks to develop scenarios for more efficient water management under NBI collaborative water resources assessment process	• Small group discussions aimed at identification of the priority issues/themes (max 3) that need to be further explored • Develop building blocks
	17:40-18:00	**Report from breakout sessions and Plenary Discussion/Synthesis**		Short report back and Guided Discussion	• Collective synthesis and agreement on main issues • This information will be used in Session 5 (next day)
	Short Recap of Day 1				

Day 2 (17 May)

Session 4. Energy-Water Nexus: Opportunities in regional power trade for sustainable economic growth in the Nile Basin *(09:00-11:30)*

Time Breakouts		Format	Facilitator/ Presenter	Title / Contents	Specific objectives
09:00-11:30	09:00-09:30	**Keynote, by main facilitator of Topic 1 (30min)**	Ken Strezpeck	**Keynote Address on 'Energy-Water Nexus: Leveraging basin-wide opportunities for regional power trade for sustainable economic growth in the Nile Basin'** In-depth discussion about policy options for management and development of basin resources, focusing on the nexus water-energy security, and the benefits of cooperative management regarding power production, trade and investments can make to resolving water-related trade-offs (between sectors/ between countries/etc.); Introduction to scenarios that affect future water-related energy demands, infrastructures, approaches to national and regional energy security, etc.	• Provide Background and state-of-the-art • Provide summary of main concepts, methodologies, approaches, etc. • Provide main pointers for the discussion(s) under Topic 1
	09:30-10:00	**Three short specialised presentations (10mn each)**	Perrihan Al-Riffai	**Energy-Water Nexus: Efficient investments, infrastructure and trade-offs**	• Engage with Keynote speech • Provide insights on selected (and complementary) key/ specialised issues • Provide additional pointers for the discussion(s) under Topic 1
			Ephrem Tesfaye	**Regional power pools - the example of EAPP**	
			Abdulkarim Seid	**NBI experience in regional power trade**	
	10:00-10:20	**Country presentations (5min each)**	Country a Country b	Reflections on how at national level (in different countries) energy security issues are being (or not) addressed, how and why	• Reflections on country experiences • Get policy-makers engaged in the discussions
	10:20-10:40	**Q&A + Plenary Discussion (20 min)**	*Ana Cascão*		• Promote collective discussion about topics presented • Pre-identification of main issues at stake
	10:40-11:10	**Breakout session (maximum 3 groups) (40min)**	Each group should select a rapporteur	**Orientation for Breakout Session** (10:40-10:50) **What are the priority themes of Energy-Water nexus for ensuring regional energy security?** Identification of the key policy/management choices (specific to Energy-Water Nexus) that can be used as potential building blocks to develop scenarios for more efficient water management under NBI collaborative water resources assessment process	• Small group discussions aimed at identification of the priority issues/themes (max 3) that need to be further explored • Develop building blocks
	11:10-11:30	**Report from breakout sessions and Plenary Discussion/Synthesis**		Short report back and Guided Discussion	• Collective synthesis and agreement on main issues • This information will be used in Session 5 (next day)

11:30-12:00 Coffee Break

Session 5: Leveraging basin-wide opportunities for addressing the growing water, food and energy demands in the Nile Basin *(12:00-13:00)*

- Presentation on main ideas from the three thematic sessions, *by Facilitators or selected rapporteurs*
- Plenary discussion on "Identifying the building blocks"
- Synthesis of main points (themes/issues/blocks, and identification of synergies between them

13:00-14:00 Lunch

Session 6: High-Level Panel with Nile-TAC members *(14:00-15:00)*

A Panel Discussion with policy-makers to discuss how can the NBI can support the Nile Basin riparians in bringing forward a regional approach to leverage basin-wide opportunities (as analysed and discussed during the two days of the Forum)

Session 7: The Nile Basin economists' forum: way forward *(15:00-16:30)*

- Presentation on: Proposed roles, and formats for the continuous engagement of economists in Nile Basin water resources management and development issues, *by NBI representative*

- Plenary discussion

Closing Session*, by Organisers*

Annex 2
Bios of Speakers

Prof. Marc Jeuland is an Assistant Professor in the Sanford School of Public Policy and the Duke Global Health Institute at Duke University, a senior research fellow at the Institute for Water Policy at the National University of Singapore, and is a Research Network Member with the RWI - Leibniz-Institute for Economic Research. His research interests include nonmarket valuation, water and sanitation, environmental health, energy and development, the planning and management of trans-boundary water resources and the impacts and economics of climate change. He is one of the co-founders of the Sustainable Energy Transitions Initiative. He completed his dissertation titled "Planning water resources development in an uncertain climate future: A hydro-economic simulation framework applied to the case of the Blue Nile" in 2009, and has been working on hydroeconomic analyses of Nile Basin investment options and other issues since 2006.

Dr. Khalid Siddig is a Senior Researcher at Humboldt-Universität zu Berlin, an Associate Professor of Agricultural Economics at the University of Khartoum, Sudan and a GTAP Research Fellow. During the last 17 years, his research has been assessing the implications of agricultural, food, energy, and water policies in east Africa and the Middle East. A selection of the courses he teach includes simulation modeling of policies and markets, poverty and development strategies, agricultural and food policy, rural development policies and institutions, advanced policy analysis modeling and Partial and general equilibrium modeling. Before joining Humboldt-Universität zu Berlin, he worked for the University of Hohenheim and UNCTAD.

Professor Julien Harou is Chair in Water Engineering since November 2013. Previously he was a lecturer at University College London in Civil, Environmental and Geomatic Engineering. Julien has a PhD from the University of California Davis in water resources management and economics. His research area is water resources planning and management. His group designs approaches and builds tools to help governments, water agencies and utilities better manage water resources in the UK and worldwide. His research focuses on managing water scarcity and planning infrastructure investments using hydro-economic and multi-criteria approaches. Recent collaborators include the World Bank, IUCN, TNC, UK water regulators (EA, Ofwat), UK water companies, WWF, DEFRA, the European Commission, and various consultants. In 2010 he received a NASA Launch Innovator award for his group's contributions to water management and open software.

Professor Amaury Tilmant is professor at Université Laval (Quebec-City, Canada) since 2010. Over the past 15 years he has acquired significant experience in large-scale, transboundary, water resources systems, primarily in the Middle-East (Jordan, Euphrates-Tigris river basins) and in Africa (Senegal, Incomati, Zambezi and Nile river basins). Recent achievements include the development of a generic hydro-economic model, the development of methodologies to assess the cost of non-cooperation in transboundary river basins, the analysis of hydropower-to-environment water transfers as well as the water-food-energy nexus. Current research and consulting activities focus on assessing the economic value of various hydrologic information, assessing the trade-off relationship between food and energy security policies in regional water and energy systems, and on the development of benefit-sharing mechanisms in transboundary river basins. Prof Tilmant served as the transboundary water resources management and modeling expert for PIDA (Program for Infrastructural Development in Africa), which has been endorsed by African Heads of State and Governments in January 2012 in Addis Ababa, Ethiopia.

Dr. Bart Hilhorst has over twenty-five years of experience in land and water resources management, with a focus on forward thinking in natural resources development and use. Mr. Hilhorst has worked in more than 20 countries in Africa, Asia, and the Middle East with various agencies and institutions including the Food and Agricultural Organization of the United Nations (FAO), the United Nations Regional Center for Preventive

Diplomacy in Central Asia (UNRCCA), and the Nile Basin Initiative (NBI). Bart Hilhorst has extensive field experience in complex water projects and served as a Chief Technical Advisor for FAO project "Information Products for Nile Basin Water Resources Management". Mr. Hilhorst has particular knowledge of using scenario thinking to support strategy formulation for natural resources management, and to facilitate dialogue processes regarding complex water allocation challenges. He coordinated the development of the national water resources strategy for Uganda, facilitated a comprehensive multi-stakeholder scenario process that investigated the complex water-agriculture-energy nexus in the Aral Sea basin, and designed and facilitated a scenario project on the 'future of Nile cooperation' for the Nile Basin Initiative. He is currently leading the strategic basin assessment of Brahmaputra river in India. In his capacity as natural resources expert, Bart Hilhorst has been contributing to Al Jazeera News, Al Jazeera Inside Story, Euro News, Rai Italia, and Media News Group (East Africa).

Dr. Claudia Ringler is Deputy Division Director of the Environment and Production Technology Division at the International Food Policy Research Institute (IFPRI). She also manages IFPRI's Natural Resource Theme and co-leads the Institute's water research program. She is currently also a co-manager of the Managing Resource Variability, Risks and Competing Uses for Increased Resilience (VCR) of the CGIAR Research Program on Water, Land and Ecosystems (WLE), chairs the Food, Energy, Environment and Water Network (FE^2W) and is associated with the Sustainable Water Futures Program of Future Earth. Her research interests are water management, global food and water security, natural resource constraints to global food production, and the synergies of climate change adaptation and mitigation. She has more than 100 publications in these areas. She has worked in river basins all over the world, including the Maipo and Pirapama in Latin America, the Limpopo, Niger and Nile river basins in Africa the Aral Sea Basin in Central Asia and the Dong Nai, Indus, Mekong and Yellow River Basins in South- Southeast and East Asia.

Professor Rashid Hassan is currently a Professor at CEEPA, University of Pretoria. He served as the founding Director of CEEPA till 2016 and has previously worked at the CSIR in S. Africa, CIMMYT International in east Africa, and University of Juba, in Sudan. Served as member of many national and international Boards & Science Councils including: The UN Committee for Development Policy at ECOSOC, The CGIAR Science Council – ISPC, GEF Science and Technical Advisory Panel-STAP IV, Science Panel and Co-Chair of the Condition and Trends Working Group of the Millennium Ecosystem Assessment, High Level Panel of Experts (HLPE) on Food Security and Climate Change of the UN CFS, Academic Advisory Panel for the World Development Report (WDR 2009) on climate change, Stockholm Resilience Centre Board, Stockholm Environment Institute (SEI) Science Advisory Council, Human Sciences Research Council of SA Board. Research Fellow of the Economic Research Forum (ERF) for its Region that includes the entire Arab Region together with Turkey and Iran, Member of the Academy of Sciences of SA and Fellow of the World Academy of Sciences (TWAS), Senior Fellow of ZEF at Bon University, Senior Fellow of the African Association of Agricultural Economists. He received the Chancellor Medal and four times recipient of Academic Excellence Award for Research at University of Pretoria. Founding Chief Editor of the African Journal of Agricultural and Resource Economics, and associate editor and member of editorial Boards of many international journals and has published over 160 articles and chapters and 14 books. Holds MSc and PhD degrees in economics from University of Khartoum in Sudan and Iowa State University, USA. Main research expertise covers broadly the economics and policy of agriculture, natural resources and environmental management with current special interest in environmental accounting, climate change economics and sustainable management of natural ecosystems.

Dr. Tingju Zhu is a Research Fellow at the International Food Policy Research Institute (IFPRI) where he conducts interdisciplinary research at the interface of water management, food security, and sustainable development using engineering, economic and policy analysis methods. He joined IFPRI after graduating with a Ph.D. in Water Resources Systems Engineering, with minor in Agricultural and Resource Economics, from the University of California, Davis. While working at IFPRI, he has led and participated in a number of research projects in Africa and Asia. He serves on PhD dissertation committees and is an associate editor or guest editor of international academic journals.

Dr. Hellen Natu is the Regional Manager of the Nile Basin Discourse. Hellen holds a PhD focusing on Policy and Market Research from the Institute Agricultural Sciences and Environmental Development, University of Giessen, Germany. Her Bachelors and Masters Degrees attained from the University of Nairobi, Kenya. She has Certificates in various fields and a wealth of experience in Policy, Citizen and grassroots community engagement discourse; Socio-economics of Integrated Water Resources Management; Agriculture & Development; Value-chain Analysis, Markets and Trade; Resources Management & Policy Analysis; Program & Project Management, Capacity Assessment & Development. Her focus is on livelihood enhancement for communities in Sub-Saharan Africa.

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Annex 4

Economy-wide Economic Tools to support Water Resource Development and Management in the Nile Basin

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1. Overview Water Resources Development and Management and Economic Analysis

Water resources development has been an issue in public policy for millennia. The application of formal economics to water issues was limited “until with a few thoughts in this direction being expressed in the 1920s but with the real impact is coming in the 1930s-40s. But it was not until the latter part of the 40s and early 50s that the serious thinking of the preceding decade was published... By the latter part of the 1950s and the 1960s a wider professional concern with public investment group in articles and books have continued to appear.” (Smith and Castle, 1964). A search of books related to water resources and economic from WorldCat which includes MIT Libraries catalog and library catalogs worldwide returns 17 books from 1875 to 1964 and 778 from 1964 to 2018. Figure 1 shows a dramatic jump in the 70s and steady production on 80 and 90s with a marked increase in the twentieth century. The boast in books on the topic is follows the publication of the Dublin Principles in 1992 and the founding of the Global Water Partnership in 1996 and the popularization of the Integrated Water Resource Management.

