International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Address: IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria
Email: repository@iiasa.ac.at **Telephone:** +43 (0)2236 807 342

Report

East Africa Water Scenarios to 2050

Authors: Sylvia Tramberend[1], Robert Burtscher[1], Peter Burek[1], Taher Kahil[1], Günther Fischer[1], Junko Mochizuki[1], Yoshihide Wada[1], Richard Kimwaga[2], Phillip Nyenje[3], Risper Ondiek[4], Prossie Nakawuka[3], Canute Hyandye[5], Claver Sibomana[6], Simon Langan[1]

1 International Institute for Applied Systems Analysis, Austria
2 University of Dar es Salaam, Tanzania
3 Makerere University, Kampala, Uganda
4 University of Natural Resources and Life Sciences Vienna, Vienna
5 Institute of Rural Development Planning, Dodoma, UR Tanzania
6 University of Burundi, Bujumbura

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water futures and solutions

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Abbreviations

AEZ	Agro-ecological Zoning
AR5	The IPCC Fifth Assessment Report
CWatM	Community Water Model
EAC	East African Community
ECHO	Extended Continental-scale Hydroeconomic Optimization model
EA-RVS	East Africa Regional Vision Scenario
EFRs	Environmental Flow requirements
eLVB	Extended Lake Victoria Basin
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-ecological Zoning
GCMs	General Circulation Models
GDP_{cap}	Gross Domestic Product per capita
IPCC	International Panel on Climate Change
LVBC	Lake Victoria Basin Commission
MDGs	Millennium Development Goals
RCP	Representative Concentration Pathways
REF	Reference Scenario
SDGs	Sustainable Development Goals
SSP	Shared Socio-Economic Pathways
UN	United Nations
WCI	Water crowding index
WEI	Water exploitation index
WFaS	Water Futures and Solutions Initiative
WFS	World Food System Model

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Abstract

The 'Water Futures and Solutions Initiative' seeks to incorporate water science into water policy and planning, and applied water management issues. After a global analysis we present here an analysis for East Africa to understand development trends of future water supply and demand for all water users across different economic sectors. The analysis uses a nested scenario approach to connect different spatial scales and address future development pathways. An integrated modelling framework, with the core elements of the hydrological model CWatM and the cost-optimization hydro-economic model ECHO, is used to explore two future development scenarios.

Guided by regional development visions including the 'East Africa Vision 2050' and regional stakeholders, we develop an "*East Africa Regional Vision Scenario*". A "*Business As Usual*" scenario is based on the "Middle of the Road" scenario of the widely used Shared Socio-Economic Pathways. These scenarios inform the setting of modelling parameters for the quantitative analysis of water supply and demand of the extended Lake Victoria Basin (eLVB) until the 2050s. The eLVB covers the up-stream hydrological watershed of the river Nile. It covers an area of 464 thousand km^2 of the African Great Lakes region and is home to more than 70 million people today.

A doubling of population in the eLVB combined with strong economic development will lead to a significant increase in water demand. Depending on scenario, the growth is most pronounced for expanding irrigation and supplying domestic water. Climate change is characterized by increasing temperatures combined with higher precipitation variability with a tendency that rainy seasons become wetter and dry season dryer. Land use changes largely compensate for the effect of higher evapotranspiration due to rising temperatures, which would otherwise lead to lower runoff. Water storage in the large lakes leads to a considerable delay in the response time of river discharge. The combination of all development trends of the eLVB water system indicates that despite the increasing water demand, the changes in the discharge and flow regime of the Nile will be small.

Both scenarios show more moderate water scarcity when measured using the Water Exploitation Index (ratio of water resources and demand) compared to water scarcity when measured using the Water Crowding Index (per capita water resources). This points to a high degree of 'economic water scarcity' in the eLVB because the regionally estimated water demand is apparently lower than the globally unified 'entitlement' of a per capita indicator of water resources only. However, there is a high spatial variability in water scarcity development trends, which are most pronounced in the Kagera, Mara and Simiyu sub-watersheds.