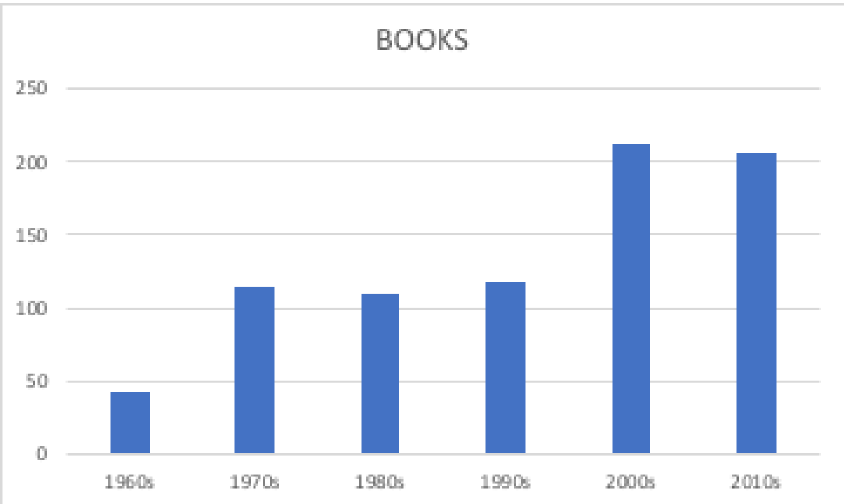


Figure 1 ***Books Published on topics related to Water and Economics***

Smith and Castle (1964) in the Introduction to the classic book "Economics and Public Policy in Water Resource Development" suggest that

> *The approach to (water) policy has been rather pragmatic for this is the nature of public action. To understand it and to be useful in its development, a point of view which does not attempt to look at the whole problem nor integrate the many facets yield results that are lacking in relevance. Anyone who studies water policy-the resolution of conflict over water resource uses-is impressed by the multiplicity of interest groups and the variety of objectives. No one academic discipline has with in it constructs which can handle all of the policy issues. Man, as an analyst, must exercise care as he may leave the impression that he can do more than he is really equipped to do. Policy change in fact is incremental.*

Their words reflected the impact of the groundbreaking research coming out of the Harvard Water Program (1956 to 1960) "devote to the methodology of planning or designing complex, multiunit, multipurpose water resources systems" apply "Techniques of economics engineering and governmental analysis",,, "enabling new or improved techniques of analysis" to be applied by water resource agencies in the USA and internationally. The report on this research was published in the seminal volume "Design of Water -Resources Systems: New Techniques relating Economic Objectives, Engineering Analysis and Governmental Planning. (Maass, et Al 1962)

Many of the concepts found in the Dublin Principles and Integrated Water Resources Management can find their roots in the work of the Harvard Water Program.

This monograph will build on the shoulders of the early developers of the foundations and application of benefit-cost analysis to water resource project analysis and the extension to "Water Resource Systems" suggested by the great thinkers of the Harvard Water Program. Finally, the application of sectoral and economy-wide models to understand the multiplier impacts of investments in water resource and environmental systems development and management will have on the economy and society will be discussed.

1.1. Water Resource Decision-making with Cost-Benefit Analysis

The goal of all water resources managers and policy makers is to make "efficient resource allocation" decisions related to water management activities from governmental policies, water allocation, river basin operation or investment decisions. We have accepted that we need to estimate the benefits and the costs of these activities, but this results in estimating these values are a wide-range of sectors and spatial scales.

Even as we have recognized and even applied multiple objective approaches, the dominate objective remains "economic efficient resource allocations"

Cost Benefit Analysis (CBA) , a systematic technique to the examine the "economic" feasibility of a project where feasibility is defined as "the benefits, to whomsoever they may accrue, are in excess of the estimated costs,", was effectively required for proposed federal waterway infrastructure after the Federal Navigation Act of 1936. This initiated the US ARMY The Corps of Engineers to use of CBA in the USA. The Flood Control Act of 1939 was instrumental in establishing CBA as federal policy and was extended to broader public policy based on the work of Otto Eckstein who in 1958 laid out a welfare economics foundation for CBA and its application for water resource development. (Eckstein, 1958).

“There is fairly general agreement that benefit – cost analysis is subject to many weaknesses there is also recognition that benefit – cost analysis can be and has been distorted and abuse… I should like to submit… that benefit – cost analysis by the government appears worthwhile in spite of its weaknesses, its risks in its relatively small, direct influence upon the actual costs of events. ” (Ciriacy–Wantrup, 1964)

To assist the water resource community to avoid the pitfalls with the BCA, the American Geophysical Union, published to monogram on the application of BCA to Water Systems,

Benefit-Cost Analysis of Water Systems Planning (Howe, 1972) and *Multiobjective water resource planning* (Major, 1977). Many other similar texts were published as presented above. An edited volume that provides an excellent coverage of both the theory and application related CBA and water is *Cost-Benefit Analysis and Water Resources Management* (Brouwer and Pearce, 2005).

Even with these excellent tools the application of CBA remains under the cloud of some of the concerns of the pioneers in the field.

Steiner (1959) suggests the essential feature of the models used for an appropriate CPA is:

“it's recognition of the general equilibrium character of the consequences of a specific public investment decision that result from both the source (S) of the funds and the displacement (if any) that occur; a central conviction of the model is that second – and even third- round effects may not me negligible."

Thirty years later, Varian (1989), suggests a general equilibrium framework for benefit-cost analysis: *"We start from a simple methodological premise: there is only one correct way to do cost-benefit analysis. First, formulate an economic model that determines the entire list of prices and incomes in an economy. Next, forecast the impact of some proposed change on this list of prices and incomes. Finally, use the utility functions of the individual agents to value the pre- and post-change equilibria. The resulting list of utility changes can then be summarized in various ways and presented to decision-makers."*

Steiner’s and Varian’s concerns remain in part because most CBA as practiced today makes use of partial equilibrium and/or static prices and incomes. A long history of texts (Baum and Tolbert, 1985; Brent 1990; Gittinger 1984; Mishan and Quah, 2007; Harberger, Jenkins, and Kuo,2009) and handbooks on Cost-Benefit Analysis (see for example, Treasury Canada 2007; Australian Government 2006; US Dep’t of Health and Human Services 1993; FEMA 2011; European Commission 2008; Transport Canada 1994, and US FAA 1999) contain hundreds of pages and many topics of how to apply a limited sequence of partial equilibrium analysis to achieve the goals of a “general equilibrium economy-wide analysis” (Robinson, 2017), “entire list of prices and incomes in an economy” and “pre- and post-change equilibria.”

2. Economy-Wide Multi-Sector Economic Models

Varian provides a compelling rationale for consideration of economy-wide tools as increasingly essential for robust benefit-cost analysis. Economy-wide models include several distinct approaches, including input-output models, macroeconometric models, hybrid input-output-macroeconometric models, and general equilibrium models – the term "economy-wide" usually refers to a national level analysis, but could also apply to a region, or globally. As noted in a recent review of economy-wide modeling, a key common characteristic of these models is that they disaggregate the overall economy of a country or region into a number of smaller units, or agents, that are each represented by an appropriate sub-model, which in turn interacts with other agents (or sub-models) in an attempt to simulate the activity of markets for goods and inputs to production (SAB 2017). These agents include industries, service providers, households, governments, and many more. The most suitable approach for measuring social costs, as is the aim in most benefit-cost analyses, is general equilibrium modeling. Other economy-wide modeling methods should not be used if the aim is to evaluate social cost, but they may be suitable for evaluating certain economic impacts (e.g., changes in GDP or employment levels) in particular circumstances (SAB 2017). In this paper, we use examples of recent work (in Section 2) and a broad outline of available resources to Nile Basin Countries necessary to conduct an economywide modeling analysis (in Section 3) to argue that conditions now exist to apply these models much more broadly in the Nile Basin to enhance benefit-cost analyses.

The exciting prospect that this paper explores is the recent advance in methods that allows an increasing level of incorporation of non-market welfare considerations into economy-wide tools. This development in turn facilitates a much better understanding of how water and environmental interventions affects metrics of great interest to policy-makers: for example, overall GDP growth, labor productivity, sectoral patterns of output, and distribution of income and welfare among populations.[1] In particular, this advance facilitates, in principle, incorporation of any of a wide range of health and nutrition outcomes that cumulative impacts over time in the form of human capital erosion or accrual, though in practice the technique has been demonstrated for a more limited set of environmental health; water, sanitation, and hygiene improvements; agricultural production (with extensions to nutrition); and child and maternal time savings that can be directed toward education.

The application of these tools to the priority water and environmental development policies has, until recently, been very challenging, and more so in low- and middle-income country settings. In addition to the substantial burden of collecting relevant and reliable data across a national economy, applying these methods to assess water and environmental interventions (including agriculture and water resource/sanitation) necessarily involves moving beyond traditional market economics to incorporate non-market activities that, in turn, should affect both market economic indicators and household welfare. A classic example would be reducing disease through village water supply and sanitation (WASH) , which has several beneficial outcomes for an economy: 1. It reduces spending on disease treatment expenditures; 2. It enhances labor productivity, and potentially converts time spent recuperating to leisure time, by fostering a healthier working population; 3. It improves individuals welfare by reducing pain and suffering and other implications of health that might not readily be captured but the first two categories (such as changes in lifetime savings and consumption patterns). The first effect can be readily accounted for in economy-wide models as a market effect, and the effect of reallocating that spending elsewhere can be assessed.

[1] Concerns about the level of sectoral and income class disaggregation in the particular CGE applied may limit these tools ability to effectively estimate distributional effects (SAB 2017), although as noted below there are examples of applications for distributional effects in data-rich environments (e.g., Saari et al. 2014) – the necessary income group-level data is more typically found in developed countries.

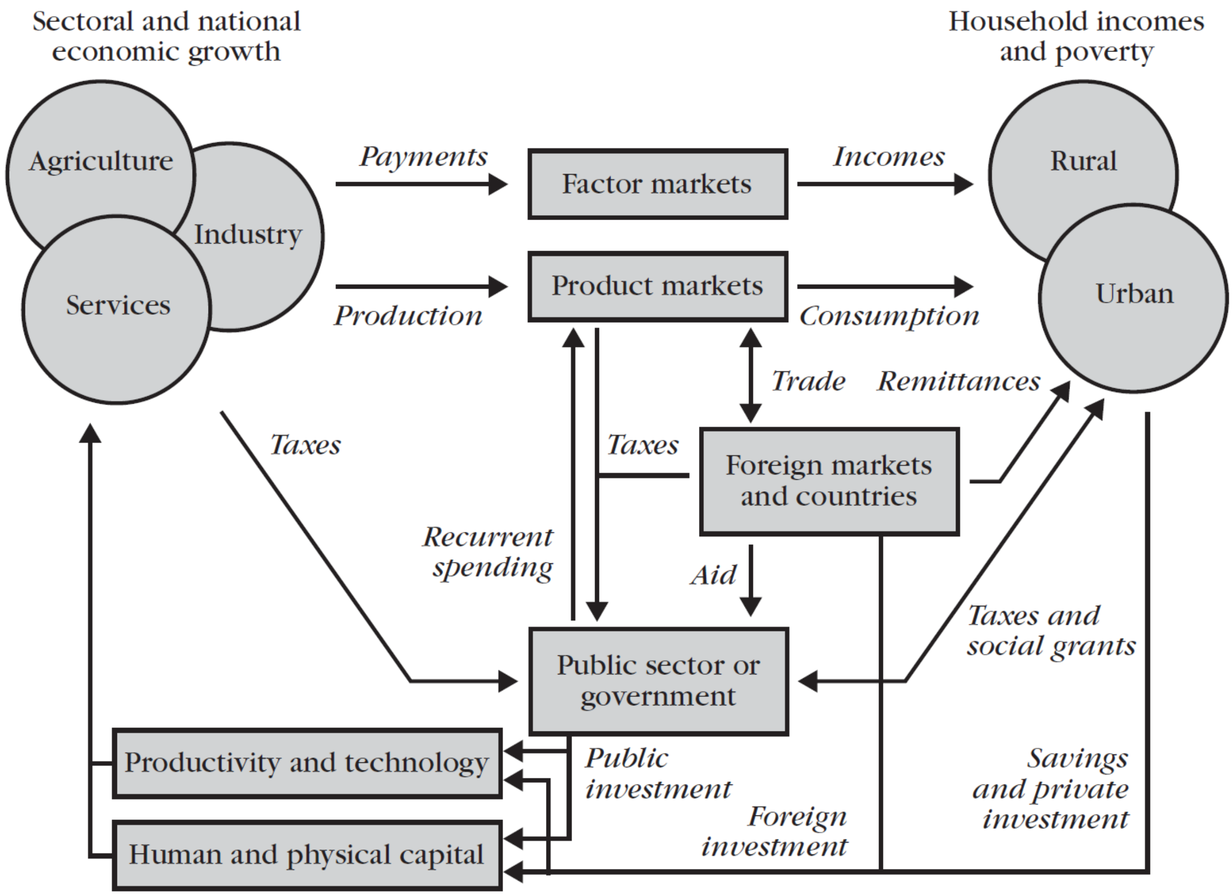
The second effect, while not commonly addressed in economy-wide models, is nonetheless tractable for incorporating in economy-wide models – and this paper clarifies some recent examples that pave the way for wider applications. The third effect is very difficult to capture in economy-wide models – one reason that economy-wide models should be used in conjunction with BCA, rather than a full replacement.[2] We argue in this paper that conditions now exist to apply these models much more broadly in the Nile Basin, yielding a much better understanding of how water and environmental interventions can have important "multiplier" effects over time, as resources previously used to combat disease are reallocated to productive use, and time spend recovering from disease is reallocated to education, the labor market, and even enhanced leisure.

With the dawn of digital computing came the development of economy-wide computable general-equilibrium (CGE) models (Dervis et al, 1982) with application for macro-economic policy and development planning. The economy-wide CGE model captures all income and expenditures within an economy during a given year. National production is disaggregated across detailed subsectors within agriculture, industry and services. **Figure 2** is a schematic of this general structure. Economic sectors employ factors of production (land, labor and capital) to produce goods and services that are supplied to national product markets. Factor incomes are paid to households – either directly or indirectly after paying taxes – and these incomes are used to finance consumption spending and/or savings. The model is "general equilibrium" because household factor incomes come from the production process and are used to buy the outputs that sectors produce, i.e., they capture the full circular flow of goods and incomes between households and sectors. The model also includes the government sector and the rest of the world, actors that buy and sell goods within domestic markets (e.g., foreign trade or government subsidized education and health services). Finally, household, government, and foreign savings (e.g., foreign aid inflows) provide the funds needed to finance investment spending (i.e., gross capital formation). For many growth analyses, particularly in developing country contexts, a dynamic CGE model is recursive dynamic, which means that the level of investment spending in the previous period determines the amount of new capital available this year. Through the equilibrium estimation process, new capital is distributed to sectors in the model that are relatively more profitable.

A Social Accounting Matrix (SAM) serves as input data for the economy-wide (CGE) model, which is in turn used to analyze and propose economic policy recommendations. A SAM is an economy-wide data set that captures flows and circulations of products, factors, and monetary flows, and reflects the process of initial income distribution and redistribution of industries and economic institutions of an economy in a certain year. The SAM effectively parameterizes the relationship among all economic actors within an economy as inputs and outputs to that actor's market economic activity, through interpretation of National Product Accounts.

[2] Some recent research proposes a pathway to incorporating this third effect, at least in developed country contexts where information on trade-offs between wages and mortality risk are well-characterized, see Marten and Newbold (2017).

Figure 2: Schematic of the structure of an economy-wide general equilibrium model



Note: Although not illustrated here, through government policy and as a source of employment, government can interact with both product and factor markets. The rest of world sector can also interact with factor markets, for example and in particular, through global capital markets. In addition, product markets can provide an important direct source of savings for private investment to enhance productivity and technology assets. (Source: Diao and Thurlow, 2012, reproduced with permission from the author)

The SAM is a relatively straightforward concept to understand, but economywide models and, in particular, CGEs, are complex models that can be difficult to understand. At their simplest level, the models develop production functions for goods and services producing sectors, defining the relationships between factors of production and outputs; consumer demand relationships for goods; a method for tracking the stock and flow of capital; supply and demand relationships for labor; and most important, a method of “solving” for equilibrium conditions that includes assigning prices to goods in the economy. For readers who are not familiar with these models, a good primer is provided in Paltsev (2004), including a simple illustrative example of a SAM and model equilibrium estimation for static and dynamic CGEs. The distinction between static and dynamic models is described in the following passage:

"Many CGE models are comparative-static: they model the reactions of the economy at only one point in time. For policy analysis, results from such a model are often interpreted as showing the reaction of the economy in some future period to one or a few external shocks or policy changes. That is, the results show the difference (usually reported in percent change form) between two alternative future states (with and without the policy shock). The process of adjustment to the new general, economywide equilibrium is not explicitly represented in such a model.

By contrast, dynamic CGE models explicitly trace each variable through time—often at annual intervals. These models are more realistic, but more challenging to construct and solve—they require for instance that future changes are predicted for all exogenous variables, not just those affected by a possible policy change. The dynamic elements may arise from partial adjustment processes or from stock/flow accumulation relations: between capital stocks and investment, and between foreign debt and trade deficits.

Recursive-dynamic CGE models are those that can be solved sequentially (one period at a time). They assume that behaviour depends only on current and past states of the economy. Alternatively, if agents' expectations depend on the future state of the economy, it becomes necessary to solve for all periods simultaneously, leading to full multi-period dynamic CGE models. Within the latter group dynamic stochastic general equilibrium models explicitly incorporate uncertainty about the future. "[3]

In the 1980 and 1990s there was a tremendous growth in both software tools for CGE and the application to policy-relevant issues, with the most common applications in the areas of trade, and food and nutrition (Thissen 1998). In the1990s analysts began to link CGE models with natural resource and environmental analyses, with some of the first applications to clarifying the role of water resources as an input factor for market activity (see Berck, et al.(1991) on the role of water for the California economy; Lofgren, et al. (1998); and Robinson et al. (2008) on the role of water in hydropower and agriculture production in Egypt).

More recent innovations have been driven by the need to assess the impacts of climate change on market economies, the modeling and methods innovations precipitated by climate analysis provided much greater insight about incorporating non-market activities in general (such as water resources as a factor of production) which paved the way for better applications to other non-market flows, such as health services, incorporated through household health production functions.

As we describe in the next section, movement in BCA away from conventional static methods (i.e., static prices, populations, and sector productivity), such as those often used in benefit-cost analyses, has the potential to capture the cumulative impact of alleviating damage to household health and welfare, and to minimize the potential for static approaches to underestimate the costs of failing to intervene. As outlined below, conditions in Nile Basin such as more rapid GDP growth and a smaller difference between the market and non-market consequences of poor health, not to mention the critical importance of re-allocating scarce resources to more productive uses, may make applications of economy-wide modeling in those countries even more important, simply because the cumulative effects across the economy and across time are more likely to be large. Put another way, the

[3] Wikipedia entry for Computable General Equilibrium: https://en.wikipedia.org/wiki/Computable_general_equilibrium

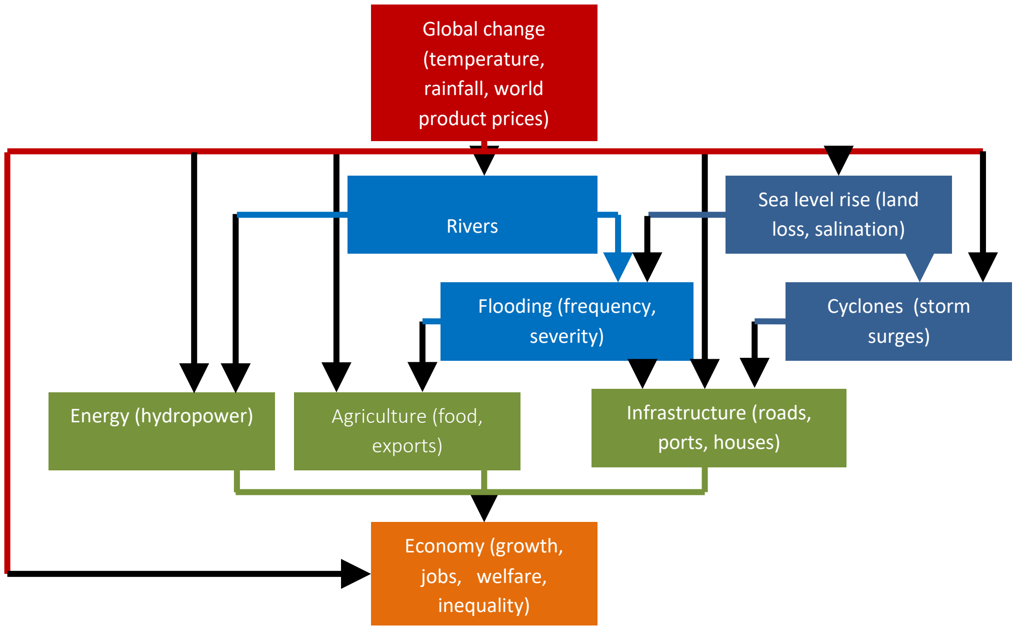
opportunity cost penalty of diverting labor and health costs for "defensive" purposes from GDP formation in the immediate term has larger long-term, cumulative effects in their faster growing economies.

Successful interventions in the water and environment sectors in Nile Basin countries are almost tautologically macroeconomically consequential via various channels of impact relating to labor supply, productivity, capital accumulation, and vulnerability to shocks, notably those that destroy physical or human capital either in the present (e.g., flooding) or in the future (e.g., childhood malnutrition). In sum, there are several good reasons to bring these frameworks to bear due to the need to capture items such as: multi-sectoral spillover effects; resource constraints; external trade balance and exchange rate effects; and government fiscal implications.

A major step forward was made possible when economy-wide models began to be standardized and made broadly accessible for developing country economies through efforts at the International Food Policy Research Institute (IFPRI), the University of Copenhagen, the University of Colorado, MIT to provide national level case study analyses for the World Bank's Economics of Adaptation to Climate Change (EACC) study prepared for the Copenhagen COP: The summary report (World Bank, 2010), Ethiopia (Robinson, et al 2013), Ghana (Arndt et al 2015), Malawi (Arndt et al. 2014), and Mozambique (Arndt et al 2011a).

Responding to the need highlighted by the EACC case studies and to assist policy makers in evaluating the potential economic impacts of climate change, as well as to identify specific regional and sector vulnerabilities, the United Nations University – World Institute for Development Economic Research (UNU-WIDER), in collaboration with external partners, has progressively developed an analytical framework, called Systematic Analysis of Climate Resilient Development (SACReD). The SACReD approach is novel in that it integrates comprehensive biophysical modeling with economy-wide economic analysis. The climate impacts and adaptations component of the SACReD framework is illustrated in Figure 3.

Figure 3: Systematic Analysis for Climate Resilient Development (SACReD) framework



The framework begins with climate change scenarios for a particular country. Climate change manifests itself as changes in projected levels for temperature, precipitation, barometric pressure, humidity and other weather outcomes. However, with this information alone, it is difficult to assess the potential impacts of climate change on many variables of interest such as economic growth, development prospects, and the material wellbeing of the population. As such, the SACReD framework traces the implications of changes in climate outcomes through a series of important impact channels—including the production of hydropower, agricultural yield, water supply/demand balance, and costs of maintaining and repairing damaged infrastructure and other installed capital.

These climate change impacts then serve as inputs into an economy-wide model of the country in question. The economy-wide models employed respect macroeconomic identities, meaning that all futures are economically coherent and account for multiple simultaneous impacts. For example, higher levels of rainfall may be favorable for hydropower generation, water supply, and agricultural production, but unfavorable for road infrastructure due to washouts or widespread flooding – both effects are accounted for in the framework. Yet, in addition, the SACReD framework respects biophysical limitations and opportunities for the use of natural resources as factors of production across a wide range of sectors – for example, the use of constructed wetlands to reduce flood risks and, in the process, effectively reduce depreciation rates of capital vulnerable to floods. Variants of the SACRED framework have been applied to Ethiopia (Robinson, et al 2013), Ghana (Arndt et al 2015), Malawi (Arndt et al. 2014), Mozambique (Arndt et al 2011a), Tanzania (Arndt et al 2011b), Vietnam (Arndt et al 2015b), Zambia (Schlosser and Strzepek 2013), and South Africa (Cullis et al, 2015).

The most recent applications of economy-wide tools extend the SACReD framework from a climate change focus to include the economy-wide implications of investment in water and environmental development and managment, which in many instances, especially in developing economies, are linked to public health (see, for example, Strzepek et al. 2016 for an application in Uganda.)

The SACReD framework allows us to better understand how natural resource stocks and flows affected not just physical environmental metrics but also economic productivity, capital accumulation pathways, and GDP growth over time. In addition to the many country-level applications of SaCRED noted in the appendix of this paper, Alton et al. (2014) used the approach to assess the implications of carbon taxes in South Africa, taking advantage of the framework's explicit modeling of water resources for various market uses for energy production (hydropower, mining, and thermal power plant cooling), as well as for other productive uses (agriculture, domestic water supply, food processing, etc.). Hassan and Thurlow (2011) used a similar approach, combining both macro- and micro-economic modeling approaches, to assess agricultural policies and nutrition in South Africa. Pauw et al. (2011) assessed the macroeconomic implications, and in particular the dynamic effects on capital accumulation pathways, by modeling impacts of extreme weather events in Malawi. In all cases, the macroeconomic tool was a critical component necessary to fully understand the economy-wide effects of policy, but also the impact on economic development goals in these Southern African contexts.

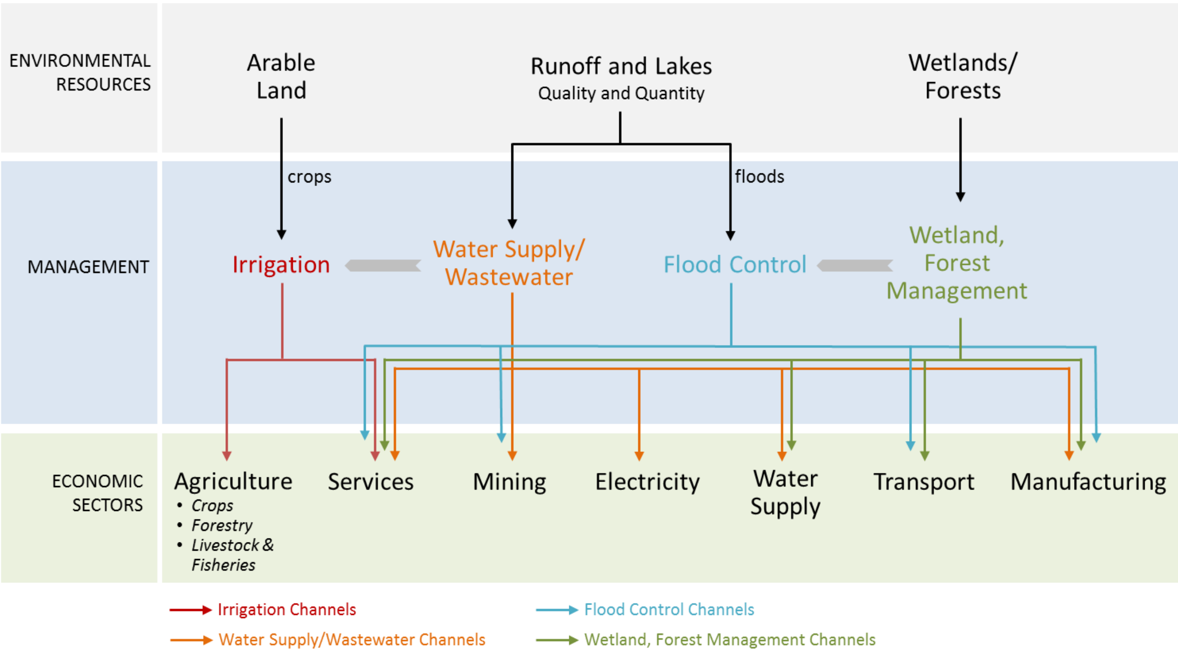
Uganda Case Study

The most recent key innovation has been combining analyses of water and environmental interventions in an economy-wide modeling context for a developing country economy – the case study that we argue represents the current state-of-the-art is an effort funded by the Uganda Ministry of Water and Environment (MWE), with World Bank support (Strzepek et al. 2016). The Uganda MWE study evaluates a broad set of planned interventions, separately and together, over 25 years and considers impacts of each GDP and overall income. The addition of public health "channels" to a modified version of the SaCRED framework provides an important illustrative application that encompasses effects on urban and rural water supply; industrial and agricultural water supply; sanitation/handwashing with concomitant gains in household time (which can be applied to human capital development) as well as reduced health effects (which enhances labor productivity); and forest resource protection, with concomitant gains in individual air pollution exposure reduction because of beneficial changes in cookstove fuels (enhancing health and labor productivity) and reduced wood gathering time (which can be applied to human capital development).

This analysis employed a detailed-sector national CGE macro model of Uganda's economy, coupled with biophysical models of irrigation water demand, crop yield, rainfall-runoff, along with municipal and industrial water demand models to produce inputs to a detailed 84 sub-basin water balance model of Uganda. Additional wetland, water quality, flood risk, and land-use models simulate the impacts of water development and environmental management investment on land, labor, and capital productivity in the economic model. The water and environmental investments impact the economy via a complex interconnection of the economic production factors of labor, capital, and natural resources – the interconnections are summarized in **Figure 4** below, with the center panel labeled "Management" representing the "levers" of investment that can be used to enhance economic productivity.