Applying a least cost option for satisfying water demand while maintaining sufficient water for environmental flows throughout the year, suggests that the majority of future water needs can be supplied from surface water sources. However, for irrigation during certain months, groundwater is required as well. The cost estimates for the water sector illustrate the importance of annual operations and maintenance costs, in addition to investment costs for the construction of infrastructure to meet the additional water demand. Uncertainties of the modelling results are mainly attributed to the projection of various drivers such as irrigation area expansion, future water use efficiency parameters, and climate change effects resulting from the use of General Circulation Models. Further, data availability and accessibility to available regional data, e.g. on costs or land use, remains a limiting factor. Finally, guided by regional stakeholders, we present an initial discussion on implications of the results for policymaking.

1 Introduction

Achieving water security in the context of competing demands for basic water supply and sanitation, food security, economic development, and the environment is a key ambition expressed in the “Vision 2050” of the East African Community (EAC). UN-Water defines water security as: “*The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*.” UN-Water (2013). The rapid growth of the economy and population, along with a high rate of urbanization expected for the region, will lead to increased water demand in all sectors and further pressure on the water quality status.

The “Africa Water Vision 2025” (UN-Water/Africa, 2003) clearly articulates the particular challenge and focus for Africa’s water management to overcome extreme poverty and advance in socio-economic development in its vision statement to achieve *“An Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation and the environment”.* The same document calls for the need of more research on how to achieve sustainable water use in Africa based on an assessment of “where we are”, “where we want to be” and “how to get there”.

The transition from the Millennium Development Goals (MDGs) to the Sustainable Development Goals (SDGs) as the reference framework for global development ambitions calls for an integrated understanding of water as a key factor for socio-economic development but also recognising the vulnerability of the water resources in terms of quality and quantity. Whereas the MDG framework catered for unilateral development trajectories limited to water supply and sanitation, the SDG framework is a holistically framed agenda, which includes water supply and sanitation, water quality, wastewater treatment, water-use efficiency, sustainable withdrawal, integrated water resources management (IWRM), and the protection of water-related ecosystems. This is likely to lead to a paradigm change in water governance with an important opportunity to steer development trajectories towards a water-secure world (Wiegleb and Bruns, 2018).

This study is an effort to respond to this quest for the member states of the EAC including Burundi, Kenya, Rwanda, Uganda, and United Republic of Tanzania. In the second half of 2016, South Sudan became a member of the East Africa Community. Because of lack of data, this study does not include South Sudan in the analysis. Guided by the basin approach as a key principle of Integrated Water Resource Management (IWRM), a particular focus of the quantitative modelling analysis is set on the Lake Victoria Basin including the basins of the Victoria and Albert Nile in Uganda, and all Nile tributaries upstream of the river gauging station of Laropi, located at the White Nile in southern Uganda close to the border of South Sudan. For the purpose of this study, we call the fraction of the Nile watershed that is upstream of Laropi the “extended Lake Victoria Basin” (eLVB). The eLVB includes areas in all five EAC countries and smaller regions in the Democratic Republic of Congo and South Sudan.

The research presented here on East Africa represents a regional case study of Water Futures and Solutions Initiative (WFaS). It seeks to incorporate water science into water policy and planning, and applied water management issues. The initiative identifies and tests solution pathways across different economic sectors. Stakeholder consultations support co-designing future development scenarios and possible solution options, which are an important input for supporting mid- to long-term water management and planning based on informed decision making. After a global analysis, the initiative has been focusing on Eastern Africa with the extended Lake Victoria Basin as a key research area for quantitative modelling.

There is a considerable amount of grey literature describing East Africa's status of development and vision. Several strategy and plan documents inform about the target space of the region's development ambitions for the coming decades. The information and data used in this study is mostly informing on national average targets but not specific to the areas of the EAC countries within the eLVB. Furthermore, the level of detail of targets differs across sectors and is often of generic nature. There is little information on how these targets can be achieved including associated costs.