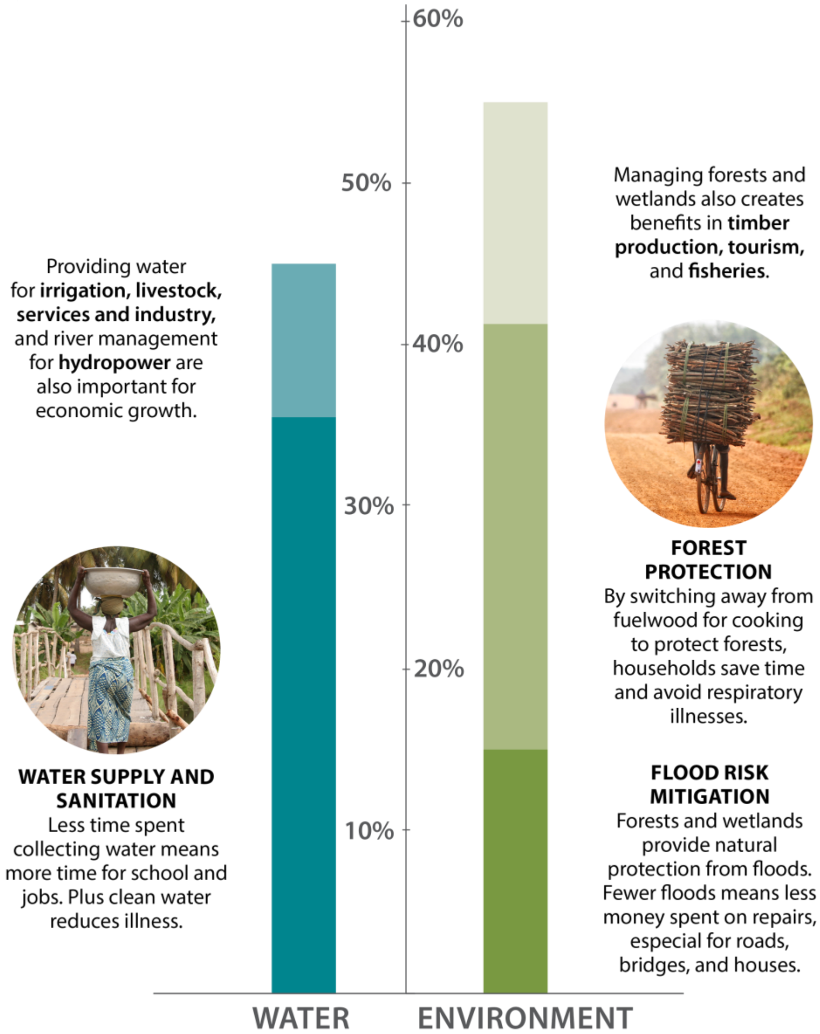
Investments that enhance factors of production ripple throughout all sectors of the economy. For example, investments in urban and rural water supply and sanitation increase the supply and quality of labor which is the major productive factor of the commercial and manufacturing sectors. Investments in environmental management improve ecosystem services such as reduced flooding, improved water quality and improved public health. These services reduce government expenditures for infrastructure repairs and health care, enhancing GDP.

Figure 4: General Framework Applied in Modeling the Economy-wide Impact of Water and Environmental Investments in Uganda



The study found that the overall increase in GDP per capita for all the investments considered is 9 percent through 2040, equivalent to an extra $111 per person in 2040 in this very fast growing population. **Figure 5** below illustrates the results of the method as applied to MWE investments, and denominated in terms of contributions to GDP growth over the 2015 to 2040 period, allocated to individual components of the investment package. The reader should be immediately struck not just by the large shares associated with environmental and water investments, but by the inter-relatedness of a multi-sector economy, water availability and quality, environmental/ecological productivity enhancements, labor productivity, and critical health outcomes, particularly among disadvantaged rural households.

Figure 5: Estimated contribution of Ugandan Ministry of Water and Environment Investments to the Total 9% Increase in GDP in 2040.



Ethiopia Case Study

One of the original EACC case studies that was an inspitation fro the SACReD framework, Robinson, et al, 2013 presents an economic analysis of climate change impacts and adaptation options suitable for developing countries with a high dependence on climate-sensitive sectors and climate-sensitive infrastructure. Climate projections across the range of high-resolution global circulation models (GCMs) are handed down to a linked system of country-specific hydrology, crop, and engineering models to generate time series of yield impacts by crop type and agro-ecological zone, as well as impacts on road infrastructure and hydropower. These time series are used to shock a multisectoral regionalized dynamic computable general equilibrium (CGE) model to determine economy-wide outcomes. By construction, the results take consistent account of intersectoral linkages as well as autonomous adaptation responses by agents to changes in relative prices and real incomes. Illustrated in Figure 6.

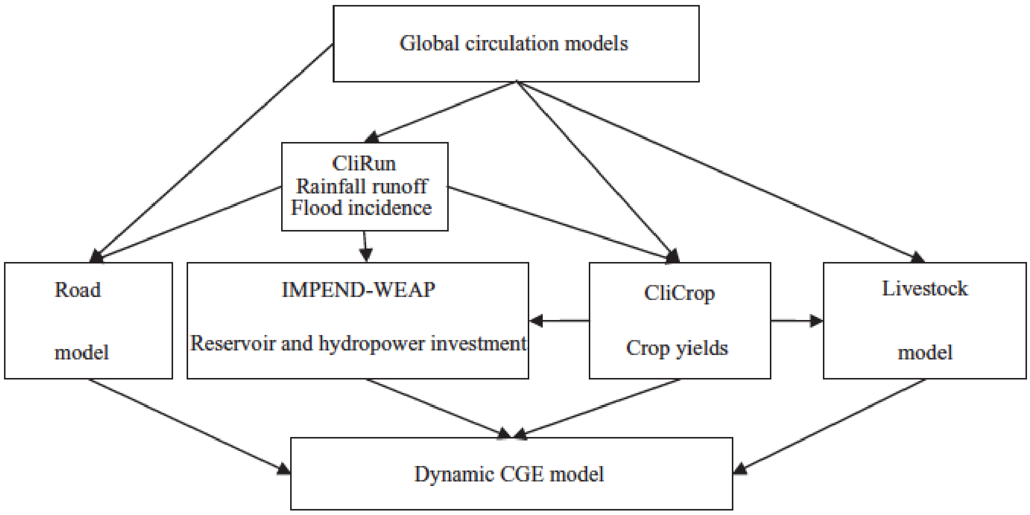


Figure 6: General Framework Applied in Modeling the Economy-wide Impact of Climate Change on Ethiopia

The dynamic simulation analysis suggests that, in the absence of externally funded policy-driven adaptation investments, Ethiopia's GDP in 2050 will be up to 10% below the counterfactual baseline, which assumes no climate change (projecting historical climate impacts). Moreover, the year-to-year variability in real income and real house- hold consumption rises significantly under climate change.

The presence of considerable initial uncertainty about the future climate calls for pragmatic and flexible adaptation strategies that favor no-regret and low-regret measures that promise net benefits under any climate scenario until uncertainty is gradually resolved over time. Given the past difficulties in adapting to historical weather variability in Ethiopia's agriculture, road network and hydropower infrastructure, investments aimed at increasing the resilience to climate change in these areas are obvious components of a no-regret adaptation strategy.

The results suggest that, with support from developed countries, suitably scaled adaptation measures could restore aggregate welfare to baseline levels at a cost that is substantially lower than a lump-sum compensation payment equal to the welfare loss. If adaptation investment costs must be financed domestically, the results are less beneficial, but still indicate high net social returns to such investment.

EGYPT CASE STUDY

Construction of the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile stands to greatly benefit Ethiopia, but its filling will have impacts on Nile inflows to Egypt. In response, Egypt has concerns that these impacts on Nile flows will have significant effects on the Egyptian economy. Despite these concerns, the extent to which Egypt's economy will be affected by GERD filling has not been evaluated.

Boehlert, et al (2017) has undertaken an analysis of this questions following the SACReD framework, but with a novel extension of coupling the water systems model with the CGE. Previous work did not have any feedback of the CGE on the Water Management Model. This study couples three models to analyze how GERD filling combined with variable Lake Nasser inflows will impact Egypt's hydropower generation and irrigation deliveries over a future 20-year period, and how these will affect economy-wide indicators including GDP. Models include a water systems model of the Nile upstream of Lake Nasser (including the GERD), a water management model of the Egyptian water system, and a computable general equilibrium (CGE) model of Egypt's economy. Illustrated schematically in Figure 7.

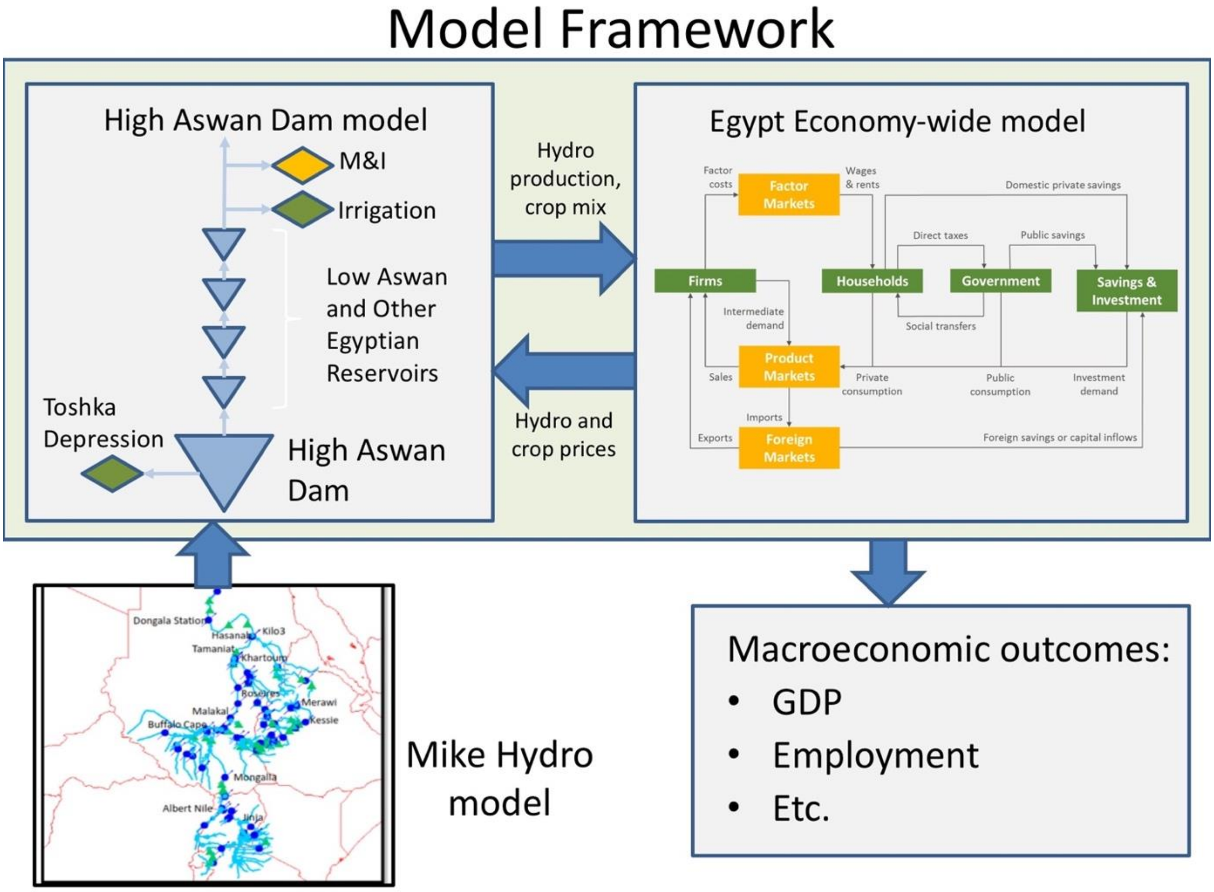


Figure 7. Modeling Framework for Assessing Economy-Wide Impact to Egypt from GERD Filling

Given that future Nile inflows are unknown, the study employs a risk-based approach, where 100 synthetically generated hydrology time series are processed through the modelling system to generate probability density functions of hydropower generation and economy-wide indicator outputs. We find that under a "worst-case" GERD filling scenario, the 5th percentile of the 100 Nile inflows to Egypt reduces hydropower generation at the High Aswan Dam by 10% per year over the first three years, which when routed through the CGE model translates to a GDP impact of 0.13% (380 US$ million based on 2014 GDP). Impacts on Egypt fall sharply after GERD filling is completed. On the other hand, considering energy benefits to Ethiopia alone, the GERD would produce over $1 billion per year in sustained hydropower revenues, suggesting that there may be room for benefits sharing.

The key conclusion of this broad literature review is that economy-wide tools provide a new and compelling tool (to policymakers, particularly in Ministries of Finance) for assessing the benefits and costs of a wide range of interventions. Some decision makers may care more about GDP than economic welfare, or may simply better understand the terminology and implications of the GDP metric. The literature points to the importance of careful scenario construction and proper evaluation of the results. There tools also can be highly sensitive to assumptions such as how the project is financed, and the ordering of investments.

3.0 Steps to Developing an Economy-Wide Modeling Framework

The undertaking of a benefit-cost analysis of a water or environmental project program policy is a significant undertaking in any setting. Performing a cost benefit analysis that includes assessment of economy-wide effects requires all of the data gathering that would be necessary for a static or partial equilibrium accounting of benefits and costs in a cost-benefit analysis. What this approach provides, provided the framework is a dynamic economy-wide model, is a mechanism to more effectively estimate second and third and fourth order impacts across the economy in addition to including nonmarket and ecosystem services to the analysis.

The economy-wide modeling approach is not a substitute for classical cost-benefit analysis but in fact is an extension that enhances the information being provided by the analysis. Taking an economy wide approach for cost-benefit analysis requires additional time and effort, but it is the authors' opinion that the costs are often less than the benefits, provided certain circumstances are evident. With that in mind, it is important to understand both the conditions under which a dynamic, economy-wide modeling approach is likely to provide compelling new insights, compared to a conventional BCA welfare analysis (i.e., what are the marginal benefits of an economy-wide approach), as well as what is involved, step-by-step, in completing the economy-wide variant (i.e., what are the marginal costs of an economy-wide approach).

3.1 CONDITIONS Where An Economy-Wide Model May Make Sense

In general, dynamic economy-wide models, compared to partial equilibrium or static economy-wide approaches, may be less attractive when: 1) the policy or investment being considered represents a marginal change relative to the size of the economy or sector being considered; 2) when beneficial effects are largely confined to a short-term time horizon, with limited long-term/cumulative impact on human and physical capital formation which contributes to long-term economic growth potential; and 3) when the costs and/or the benefits of the intervention are largely confined to a single economic sector, with few if any spillover effects through factor or product markets.

By extension, the literature summarized in section 2 above suggests that dynamic economy wide-modeling tools are best applied when the following conditions are in place:

- ***Sufficient data exist.*** A necessary requirement for any economy-wide model is that a social accounting matrix exists or can be readily developed. As noted below, the barriers to developing a SAM in almost any country in the world have been considerably lessened by efforts by the World Bank and IFPRI to make these data elements more widely available. Other data are needed to characterize the population affected by the intervention, and to characterize opportunities among these populations for reallocating time, land, water, food, or economic resources elsewhere to take better advantage of productive opportunities, often at the household level, and stratified by income where possible (as effects are likely be larger among low income populations, where even smaller interventions can represent a meaningful relative impact).

- ***Effects are large.*** The exact definition of "large" varies by country context – for example, Berck and Hoffmann (2002) suggest that in an economy as large as that of the U.S., effects smaller than $100 million annually are not likely to yield meaningful results in an economy-wide tool. The Matus et al. (2012) example cites meaningful results for effects of $30 to 60 billion in the large Chinese economy, which more than meets the $100 million threshold, but the Matus work also concludes that, in fast growing economies, the ripple effects on capital accumulation are more important than in more mature, slower growing economies. This suggests that economy-wide tools may yield important insights i even for what would be considered relatively small primary impacts in other settings.
- ***Effects have a cumulative nature over time.*** Interventions that have the potential to alter resource allocations (including time resources), affect capital accumulation (including local scale human capital), or have an intergenerational effect on household prospects are much more likely to yield synergistic positive effects as a result of deploying an economy-wide modeling approach. Opportunities for such interventions are likely more prevalent in subsistence settings where even marginal decrements or improvements in productivity of health, labor, or food production can have a noticeable effect on household prospects.
- ***Inter-sectoral implications are likely.*** Effects limited to a single sector, such as for interventions that are designed to improve a single industry's productivity, can be readily analyzed without reference to general equilibrium techniques. In Low Income settings, however, the existing literature suggests that such single sector interventions may be rare – for example, virtually any intervention in the health sector improves well-being to the point that other long-term, multiple-sector, cumulative effects can result from the reallocation of time previous spent ill, or resources previously spent on treatment, provided that opportunities exist to pursue education or economic opportunity. Economy-wide tools provide a unique mechanism to explore the potential of these opportunities.

This last point about the potential for inter-sectoral implications as a key rationale in expanding a partial equilibrium to a multi-sectoral general equilibrium approach is also emphasized in SAB (2017), where they expand on this point to further note that a strong rationale exists when *both* of the following are present [emphasis in original]:

- Significant cross-price effects, where a costly policy in one market drives consumers to buy more of a substitute or less of a complement good from another industry, and
- Significant distortions in those other markets (e.g. market power, taxes, or regulation). Distortions arising from externalities could also be captured in models where environmental quality [or in this case, health] is not separable from market goods.

SAB (2017) also notes that an economy-wide CGE model can provide a consistent and comprehensive accounting framework to analyze and combine effects of a policy change on both the cost side and the benefit side in a way that satisfies all budget and resource constraints simultaneously.

A separate point can be made about whether a sectorally resolved economy-wide model is needed, rather than a simpler aggregate macroeconomic model that is capable of capturing cumulative effects that relate primarily to overall population health. In general, we advocate for the application of the simplest models or tool capable of fully characterizing the economy-wide effects. For example, Jefferis and Matovu (2008), in evaluating the macroeconomic impact of HIV/AIDS in Uganda, apply both an aggregate growth model and a sectorally rich CGE – as they note, the aggregate growth model is well-accepted in the literature, particularly for HIV/AIDS analyses, and is simpler, but the CGE provides a broader and richer range of outputs and can more thoroughly trace impacts through the economy. Interesting, both estimate a similar magnitude of GDP impact. In another example, Hellmuth et al. (2006) applies an aggregate macroeconomic tool to assess economy-wide and long-term implications of water quality improvements on prospects for the HIV infected population of Botswana. These simpler aggregate growth modeling tools are not adequate to capture the effects of policies or interventions with multiple and complex multi-sectoral implications, however, as noted above. The simpler tools do form the basis for the "multipliers" on health improvements estimated in the extended cost-effectiveness analysis (ECEA) method (see Verguet et al. 2016). Four key distinguishing factors in deciding whether to apply an aggregate or multi-sector macroeconomic model could be: 1) the nature of the shock to the economy – in particular, whether the shock is focused on a relatively narrow demographic or sectoral component[4]; 2) The shock or intervention has broad multi-sectoral impacts such as a broad labor impact on the national economy; 3) whether there is a desire to estimate distributional impact across income classes, or distinguish the impact on urban or rural poor; and 4) whether a sectorally disaggregated set of outputs is desired, as in the Uganda case study.

3.2 Biophysical, Models

Once all the data has been gathered for the particular water or environmental program to be evaluated then a series of biophysical models must be prepared that link the proposed program to the elements of the economy. For example, for a wetlands restoration project, hydro climatic data is needed and a model of the flood mitigating properties of the wetland needs to be developed. The physical outputs of this model can then be mapped to various ecosystem services which can then be linked to the economy wide model using "channels" described above for the Uganda study. In the wetlands example, the reduction in flood peaks will lead to reduced damages of transportation infrastructure and other public and private capital. The channel in the CGE is a reduction in the depreciation of capital in the appropriate sectors.

Similarly, water and sanitation improvements, as illustrated in the Uganda study, must include models of the health benefits of clean water provision relative to the existing baseline conditions.

For effects that are mediated by biophysical processes, these models of natural environmental systems and civil infrastructure systems may be available in developing nations as they are used directly in classic benefit cost analysis for infrastructure investments . A good source for these models and expertise would be local universities and national ministries of water resources or environment. In addition, the UN water related agencies as well as the World Bank and many bilateral aid agencies have expertise and in archives of modeling efforts. Some NGOs such as the Stockholm Environment Institute provide modeling tools available free of cost for developing countries.

[4] We are grateful to Markus Haacker for expression of this point.

3.3 Public Health Models

Cost-benefit analyses that are examining public health aspects (including vaccines, prenatal and maternal health, as well as indirect effects on health mediated through food, water, or environmental pathways) will need to add additional channels that are developed from and informed by similar models that are in practice in the public health sector. For example, reduced flood damage to water supply and wastewater/sanitation facilities will decrease the need for health expenditures (cholera outbreaks) which can go directly into the CGE through a channel of reduced health sector spending.

In the recent Uganda study (Strzepek et al. 2016) three channels were identified from the literature on how clean water supply would reduce the number of diarrheal cases among children and adults. The first channel was to reduce the health costs associated with each case of diarrhea prevented, increase the labor productivity of adults due to reduced sick days and increase the effectiveness of education as children would have fewer absences. The conceptual and mathematical models as well as the data for developing health related channels was all found in the published literature and vetted with local Ugandan experts for their veracity in the Ugandan urban and rural settings. Local universities and ministries of public health as well as UN agencies, development banks and NGOs all have data expertise and modeling studies for most regions of the world.

To this point the development of channels would appear to be well within the sphere of classic cost-benefit analysis but requiring some deeper digging and conceptual framing to cast the problem into channels. The difficulty becomes when one seeks to link these channels with an economy wide model - in this case a computable general equilibrium model, CGE. Many feel that a framework using a CGE would be prohibitively expensive in terms of data gathering, model building, and accessing CGE expertise. However due to a number of global and regional efforts the data and software needed for building CGE models has become much more widely available, as described in the next section.

3.4 Social Accounting Matrices

As mentioned above the first thing needed to develop a CGE model is to have a social accounting matrix (SAM). There are many national level and sub-national level SAMs that have been developed by Ministries of Planning, Economic, or Finance for macro policy assessments. Additionally, many development banks and universities have developed SAMs for most countries. Additionally, there is the Global Trade Analysis Project (GTAP). GTAP is coordinated by the Center for Global Trade Analysis in Purdue University's Department of Agricultural Economics. The GTAP 9 Data Base features 2004, 2007 and 2011 reference years as well as 140 regions for a list of 57 GTAP commodities. A user may extract country SAMs or I-O tables from the GTAP Data Base for single country models.

International Food Policy Research Institute (IFPRI) and the World Bank have developed many national SAMS as part of their economy-wide modeling efforts. Contacting them as well as searching their archives is a great starting point.

3.5 CGE Modeling Software

Once a SAM has been developed or acquired one needs to have software to run a CGE Model.[5] It is possible to program a CGE model from scratch in any programming language but it highly discouraged. There are three popular CGE modeling software systems:

- GEMPACK (General Equilibrium Modelling Package) requires a GEMPACK license to modify the standard GTAP Model. The Centre of Policy Studies (CoPS), Australia develops and supports GEMPACK. GEMPACK licenses must be obtained from CoPS.[6]
- MPSGE is a mathematical programming system for general equilibrium analysis which operates as a subsystem within GAMS (see Paltsev 2004 for a primer on its use). The system can be obtained through GAMS, which requires a license.[7]
- IFPRI Standard Model is a "standard" CGE model written in GAMS with an EXCEL interface. The analyst is not forced to make "one-size-fits-all" assumptions. The GAMS code is written to give the analyst considerable flexibility in model specification. Obtained through IFPRI.[8] Notably, the IFPRI standard model was originally developed as a static model (Lofgren et al. 2002), but relatively recent investments have improved it to the recursive-dynamic format used in the Uganda case study featured in this paper (Diao and Thurlow, 2012).

3.6 Developing A Fully Integrated Framework

Once you have the models that represent the water or environmental project or program to be analyzed, the SAM: at national or subnational level, and the CGE software one must develop the linked framework. This requires bringing the disciplinary experts together to work on the development of the channels and their linkage to the appropriate parameters/functions in the CGE. It is not required but extremely beneficial to have someone on the team who is "bilingual" in economics and water or environmental systems who can facilitate the dialogue among the team.

A key factor is that one of the more important aspects of modeling water resource or environmental systems is the variability of the inputs to the system. Most frequently it is the climatic or weather variability usually manifested as floods and droughts that have major impacts on human systems: public health, water supply, agriculture, transportation, and economic systems. It is very important that the modeling framework model the variability explicitly and not model average parameters as these in many cases lead to the "flaw of averages", as illustrated for agricultural planning in Ethiopia by Block et al. (2010).

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[5] Note that the tools and the software referenced here do not require supercomputers but they do require modern multi-core CPUs with large RAM memory and ample disk storage for model outputs from the many scenarios that will be run.

[6] GEMPACK https://www.copsmodels.com/gempack.htm

[7] MPSGE https://www.gams.com/solvers/mpsge/index.htm. Note that a GAMS license can be obtained for as little as $500, so it represents a relatively modest investment in most contexts.

[8] IFPRI http://www.ifpri.org/publication/standard-computable-general-equilibrium-cge-model-gams. See for example Lofgren et al. (2002) for a description of how to address the issue based on existing research and data, which can be potentially incorporated into the reference case principles, methodological specifications, and reporting standards.

Cost-benefit analysis will take place by running the system with and without the proposed investments. It is therefore very important that the team carefully designed what is the baseline without the investment given autonomous behavior of an economy and the scenarios with the investments in place. This includes dimensions of the baseline and intervention scenarios that relate to population and changes in population growth determinants, energy and food prices (including world market prices), and other exogenous drivers to the system.

One very important aspect when dealing with economy wide models is identifying by whom and how investments are to be financed: grants from donors, loans from development banks, domestic tax based investments, or public-private partnership projects. How these are accounted for in the model, as lump-sum investments or annual payments to bondholders, or banks, can critically affect the results. In developing country settings in particular, it is important to have a complete accounting of the government budget within the economy-wide model. Finally, the value in using these tools is only realized when there is thoughtful analysis by a team of multidisciplinary analysts who following the wisdom of Keynes - that models offer insights and not answers.

4.0 Recommendations

Experience to date provides a strong basis to recommend the next stages of research, implementation, and capacity building needed to facilitate wider application of C economy-wide modeling in support of benefit-cost evaluations in the Nile Basin. The relevant literature summarized above has shown that it is the linkage and the systems thinking that provides for the added value of economy wide modeling in benefit-cost analysis. The Uganda application described here uses economy wide modeling to estimate metrics not usually addressed in a traditional benefit-cost analysis, namely the contributions of investments and interventions to GDP and overall country-level development objectives. These tools can also be used to estimate benefits and costs in a welfare economic framework, and these estimates are an important supplement and enhancement to a traditional partial equilibrium benefit-cost analysis.

One of our goals in this paper is to demonstrate that it is now more tractable and feasible to apply these tools in across the Nile Basin, with examples from three Nile Basin Riparian, and to illustrate that the results provide new and potentially compelling motivations to take action in the water and environmental sectors, among others. To further this goal, there are three areas where this approach can be made to be more effective and rigorous. Perhaps surprisingly, these long-term priorities are not focused on development of the major tools in the framework, so much as they relate to creating conditions to improve the operation and interpretation of these tools in Nile Basin country settings:

1. Improve the sub-national collection of economic, social, public health, natural resource and civil infrastructure data to allow for modeling of economics at the scale at which these processes actually take place and where interventions have their greatest impact. These data are the critical first step to understanding the “front lines” of the interventions of interest, facilitating the quantification of mechanisms by which health and other improvements at the district, village, and household level yield meaningful economic implications that ripple beyond the granular level at which they are implemented.