A key goal of water security is to balance "supply" and "demand" for all water users, at different spatial and temporal scales in terms of quantity and quality of available water resources. Water scarcity intensifies when water demand increases and when water quantity and/or quality decreases. Human use of available water resources includes food production (irrigation for agriculture, water needs of livestock), water use for energy generation, other (mainly manufacturing) industry, and the use for drinking, cooking, washing and sanitation at the household level. In addition, adequate levels of water should be reserved as 'environmental flows' required for maintaining aquatic ecosystem services (Pastor et al., 2014, Smakhtin, 2008). Variation of quantity and quality of available water resources throughout the year is adding to water management challenges.

This study aims to provide a deeper understanding of critical parameters for achieving water security in the East African context. We endorse the above-cited broad understanding of water security defined by the United Nations. Yet, because of limited information and data available for modelling water quality, the focus of this study is on water quantity. Scenarios enable to explore different possible development pathways against the background of uncertain futures. They help to understand long-term consequences of near-term decisions and therefore form an essential part of sustainability research. Looking into the future by developing scenarios, addresses the quest for sustainable long-term water security. Rapidly changing populations, accelerated urbanization, uneven economic growth patterns, dilapidated water infrastructure, rapid land use changes and climate change have an impact on fresh water fluxes that are often transmitted across spatial scales. An analysis of water systems must therefore aim to bridge the gap from local to regional and global scales.

This study addresses the combined challenge of the temporal and spatial scale dependencies of water systems by a scenario analysis designed to include both the regional and the global scale. We develop an "*East Africa Regional Vision Scenario* (EA-RVS)" based on existing regional visions, and use available scenarios and data (for the region) but developed in the context of global studies. Next to regional visions, the study integrates into the widely-applied global scenario development process of the Intergovernmental Panel on Climate Change (IPCC). It is characterized by a Scenario Matrix Architecture (Van Vuuren et al., 2014) including the community developed Shared-socioeconomic pathways (SSPs) (Jiang and O'Neill, 2015) and the Representative Concentration Pathways (RCPs) (Van Vuuren et al., 2011) for the characterization of climate change. With this approach, we aim to gain a deeper insight into how water can support the development aspirations up to 2050 on the one side and how the water resources are likely to be affected by these developments on the other side.

The EA-RVS is foremost guided by the "Vision 2050" of the East African Community (EAC, 2016a) and complemented by other regional strategy documents. In addition to the document review outlined above, the EA-RVS presented here is strongly inspired by a consultative stakeholder workshop 'Solutions for a water secure East Africa in 2050' convened on 4-6 December 2017 in Entebbe, Uganda. In June 2018, the workshop participants were further consulted to feedback on the story line and quantification of the EA-RVS presented in this report.

The EA-RVS is compared to the scenario SSP2 “Middle of the road” developed in the context of global scenario work. This scenario describes a business as usual situation, where the world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns (O’Neill et al., 2015). SSP2 represents a development pathway without major efforts towards sustainability. These scenarios inform the setting of modelling parameters.

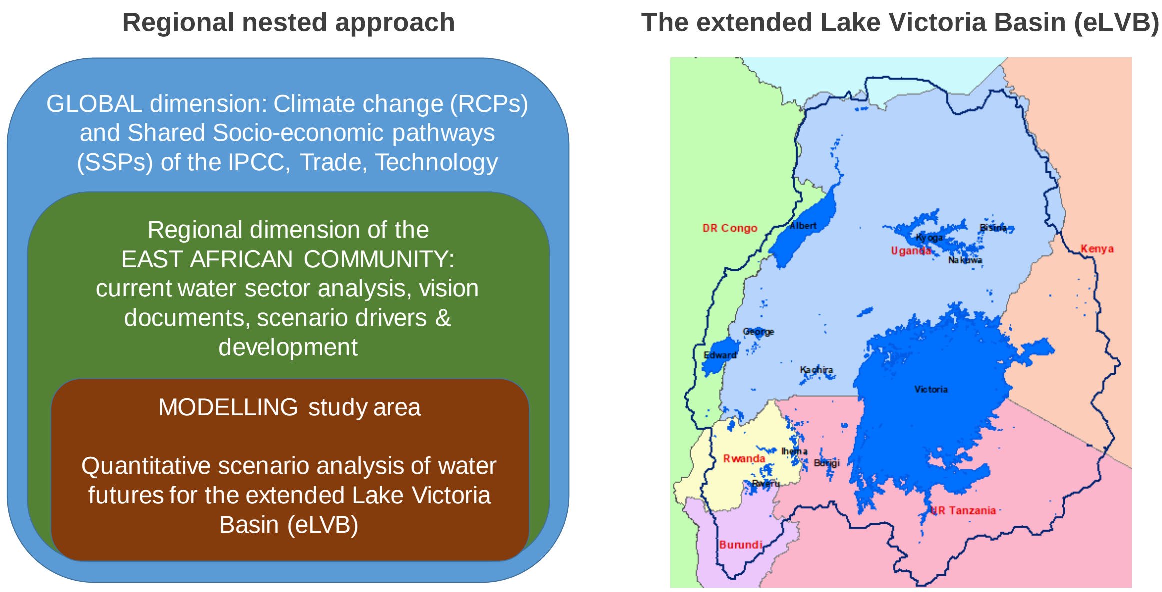
The authors attempt to provide a solid and deeper knowledge base for current and future water resource management and investments decisions required to harness water as an enabler of East Africa’s development aspirations and to maintain water security for future generations.