2. Conduct a major effort to quantify and develop mathematical relationships for the impacts between public health-based interventions/projects/programs and their outcomes on human activities (e.g. number of reduced diarrheal events per capita for increased clean water supply.) These "translational" relationships are necessary to provide the key links needed between traditional static assessments of the impact water and environmental interventions, and economy-wide modeling, thereby quantifying the potentially important cumulative, inter-sectoral, and spillover effects of these interventions. The good news is that we are in a much better position today in terms of understanding the connections between education, health, nutrition and labor productivity, thanks to the availability of hundreds of empirical studies conducted around the world on the association between social interventions and household outcomes. An important public service could be accomplished by compiling a functional and accessible database of the results of these studies.
3. Develop within governments the required interdisciplinary analytical teams that can provide the support needed for decision-makers to bring economy-wide assessments to bear on crucial public policy questions – questions that are too frequently analyzed in a static or partial equilibrium framework, resulting in unintended consequences that might have been identified by using a systems or economy wide approach. While many Ministries of Economy, Planning, or Treasury already have CGE modeling units, application to water and environmental investments requires a new set of interdisciplinary skill. This may be the largest challenge in the way of greater adoption of these tools, faced equally in developed and developing country settings.

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Annex 5

The hydroeconomics of Nile water management: Review of the current 'state of knowledge'

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Introduction

As global water scarcity increases due to increasing demand from population growth and economic development, use of resources from shared water resources also increasingly involves complex tradeoffs across different types of uses, as well as the environment. Hydroeconomic models (HEMs) represent one set of tools that help inform water infrastructure planning and management decisions. Broadly speaking, such tools aim to incorporate "regional scale hydrologic, engineering, environmental and economic aspects of water resources systems within a coherent framework" (Harou et al. 2009). Unlike simple hydrological models that that aim for simple and general descriptions of the behavior of these systems, HEMs aim for discovery or better characterization of strategies that advance the economic efficiency of water use, measured in terms of overall gross or net benefit. To do so, HEMs integrate more conventional hydrological descriptions with economic optimization or simulation methods.

Under this broad umbrella, HEMs vary considerably in their specific architecture, and modelers have commonly used them to consider a wide range of potential policies and decisions. Prior general reviews have considered both structural and applications-related issues in detail (Booker et al. 2012, Brouwer and Hofkes 2008, Harou et al. 2009, Cai 2008, Bekchanov et al. 2017). In discussing structural features and aspects, Harou et al. (2009) provide a useful characterization of such models.[1] Table 1 offers this author's own summary of some of the most salient aspects of such tools, which will also be used to guide the discussion of prior Nile basin analyses further below. Meanwhile, a recent systematic review emphasizes that much work using HEMs has focused on the most important drivers of variation in the economic performance of management solutions (for example exploring the importance of factors related to climate variability and change, or the value of energy), on tradeoffs across uses (usually as they relate to shadow values, or true opportunity costs), on the benefits of investments in physical water efficiency or demand management using price and non-price instruments, and on the gains from allowing water trading across users (Bekchanov et al. 2017). Much less attention has been given, however, to ecosystems, feedbacks from the social water use system back into the water resource system, and on integrated analysis of water-energy-food nexus issues.

As we will see in this short background paper, HEM work in the Nile basin illustrates well this variation in potential model architectures, and largely conforms to the basic trends in applications that were documented in Bekchanov's recent review. In the next section, we provide a summary of this prior work. We then provide a general synthesis of the evidence this work provides on how management of the water resources of the Nile might be enhanced, and reflect on unresolved questions that deserve attention from hydro-economic modelers.

[1] A thorough discussion of these approaches is beyond the scope of this paper. However, the reader can refer to the following sources for descriptions of these various options: Monte Carlo simulation frameworks (Jeuland et al. 2014); simple deterministic optimization (Rogers et al. 1969); stochastic optimization methods including optimization with recourse, probabilistic programming, or sampling stochastic dynamic programming (Sen & Higle 1999; Kelman et al. 1990); robust optimization and decision-making approaches (Mulvey et al. 1995; Groves & Lempert 2007); and fuzzy mathematical programming (Bellman and Zadeh 1970).

Table 1. Summary of basic choices in HEM architecture, and comments on their relative strengths and weaknesses

Options		***Description***	***Comments***
Model type:	Optimization	-What strategy is best?	-Most flexible solution space, but may be unconvincing
	Simulation	-How does strategy perform if…?	-Computational advantages and realistic institutional representation, but may underperform
Flows:	Single series	-Historical or synthetic series	-Intuitive comparisons, but future ≠ past
	Stochastic series'	-Stochastic series' sampling	-More thorough incorporation of variability, less intuitive, and future still difficult to forecast
Uncertainty:	Scenarios	-Best-worst / ranges	-Deterministic and simple, but ad-hoc
	Risk-based	-Clear probability distributions	-Amenable to standard methods of decision analysis, but assumes away "deep" uncertainty
	Other	-No clear probability distributions	-Perhaps most relevant, but may challenge decision-making
Integration:	Modular	-Linked models run separately	-Well adapted to disciplinary realities, but clunky to use, esp. for modeling interdependencies (feedbacks)
	Holistic	-Single integrated platform	-Allows modeling of feedbacks; but computational challenges may force simplification

Review of prior Nile HEM literature

Despite the strategic importance of the Nile and the extent to which it figures in discussions of potential water conflict, there has been surprisingly limited work to understand the economic dimensions of the challenge of managing its waters. Within the small set of Nile HEM studies, however, a variety of different model architectures have been applied. Also, despite this variation in methods, there is considerable agreement in the general results and conclusions, if not the details, that emerge from this body of work.

Table 2 summarizes the key features of these prior studies, in terms of the architectural choices described in Table 1, and provides summary information related to the main issues and findings of researchers using those models. Several models – for example the NEOM and Nile SDDP – have been used for analyzing multiple questions. Though there are exceptions, most models have relied on an optimization approach, deterministic flows, and holistic approaches; with objectives that have focused primarily on irrigation and energy. Here we note also that Geressu and Harou (2015) do not apply an HEM in the strict sense of the word, although their multi-objective approach does explicitly include a number of economic goals and thus deserves to be compared with the other approaches in which the objective function is purely about maximizing economic value. Another common thread across prior applications is their predominant focus on the Eastern Nile, which includes Ethiopia, Sudan and Egypt, and the fact that the greatest attention has been given to the case for hydropower dams in the Blue Nile.

The very first HEM developed for the basin was the deterministic Nile Economic Optimization Model (NEOM), which, along with the modular simulation infrastructure of Jeuland (2009) is notably one of only two such full basin models.[2] In the first paper written from analysis using this model, the authors demonstrated the large economic gains from upstream development in the basin, especially from hydropower production in the Ethiopian Blue Nile (Whittington, Wu, and Sadoff 2005). In a second and related paper, Wu and Whittington (2006) used game theoretic concepts to further demonstrate that cooperation was incentive compatible in benefiting all major riparian groups, and that numerous benefit sharing rules seemed both feasible and equitable. In considering these results, it is important to note that the annual NEOM model only considered benefits from irrigation and energy generation. The analysis demonstrated that a large portion of the economic benefits from development would arise from hydropower dams built in the Ethiopian Blue Nile, which in turn decreased the economic rationale for water withdrawal upstream in Ethiopia. It also demonstrated for the first time an important insight that has subsequently been thoroughly and repeatedly discussed in similar work: that storing water upstream in cooler and wetter locations with more favorable topography (entailing higher storage to area ratios of reservoirs) could increase water availability by reducing system-wide evaporative losses. Finally, though the paper raised the issue of a range of other benefits – drought and flood management, sediment control, environmental preservation, and domestic water supply – from infrastructure development and cooperation, it only discussed these qualitatively.

The application of the NEOM constituted the first real attempt to understand the economics of water-related development and cooperation between riparian nations in the Nile basin, and it clearly advanced the conversation related to assessment of this potential. Nonetheless, analyses using it suffered from several important shortcomings, many of which have remained important in subsequent Nile HEMs. Perhaps most importantly, the analysis did not rest on an empirical estimation of the marginal productivity of water, but rather made assumptions (that were varied in sensitivity analyses) about both the value of irrigation water supply and hydropower generation. Importantly, these assumptions were not spatially differentiated; that is, the economic value of water and power were assumed to be the same throughout the basin, except in sensitivity analyses. From an equity perspective, this is perhaps justified, since marginal values are dynamic and ever-changing, and it may be theoretically possible for low-value production systems to modernize over time. From an efficiency perspective, the key point is that these marginal net benefits are likely variable in time and space, and greatest in locations where water development is most advanced, due to lower needs for new investments and higher existing productivity.

Second, the NEOM did not evaluate the costs of new infrastructures, and so provided little information on which investments among the basket of alternatives considered were most attractive. Third, as an annual model with a monthly time step, the NEOM was not well-suited for understanding the implications of hydrological variability and change, which have long been key concerns troubling risk-averse Nile planners and water managers. For that matter, the authors conducted relatively little sensitivity analysis, other than varying the economic value of irrigation water. Some of these sensitivities have been explored more thoroughly in subsequent more papers using the NEOM (Jeuland, Wu, and Whittington 2017, Wu, Jeuland, and Whittington 2016), in particular issues arising from interactions among different institutions for cooperation, hydrological variability, and economic values. All such analyses however assume perfect foresight and are thus insufficient for understanding the importance of stochastic flow variation.

[2] The NEOM built on an earlier and simpler model developed by Guariso and Whittington (1987) to study the potential for hydropower production in the Blue Nile.

Table 2. Summary of prior Nile HEM-based analyses

Author(s)	*Year*	*Model type*	*Flows*	*Uncertainty*	*Integration*	*Issues addressed*	*Key findings / policy messages*
Wu (NEOM)	(2017, 2005, 2016, 2006)	Optimization	Deterministic	Flows, dams, energy value	Holistic (full basin)	-Upstream dams -Politics & water rights	*Cooperation: Much potential for benefits *Distribution of benefits strongly depends on institutions (degree of cooperation) *Power trade really important
Strzepek	(2008)	Optimization	Deterministic	Capital shocks	Holistic (Egypt)	-Aswan Dam	*HAD has had large multi-sectoral impacts
Block (IMPEND)	(2010)	Optimization	Deterministic	Climate scenarios	Holistic (Eastern Nile)	-Blue Nile dams	*Accounting for reservoir filling & El Nino-like climate decreases net benefits
Jeuland models	(2010b, 2014, 2009)	Simulation	Stochastic	Flow, development	Modular (full basin)	-Blue Nile dams	*Climate change affects dams' benefits via several pathways *Large benefits; more & smaller dams are best; cost of investment delays is high
Nile SDDP	(2010, 2014)	Optimization	Stochastic	Infrastructure	Holistic (Eastern Nile)	-Downstream risks post GERD	*Evaporative savings from coordination *Large benefits; Downstream externalities could be positive, even in dry years
Dinar	(2013, 2016)	Optimization	Deterministic	Initial rights	Holistic (Eastern Nile)	-Cooperation on the Blue Nile	*Fragile basis for cooperation; GERD adds benefits; results sensitive to rights distribution
Geressu et al.	(2015)	Optimization	Deterministic	Weights for decision variables	Holistic (Eastern Nile)	-Blue Nile dams	*Significant tradeoffs across objectives
Shom et al.	(2015)	Optimization	Deterministic	Flows, prices, development	Holistic (Sudan only)	-Sudan tradeoffs	*Ag-power tradeoff limits irrigation in Sudan

Notes: Colors indicate the following are included…

Irrigation, hydropower, siltation	Irrigation, hydropower, flood control	Economy-wide	Irrigation, hydropower

Other than this work with the NEOM, several other frameworks – IMPEND, Jeuland's modular simulation framework, the Nile SDDP, and the multi-objective approach of Geressu & Harou – have been applied to analyze the economics of new Nile infrastructure. These analyses have focused almost exclusively on Blue Nile dams, but have added important nuance to the findings discussed above. Block & Strzepek (2010) notably considered transient (filling stage) costs of such projects, and noted that the economics of individual dams were only slightly favorable once these costs were explicitly considered. Their Investment Model for Planning Ethiopian Nile Development (IMPEND) model was also used to explore the potential implications of future hydrological change, notably from changes in the frequency of El Niño and La Niña events or from other aspects of an altered climate (Block and Strzepek 2010). Such changes were shown to further reduce net benefits to close to zero in some potential situations.

Two papers using the Nile SDDP, a more complete stochastic optimization framework, provided further details on the nature of the benefits that Blue Nile dams would provide, in particular the Grand Ethiopian Renaissance Dam (GERD). First, they elucidated how such storage would allow changes to the drawdown-refill cycle at Aswan (namely allowing lower average storage levels) that would generate evaporative savings of about 2.5 billion cubic meters per year, without increasing Egypt's risk of water shortfalls. Benefits would also accrue to Sudan in the form of expanded irrigation, and the flood peak in the Blue Nile would be reduced. Using a multi-objective framework, Geressu & Harou (2015) further demonstrated the nature of dam design tradeoffs, particularly between designs that would maximize firm versus average power generation, as well as higher upstream versus downstream benefits. They also argued that planned reservoirs – particularly the GERD – were larger than necessary given tradeoffs between costs and power generation, although such large designs did maximize energy production.

Jeuland & Whittington (2014) came to a similar conclusion, using a very different modular simulation approach that linked a stochastic streamflow generator with hydrological and Monte Carlo-based economic simulation models. They showed that Blue Nile systems designs with more and smaller reservoirs (compared to fewer larger ones) were more robust to downside risk across a range of climate and economic development conditions, while maintaining sufficient flexibility to capture upside potential. They also identified the high cost of delay, and described this as a likely key motivator for the decision to move forward with the GERD project prior to successful conclusion of negotiations over a basin-wide cooperative treaty on the Nile. In related papers, they further demonstrated that some of the most important drivers of variation in system performance were related to economic variables, notably the social discount rate (a normative and macroeconomic parameter), the marginal value of energy production and its change over time, and the cost of downstream irrigation deficits in Egypt, in addition to more commonly considered hydrological parameters such as system runoff and natural flow variability (Jeuland 2010b, 2009, Jeuland 2010a). And though theirs is the only model to explicitly account for flood control benefits as well as costs such as resettlement and loss of recession agriculture in Sudan, these represent a relatively small fraction – if a locally concentrated one – of the total economic value generated by Blue Nile infrastructure.