2 Methods and data

2.1 Study approach

The study employs a nested scenario approach. It links global and regional data to account for interconnections across space. To address the uncertainties of future development pathways, we develop and analyse two plausible scenarios until the 2050s. Figure 2-1 presents a comprehensive overview of the information flow and integration across spatial scales.

Figure 2-1. Nested study approach and map of the extended Lake Victoria Basin



First, the global dimension considers system characteristics that extend beyond national borders and continents such as climate change, trade and technological progress. Key constituencies at the global level include the United Nations, the World Bank, and the IPCC, all compile data of relevance for the water sector. Foremost, the IPCC has been developing global analyses and data on climate change and the scenario narratives of the shared socio-economic pathways.

Second, at the regional scale of East Africa, the EAC is increasingly developing into an influential regional constituency. We first analyse the current status of water use and challenges in the five founding countries of the EAC (Kenya, UR Tanzania, Burundi, Rwanda, and Uganda). Next, we explore the water development target space for the EAC. A key aim is to develop a regional vision scenario narrative that reflects aspirations of regional stakeholders and vision documents. Important scenario drivers can only be assessed at the national level, including demography, economic growth, or irrigation development plans.

Third, for quantitative scenario modelling, the study has selected the upper reaches of the Nile basin, the extended Lake Victoria Basin (eLVB). The eLVB is a transboundary basin in the tropics including seven countries and large freshwater resources vital for East Africa's development aspirations. For two scenarios, we develop water futures at a high spatial resolution of a 5x5 arc-minute (about 10x10 km) hydrological model connected to hydro-economics of 61 sub-basins.

2.2 Review of regional documents and stakeholder workshops

Projecting the water balance is a function of water availability and demand over time, which depends on socio-economic development as well as environmental and climate change related aspects. Available regional vision documents have been screened for qualitative and quantitative information on drivers affecting the regional water balance. Variables needed as input parameters for quantitative modelling of sectoral water demand include socio-economic development trends (population, GDP, energy use) and parameters of technological change (efficiency improvements for the respective sectoral water use, e.g. irrigation efficiency) or structural changes (e.g. changes in crop structure, and urbanization).

Two stakeholder workshops (Burtscher et al., 2018, Burtscher et al., 2019) helped to deepen the understanding and refine socio-economic and bio-physical drivers (first workshop) were further used to set modelling parameters and also to verify and discuss the modelling results (second workshop). The first workshop was dedicated to work on development scenarios for the coming decades (up to 2050). Using a number of engaging facilitation techniques, this discussion happened based on an incasting technique. Incasting is a foresight technique that explores the specific details of a possible future based on a more general scenario description (Schultz, 2003).

The East Africa regional scenario narrative is derived and informed by the review of regional documents and enriched by workshop participants including more than 50 stakeholders from government agencies, academia, civil society and private sector. The second workshop focused on presenting the draft modelling results including discussions on refining parameters and drivers that led to a second round of model runs.

2.3 The Community Water Model

IIASA's Community Water Model (CWatM) is used to assess East Africa's water supply, water demand and environmental needs over time until 2050 to identify the populations and locations mostly affected by these changes related to water scarcity, droughts and floods. The model is designed for this purpose in that it includes an accounting of how future water demands will evolve in response to socioeconomic change and how water availability will change in response to climate. CWatM represents one of the new key elements of IIASA's Water program. It has been developed to work flexibly at both global and regional level at different spatial resolutions. The model is open source and community-driven to promote our work amongst the wider water community worldwide and is flexible enough linking to further planned developments such as water quality and hydro-economic modules.

CWatM can use different datasets of daily meteorological forcing which are used as the inputs to calculate potential evaporation. Elevation data on sub-grid level and temperature is used to split precipitation into rain and snow and the degree-day factor method is used to calculate snow melt. Soil processes, interception and evaporation of intercepted water are calculated separately for four different land cover classes (forest, irrigated, paddy-irrigated and other land cover class) and the resulting flux and storage per grid-cell is aggregated by the fraction of each land cover class in each grid-cell. Infiltration capacity of the soil is estimated using the Xinanjiang model. The model calculates preferential bypass flow i.e. flow that bypasses the soil matrix and drains directly to groundwater. Soil moisture redistribution in three soil layers is calculated using the van Genuchten simplification of the Richards equation.

Groundwater storage and transport are modelled using a linear reservoir. Capillary rise from groundwater to the soil layers is included. Runoff concentration in a grid-cell is calculated by using a triangular-weighting-function. CWatM applies the kinematic wave approximation of the Saint-Venant equation for river routing. Reservoirs are included and simulated using a simple general reservoir operation scheme. Lakes are simulated by using the Modified Puls approach.

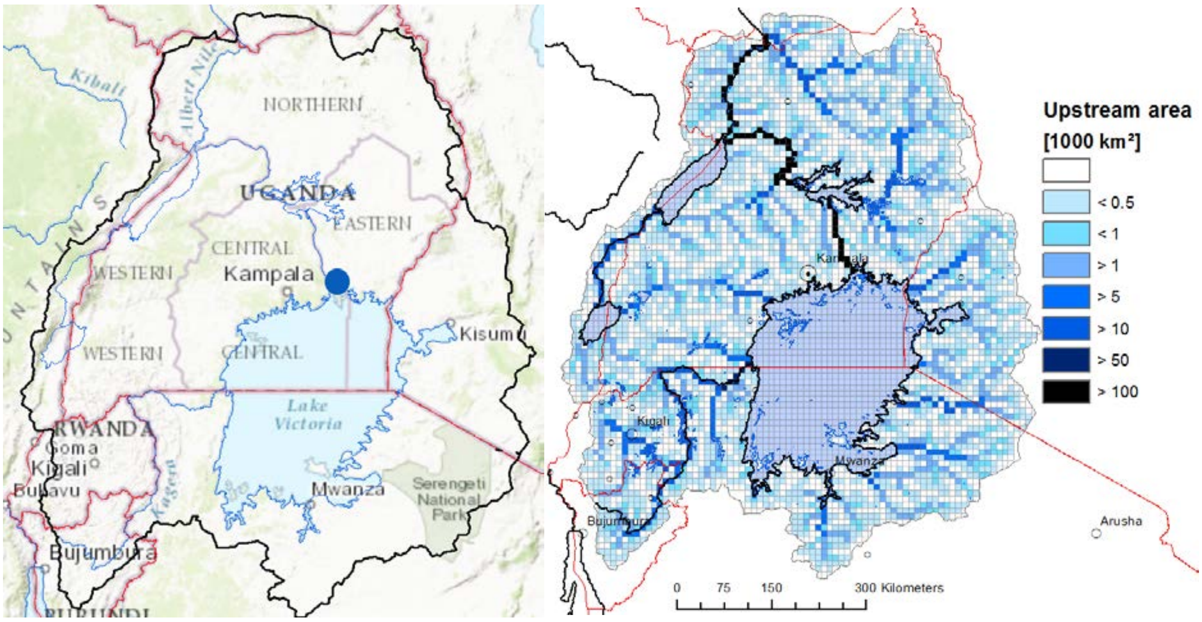
Water demand and consumptions are estimated for the sectors of livestock, industry and domestic using the approach of (Wada et al., 2011). Water demand and consumption for irrigation and paddy irrigation are calculated within CWatM using the crop water requirement methods. This irrigation scheme can also dynamically link the daily surface and soil water balance with irrigation water.