A more narrowly conceived HEM is that used by Satti et al. (Satti, Zaitchik, and Siddiqui 2015), which considers on the Sudanese Blue Nile. Building on one of the insights from the original NEOM analysis, the main contribution of this analysis was to better characterize the importance of the internal tradeoff faced by Sudan, between irrigation and power generation. This tradeoff increased considerably following construction of the Merowe Dam, a hydropower dam located along the Main Nile in Northern Sudan. In brief, additional water withdrawal for irrigation in central Sudan reduces storage and flows through Merowe's turbines, thereby decreasing head and power generation.

The two remaining modeling efforts that include HEMs are quite different from those discussed above. The first is a game theoretic approach used in several papers that is unique in setting aside the constraints imposed by the existing institutional context in the Nile (Dinar and Nigatu 2013, Nigatu and Dinar 2016). This prevailing institutional context, assumed to hold in other HEM analyses of Nile allocation and infrastructure problems, is constrained by the 1959 Nile Waters Agreement between Egypt and Sudan. In their alternative analyses, Dinar & Nigatu consider instead a welfare-maximizing allocation of water by a social planner, and a different "allocate-and-trade" institution that could be used to approximate it. Both of these institutions essentially demand greater water use efficiency in Egypt. And while many readers of these papers might be skeptical of the realism of generating wholly new institutions for water sharing in the Nile, one interesting conclusion that emerges from this work is that the core for cooperation is quite small, in contrast to what is argued in Wu & Whittington (2006). The reason for this very different result is that assuming a different starting point – where water rights downstream are not ensured – increases the potential benefits of unilateral actions, for upstream countries like Ethiopia. A slightly different, but more realistic outcome that is discussed in Jeuland et al. (2017) is that increased upstream storage in Ethiopia enables Sudan to increase her share of water use up to the levels allowed by the 1959 Nile Water Agreement, which would in turn reduce water availability in Egypt, which has become accustomed to receiving a surplus of water relative to the allocation specified in the treaty, due to lower withdrawals in Sudan.

The final one is a computable general equilibrium (CGE) framework used to explore the value of the Aswan Dam within the Egyptian economy (Strzepek et al. 2008). These authors used the model to analyze how the historical series of Nile flows affect power generation, irrigation, and navigation with and without this infrastructure, accounting for forward and backward linkages between water and the economy. They calculate a total gain of 3-4% of annual GDP, based on 1997 levels, for the direct benefits and the lower risk due to reduced variability. Strictly speaking, economy-wide approaches are not typically considered to be HEMs, because they do not include the detailed spatial and temporal representation of water resources systems. Nonetheless, this model does provide valuable insights that move beyond specific sectors that are typically favored in HEMs, by accounting for indirect economic effects.

Discussion

As discussed above, a range of HEMs with different features have been applied to analysis of Nile water resources planning problems. The bulk of existing work has focused on the Eastern Nile or on countries in the Eastern Nile, namely Egypt, Sudan and Ethiopia, and much of it has been aimed at assessing the value and impacts of large dams in the Blue Nile. Overall, this work points to the favorable economics of the use of dams for hydropower generation in the Ethiopian Blue Nile, noting that such projects would produce large amounts of energy, help ensure more consistent water supply and flow in Sudan (benefitting her in terms of hydropower uplift and better irrigation water availability), and even increase overall water availability from the system (by allowing modification of operations at Aswan, and therefore lowering evaporation). Some work, however, highlights the economic risks for downstream countries, especially for Egypt, should existing water uses and/or treaties not be honored.

Despite the general agreement and consistency in results across these various models, it is worth reflecting on how model structure influences the types of questions that can be considered, and the insights that HEMs have helped provide. Deterministic models using well-known flow patterns have perhaps been most helpful in demonstrating the potential benefits of development opportunities, because they are most easy to understand, especially to water resource engineers who have become accustomed to analyzing historical flows. Yet managers and decision makers have often found these tools to be unrealistic, and insufficient for planning in the context of risk, especially because of the issue of perfect foresight. Stochastic optimization helps to partly address these critiques, yet continues to impose perfect foresight. Meanwhile, simulation models avoid this problematic assumption but may perform sub-optimally. Economy-wide models such as that applied by Strzepek et al. ignore nonmarket aspects, and have enormous data requirements, especially when used dynamically (which was not the case in that study).

In addition to this, there are some very notable blindspots in the Nile HEM literature. To date, models have largely ignored the White Nile and tradeoffs and interdependencies within the Equatorial Lakes Region. This is largely a reflection of the hydrology of the system and the fact that the White Nile supplies only a modest amount of flow to the Main Nile, but the Baro-Akobo-Sobat and Atbara systems have also been understudied. The upper riparians have plans for development on all of these tributaries, and the collective changes induced could be very significant. Second, there continues to be much debate over how to integrate the complex hydrological dynamics of the Sudd and other wetlands in South Sudan into HEM models. Jeuland (2009) developed a regression based approach to model outflows from the Sudd, based loosely on the approach described in the Nile DST (Georgakakos 2007), but the data on which this approach is based are poor and have not been updated since the late 1980s. Third, as noted above, the HEMs applied to the Nile have focused almost exclusively on hydropower and irrigation. Only a few analyses have gone beyond these (Jeuland 2009, Nigatu and Dinar 2016). A large class of nonmarket costs and benefits have thus been ignored, and important economic questions related to siltation, the value of watershed protection, salinization in Egypt, and the value of the wetlands in South Sudan, remain unanswered. Connectivities between surface and groundwater, and the potential for conjunctive use of water in irrigation to relieve pressure on river water, has similarly been ignored. Fourth, much analysis has indicated the hydropower potential in Ethiopia, but smaller options exist in the Equatorial Lakes region, and no studies have adequately considered the issue of power trade and whether sufficient demand in locations that could be connected to these large power projects. This point has been made in the context of the GERD, which will generate far more power than Ethiopia can possibly absorb, for many years (Whittington, Waterbury, and Jeuland 2014). It could be that power trade favorable to producing countries such as Ethiopia could help unlock the impasse over water rights in the Nile Basin, but how such agreements should be structured has scarcely received any attention.

HEMs could therefore play an important role in continued planning processes, not only in considering these underexplored issues, but also in continuing to clarify the economic tradeoffs between different objectives. Choices about model architecture will matter in how these questions are answered, and methodological pluralism and use multiple models should therefore continue to be encouraged.

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Annex 6

The hydroeconomics of Nile water management: Building blocks for future scenario-based analysis

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Introduction

Identifying and analyzing the effects of various strategies for water resources development and management under different scenarios of future change plays a pivotal role in guiding decision-making and coordination among the countries sharing those resources. The Nile Basin is endowed with tremendous resources of water and land, yet there is currently a lack of agreement about how to best develop and exploit this potential to sustainably generate economic value over time. Insufficient attention has also been paid to economic dimensions of water productivity in prior work and negotiations, and how these relate to cooperation or the lack of it between different stakeholders.

To facilitate collective decision-making, the Nile Basin Initiative (NBI) Secretariat launched a Collaborative Water Resources Assessment Process (NBI and GIZ 2017). Through this process, member countries have previously worked to develop a common and shared understanding of the baseline conditions in the Nile Basin. The aim is for them to now collaborate to identify options for the future management and development of the Nile's shared water resources, which will best enable countries' to meet their growing water, food and energy demands sustainably and with minimal undesirable effects on other basin countries. This requires use of methods that facilitate evidence-based planning around various ideas and solutions proposed by different stakeholders and interests in the basin. One set of useful methods for this type of analysis is hydro-economic modeling, which endeavor to discover or better characterize strategies that advance the economic efficiency of water use, measured in terms of overall gross or net benefit. Such tools are also helpful for clarifying the most critical tradeoffs between uses of different types and across space and time.

Of course, uncertainty about the future challenges water resources planning, especially given the long-lived nature of water infrastructure and the inherent rigidity of water managing institutions (Jeuland and Whittington 2014). One key element in this dynamic relates to the actions taken by individual countries and their effects on the system; i.e., understanding the implications of uncoordinated water resources development. Assessment of the economic consequences of such development choices requires analysis that moves well beyond physical accounting for volumes of water, to also consider the economic value of water in alternative uses, and the opportunity costs they entail.

This short paper builds on several previous efforts. First are synthesis reports that summarize completed and ongoing analytic work for strategic water resources analysis carried out by the NBI. Second are the presentations and discussions held during the first Nile Basin Economists Forum, which took place in Entebbe, Uganda (16-17 May 2017). During that meeting, experts reflected on the role of HEMs in water resources planning, and especially on their prior use in analysis of Nile development questions; an accompanying paper summarizes the state of this knowledge (Jeuland 2017). Third, and also from the forum, participants engaged in wide-spanning discussions on key management questions in the Basin, the answers to which would be better informed by economic analysis and economic thinking. As stated by the organizers, the "key aim of the Forum [was] to explore the economic dimensions of water use in the basin and enrich the riparian dialogue, sparking new ideas for cooperation, co-development of solutions, and an economic analysis of alternative development options" (NBI and GIZ 2017).

The principal aim of this paper is to synthesize the main points that emerged from these previous analyses and discussions, and to offer a set of policy and development "building blocks," the value of which could be clarified using economic analysis or economic methods. While this paper focuses primarily on the contributions that hydro-economic models (HEMs) could offer, the relative strengths of other relevant approaches (e.g., food-water nexus or computable general equilibrium models, or applied survey methods) are mentioned when these are deemed more appropriate.

Brief review of these inputs

NBI strategy documents

Expert contributors to the Nile Economists Forum

The Nile Economists Forum included expert input related to three themes: a) use of HEMs for efficient water management; b) Food security and food-water nexus analyses and thinking; and c) Power trade and energy-water nexus analyses and thinking. Under each theme, a keynote address was followed by shorter specialized presentations from economists representing both international and riparian country perspectives, and group discussions (these inputs are summarized in the next section).

Focusing primarily on the inputs from the HEM experts, the keynote presentation described these tools in general terms, offering reflections on the range and variety of model architectures and how they influence the types of analyses that can be conducted. It was noted, that there has been relatively limited, and mostly reactive, work to understand the economic dimensions of the challenge of managing the Nile Basin waters (compared to more conventional engineering analyses). As discussed in an accompanying document on the 'state of knowledge' from prior HEM work (Jeuland 2017), these analyses have been almost exclusively related to the value of large dams in the Ethiopian Blue Nile, and they have not had a significant influence on the decisions that have been made to pursue specific projects and plans (this was confirmed by the country presentations on the theme). Still, we can observe that a variety of different model architectures have been applied to study this limited set of questions, and that there is considerable agreement in the general results and conclusions that emerge from this body of work, which lends some confidence to the ability of these tools to generate consistent results. Details on these general findings can be found in Jeuland (2017).

In this and other presentations, the value of hydro-economic or similar analyses was demonstrated for understanding the following types of issues:

- Clarifying the nature of the interdependencies in water resource systems, e.g., how upstream actions and choices influence downstream outcomes (Wu et al. 2013, Jeuland et al. 2014), or how climate can affect food prices and therefore marginal water productivity (Siddig et al. 2016);
- Demonstrating tradeoffs between uses (Bekchanov et al. 2017);

- Characterizing the opportunity costs associated with decisions to pursue specific infrastructure investments, that seem reasonable at first glance, but diminish (or even eliminate) the value of other potentially better investments (Jeuland and Whittington 2014);
- Assessment of the value of water savings and efficiency improvements, especially in irrigation (Bekchanov et al. 2016);
- Elucidating the tradeoffs across multiple objectives that may be important to policy-makers (Geressu and Harou 2015);
- Quantifying the cost of non-cooperation in these systems, or the foregone value of not coordinating both in investment and institutional planning and in management given existing infrastructure and institutions (Jeuland et al. 2014, Arjoon, Tilmant, and Herrmann 2016, Tilmant and Kinzelbach 2012); and
- Demonstrating the importance of non-hydrological factors in affecting the value produced by water management strategies (Jeuland 2010).

Under the other themes, the food-water interactions session highlighted the strikingly low yields in Nile countries, even in irrigated agriculture, which significantly limit the value of agriculture-oriented development. These low yields relate to much more than a lack of effective use of water: non-biophysical constraints on land tenure, security, infrastructure, and value chain infrastructure are likely as significant roadblocks. As such, agriculture-oriented development needs to relax multiple constraints, an issue that the virtual water trade literature largely ignores. With regards to energy, the large number of interconnection projects in the Basin should help to make the system more resilient and should also increase interdependency and benefit sharing possibilities, but whether this potential is realized will be another question, and institutional design is critical. Outside of hydropower, there has been much less work on water-energy nexus questions in the Nile Basin than on the other topics.

Discussions among Nile Economists Forum participants

The group discussions at the Forum were robust and engaging. A number of issues were identified that could be considered more carefully with HEMs and other economic tools. Grouping these together and streamlining the list, I created Table 1.

Recommendations for 'building blocks' to be considered, and applicability of specific tools

On the basis of the information reviewed above and on the state of knowledge related to hydroeconomic analysis, I propose a set of "building blocks" or options that should perhaps be considered in future economic analysis that would be commissioned by the Nile Basin Initiative. These are briefly summarized in Table 2, and the text provides a more complete narrative description of each such building block. Again, the emphasis is placed on issues to which HEMs can speak, and I highlight the specific contributions that HEMs can make regarding those building blocks. I also offer suggestions for filling other gaps or answering different types of questions, should they be deemed important.

Table 1. Grouping of major planning issues to which analysis could provide valuable input, according to participants in the Nile Economists Forum participants

Issue #	General theme(s)	Description
1	Benefit-sharing	What can we say about the comparative advantages of different countries, and the value of specialization and trade vs. diversification of water resources benefits generation? (Trade, geography of water productivity, food vs. energy, value of water in different uses)
2	Robustness	What are the most important drivers of change or of the economic value proposition of different solutions? (Climate, hydrological variability, politics, macroeconomic conditions, population growth, tastes)
3	Irrigation efficiency	What is the economic and cooperative case for efficiency improvements (i.e., making water work harder via demand management or physical improvements)
4	Nonmarket values	How can we think about ecosystem values in the Nile, and also the value of environmental services? (salinity control in Egypt's delta, upstream watershed mgmt., sediment flows, pollution control, flood control, fisheries)
5	Tradeoffs	What are the important economic tradeoffs in the basin? What is the current economic value of water in different uses? (cost of meeting limited objectives (e.g., food, energy), existing institutions, shadow values)
6	Economic appraisal, including distributional analysis	What is the case for infrastructure investment in the Nile? How can the benefits of this development be shared equitably? (size, portfolios of projects, multipurpose vs. single purpose)
7	Supply augmentation	What is the economic place for groundwater management and exploitation in the Basin? Wastewater reuse?
8	Water-energy	How should we compare hydropower with other alternative (conventional or renewable) energy sources (diversification, interdependencies, comparative advantage)
9	Resource pricing	How should tariffs be set? (Irrigation water, energy, finance vs. efficiency, etc.)

Building block #1: New water storage / run-of-river projects

One of the most traditional applications of HEMs is to consider economic outcomes under different scenarios of development of storage infrastructure, and the Nile Basin is no exception to this tendency, as discussed in the state of knowledge document (Jeuland 2017). Still, we note that the focus to date has been concentrated on projects in the Ethiopian Blue Nile. HEMs can be used to help guide the selection of projects or configurations of projects, or their sizing and design, from an economic perspective that aims to maximize system net benefits. Careful economic valuation that allows characterization of power generation or other benefits provides important input information for detailed analysis of specific projects, or models can be used as screening tools to select more efficient combinations of projects that satisfy other non-economic objectives. Importantly, HEMs allow analysts to understand the basin-wide consequences of these projects, rather than simply focusing on the local effects and outputs of those new investments. In assessing the value of power production, however, it is important to consider the cost of alternative technologies, including non-hydropower renewables and conventional energy generation technology. Also, full comparisons with these alternatives or analysis of opportunities for complementary production typically require more complete energy systems models capable of accounting for intermittency, the timing of generation relative to peaking demands, and transmission capacity. These will usually require shorter time steps and greater specificity in demand sites than what most HEMs are built to offer, and explain why fully integrated hydro-energy models remain relatively rare in the literature and in planning models.

Table 2. 'Building blocks' or options for development of the Nile, that should be subject to economic analysis

#	Building block type	Role of HEMs in this analysis
	System design	
1	New water storage / run-of-river projects	HEMs can be used to optimally select and design new dams, or to calculate economic benefits given specific system configurations
2	Large-scale irrigation expansion	HEMs can be used to optimally select and design new irrigation schemes, or to calculate economic benefits of specific projects
3	Investment in irrigation efficiency infrastructure	HEMs can be used to optimally select and design irrigation efficiency technology, or to calculate economic benefits of specific projects
4	Investment in flood protection infrastructure	With careful parameterization, HEMs can be used to optimally select and design flood protection infrastructure (levies, dams, etc.), or to calculate economic benefits of specific projects
5	Investment in sediment control / watershed protection	HEMs can be used to calculate the costs of erosion, in terms of reduced benefits from dams, irrigation, or other schemes
6	Investment in supply augmentation	HEMs can be used to calculate the benefits of groundwater or conjunctive water use, wastewater reuse, interbasin transfers, etc.
	System operations	
7	Operating rules for control infrastructure	HEMs can be used to characterize system-wide optimal filling and coordination strategies, or to assess the costs of strategies that achieve other objectives (upstream objectives, faster filling, etc.)
8	Water allocation rules / trading / pricing	HEMs can be used to characterize optimal water allocations for consumptive use, or to assess the costs of mandating that specific water requirements are met (with and without trading, and subject to allocation institutions such as pricing)
9	Power trade	With some effort to integrate with energy systems models, HEMs can be used to characterize optimal power distribution from hydropower facilities, or to assess the costs of mandating that specific supply requirements are met (subject to allocation institutions such as power tariffs)
10	Environmental or minimum flow regulations	Costing can be done by imposing flow constraints in HEMs and calculating shadow values; benefit valuation requires survey work
11	Rules for managing extreme events	HEMs can be used to characterize optimal to assess the costs of mandating protections against extreme events

Building block #2: Large-scale irrigation expansion

Similarly to the case for storage or run-of-the-river projects, HEMs are also frequently used to consider basin-wide economic consequences of irrigation expansion. This issue has also been studied in the Nile, and primarily in the Eastern Nile – namely in Sudan and Ethiopia (Jeuland 2017). Nonetheless, prior Nile applications have ignored a number of important dimensions of such projects, largely because these require more detailed survey data than researchers have been able to obtain: a) Differences in local water productivity; b) the effects of altered cropping choices on marginal benefits; and c) relative advantages of irrigation over rainfed agriculture. Such issues should be explored, if questions about comparative advantage are to be addressed. For some types of questions, particularly those relating to the relative value of investments in rainfed versus irrigated agriculture, full agricultural systems models may be needed.

Building block #3: Investment in irrigation efficiency infrastructure

In addition to considering irrigation expansion, HEMs can be used to assess the value of irrigation efficiency improvements in existing schemes, although such analysis has not yet been done for the Nile. Such investments need not be limited to infrastructure improvements such as lining of canals, but could also consider watering technology (e.g., flood versus sprinkler versus drip irrigation) or water-use practices (e.g., better timing of deliveries). One reason such analysis has been fairly limited in the Nile is that irrigation using Nile water has been very limited, except in Egypt and Sudan, and so the transboundary consequences of inefficient irrigation have been limited. As water scarcity and upstream irrigation increases, water use efficiency will become a greater concern, however. More efficient irrigation systems in Egypt could also bring on salinization problems as well, if flows of saline water into the Mediterranean are constricted. Consideration of the dynamics of salinization in particular would be difficult using conventional HEMs; integration with more sophisticated water quality models would be required for such research.

Building block #4: Investment in flood protection infrastructure

No HEM work in the Nile has explicitly considered flood protection, except Jeuland's simulation framework, which projects flood damages based on peak flows in the Blue Nile and at Khartoum (Jeuland 2009). Such analysis is difficult, but careful parameterization of flood damage functions based on surveys of assets at risk can allow selection of optimal flood protection strategies and estimation of their net benefits, given other objectives. Such models may require a more refined spatial and temporal representation than is common in most planning HEMs, but modern computational methods allow solutions for more highly-resolved formulations.

Building block #5: Investment in sediment control / watershed protection

Similarly, HEMs can be used to calculate the costs of erosion, in terms of reduced benefits from dams, irrigation, or other schemes. For example, siltation may require modification of designs for infrastructure, or may shorten the lifespan of these assets, and these additional costs or reduced benefits can be included in HEM-based analyses. Similarly, models may incorporate management costs arising from high silt loads, as was done in Jeuland (2009). To date, however, modeling of the value of upstream watershed protection has been limited by the inability to clearly link such investments to reduced silt loads in the downstream river system, a connection that needs to be clarified prior to more detailed economic analysis.

Building block #6: Investment in supply augmentation

Although such options may be limited in the Nile Basin (no models have considered such issues to date), HEMs have been used in other systems to calculate the benefits of water supply augmentation, via development of infrastructure that facilitates interbasin transfers. Somewhat less common are applications that include connectivity to groundwater systems, although work in the Ganges and other contexts has considered this possibility (Wu et al. 2013). Models that include groundwater pumping account for the cost of pumping, and sometimes include aquifer recharge-depletion dynamics (Pulido-Velazquez et al. 2008). Finally, the economics of wastewater reuse could be assessed as a strategy for relieving water shortage, particularly in downstream locations in the basin. Here, as with modeling to consider building block #3 (irrigation efficiency), there would be a need to adequately consider the risk of salinization of agricultural lands, particularly in the Egyptian delta. Going beyond salinization to consider the economics of other pollution problems is not recommended at this time, given that water quality models are generally insufficiently accurate to assist with long-term planning.

Building block #7: Operating rules for control infrastructure

Moving from investment to operations and management, the first set of policies that could be considered consists of the operating rules for dams and other water control infrastructures in the Nile. Optimization HEMs that have been used frequently solve for the most efficient operating rules from a national or basin-wide perspective, but these models assume perfect foresight, or close to it. Simulation models, on the other hand, take existing or target operating rules as given, and compute economic benefits conditional on those rules. Work that combines these approaches creatively, or imposes constraints on the operations in optimization models, could provide insights about the potential value of coordination. HEMs more generally could help inform more coordinated management of infrastructure, to capture evaporation and other efficiency savings. It is no accident that optimization HEMs in fact helped researchers identify the evaporation benefits that Blue Nile dams could provide, because these depend on coordination and lower storage in Lake Nasser. Yet coordination could yield other benefits, to irrigators in Sudan, in terms of hydropower uplift, or even for reducing backwater effects that occur in the White Nile when the Blue Nile flood is greatest.

Building block #8: Water allocation rules / trading / pricing

Besides operating rules for control infrastructure, allocation rules to consumers of water are another very important policy variable. Allocation rules could be established as quotas or targets for various users (this is the prevailing approach in the basin), and shadow values computed. These shadow values would indicate the relative value of water in alternative uses, given those targets. Alternatively, the gains from more efficient allocation could be assessed, by allocating water according to where its marginal value is greatest, thereby providing insight on how efficient water pricing could increase economic benefits.

HEMs have been used in other systems to study the benefits of water trading that incentivizes higher value uses, given transaction costs or frictions in trading institutions. Alternatively, optimal allocations could be determined given other constraints or objectives, perhaps related to a guaranteed water supply to irrigators (for food security), or to environmental objectives (this is further discussed under building block #10.

Building block #9: Power trade

There is considerable discussion of power trade in the Nile Basin, as this is a clear potential domain for benefit-sharing. Some countries are well endowed with potential hydropower sites, such that developing would provide surplus power relative to demands over the short to medium term. Other countries, meanwhile, suffer from serious power shortages. To date, however, no HEM has adequately tackled this issue, in large part because it requires integration with an energy systems model that incorporates transmission capacity, but also because energy supply and demand operate on a different time scale (a much shorter time step) from that considered in most HEMs, which typically have biweekly or monthly time steps. Nonetheless, given the importance of power trade for cooperation in the Nile, this should be a building block for future analyses. Jeuland et al. (2017) showed in very basic analysis that the benefits of power trade in the Eastern Nile could be significant, but they did not consider the details of transmission. More sophisticated analysis of this issue is clearly warranted.

Building block #10: Environmental or minimum flow regulations

Similarly to building block #8 on allocation rules, HEMs could be used to assess the opportunity costs of reserving minimum or other flow requirements within different portions of the river system, by imposing these as constraints that limit those allocations. More sophisticated work would actually try to value the benefits of keeping water in the river, for both ecosystem services utilized by local populations (e.g., navigation, fisheries, recreation, recession agriculture) or for ecosystem protection itself. This latter work would require complementary data collection efforts (field surveys) related to both market (e.g., for fish or navigation) and nonmarket or subsistence values (e.g., recreation, non-marketed goods and services). In their review of HEMs, Bekchanov et al. (2017) noted that incorporating such values into water-economy models is an area where additional research and effort is needed, and that the majority of existing models either ignore these important aspects, or simply utilize environmental flow constraints without discussing or justifying them.

Building block #11: Rules for managing extreme events

The final operational building block complements that related to flood infrastructure, and is closely related to building block #7 in considering how operations of control infrastructures could help to manage extreme events. For example, dams can be managed aggressively to control floods, by keeping storage levels low as the flood peak approaches. In addition, dams can be managed to mitigate droughts downstream, by releasing water when it is most sorely needed by irrigators (when rains fail, or if the timing of rains is disrupted). As with many of the operational questions on this list of building blocks, few HEMs have been used in the Nile to assess the value of such "insurance" to riparians. This is a potentially important issue, particularly where climate variability is high.

Concluding thoughts

Given the increasing water scarcity facing Nile Basin riparians, there is a growing need for careful analysis of the tradeoffs between their different development objectives, and on ways to make water use more efficient and beneficial. As discussed above, HEMs could be applied to study economic questions related to both infrastructure investments (storage, flood protection, irrigation network expansion or efficiency-improving technology, watershed protection, and supply augmentation) and institutional or management (operating rules for control infrastructure, allocation institutions, power trade arrangements, and environmental regulations) options in the Nile Basin. Fully successful use of these tools for some purposes would require additional data collection and analysis, however. Key hurdles relate to the lack of careful valuation studies, both with respect to water productivity and nonmarket costs and benefits of different solutions, the lack of sufficiently resolved (in space and time) hydrological and water use data, and a lack of knowledge on the impacts of specific investments (e.g., watershed protection). In the absence of better empirical studies on these issues, analyses that are somewhat more limited in scope remain possible.

Many of the ‘building blocks’ identified in this document relate to notable gaps highlighted in the state of knowledge based on HEMs. As noted there, prior work has largely ignored the White Nile and tradeoffs and interdependencies within the Equatorial Lakes Region. The upper riparians have plans to pursue various development projects, and the collective changes induced by these could be very significant. Existing work has scarcely considered issues other than hydropower and irrigation, and even the latter has only been studied superficially (applying rather crude assumptions about water productivity, and ignoring efficiency questions entirely). Thus, a large class of nonmarket costs and benefits have been ignored; important economic questions related to siltation, the value of watershed protection, salinization in Egypt, and the value of the wetlands in South Sudan, remain unanswered. Supply augmentation using groundwater irrigation has not been studied, and no studies have carefully considered the issue of power trade. Additional work with HEMs could play an important role in filling some of these gaps.

Finally, it is worth re-emphasizing that economists could help the basin riparians think about some of the complex Nile management problems in different and new (hopefully productive) ways, using HEMs and other tools. Economists and social scientists could help clarify how incentives for countries to free-ride lead to inefficient outcomes, and how thinking about economic benefits could lead to identification of new and more effective solution sets (and away from a mono-causal focus on biophysical aspects shrinks and constrains opportunities). Creating a Nile economic council with representation from country economists could be a useful step to identifying areas of potential progress, and another could be to integrate economists into the NBI team.

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ONE RIVER

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