CWatM is written in Python 3.7 and C++ as an open source project under the term of the GNU General Public License version 3. The code can be used on different platform (Unix, Linux, Window, Mac) and is provide through a GitHub repository (see https://github.com/CWatM/CWatM). It comes with the code, an executable for Windows, a test case (River Rhine basin) and a settings file and some tools like calibration routines. Online documentation including documentation on the source code can be found on the IIASA webpage of CWatM (see https://cwatm.iiasa.ac.at).

Modelling study area

The high-resolution models cover the White Nile downstream of station Laropi (North Uganda) including an area from south of Lake Victoria to Lake Albert. The extended Lake Victoria Basin (eLVB) includes 6 major sub-basins (Mara, Simiyu, Kagera, Semliki, Victoria Nile, Lake Victoria), the fraction of the White Nile basin located in Uganda up to Laropi, and major lakes like Lake Victoria, Lake Albert, Lake Edward and Lake Kyoga (Figure 2-2).

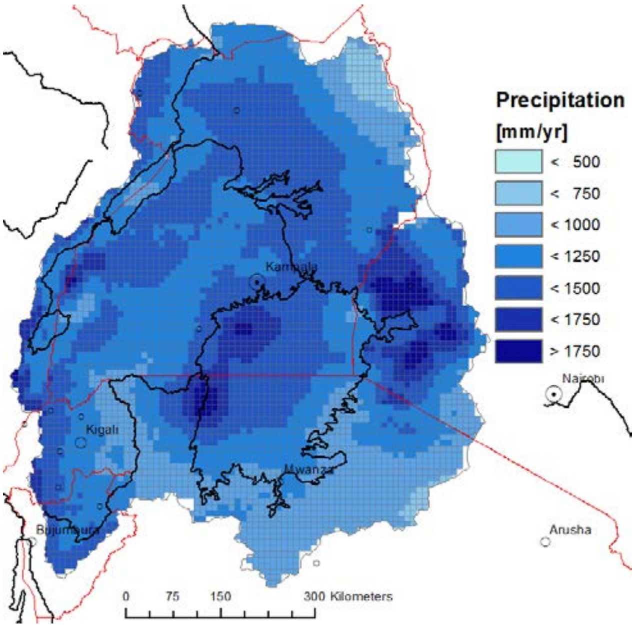
Figure 2-2. Extended Lake Victoria Basin (eLVB) and upstream area



Calibration

For calibration of the 5 arc minute CWatM meteorological data are required. For the historical period between 1979 and 2010 a global dataset on meteorological forcing data (i.e. precipitation, temperature, radiation, humidity) on daily base from (Weedon et al., 2014) is available. Figure 2-3 shows the average precipitation to illustrate the spatial variability of the basin.

Figure 2-3. Average precipitation 1979-2010 WFD-EI dataset



Source: CWatM

The simulated discharge data of the model are compared to historical measure of discharge for certain station. The Ministry for Water and Environment Uganda provided time series for several station in Uganda. We used the river discharge data from the stations Jinja, Semliki and Laropi to calibrate the model. The calibration itself is using an evolutionary computation framework in Python called DEAP (Fortin et al., 2012). DEAP implemented the evolutionary algorithm NSGA-II (Deb et al., 2002).

As objective function we used the modified version of the Kling-Gupta Efficiency (Kling et al., 2012), with r as the correlation coefficient between simulated and observed discharge (dimensionless), β as the bias ratio (dimensionless) and γ as the variability ratio.

$$\mathrm{KGE'} = 1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$$

$$\text{where: } \beta = \frac{\mu_s}{\mu_o} \text{ and } \gamma = \frac{CV_s}{CV_o} = \frac{\sigma_s/\mu_s}{\sigma_o/\mu_o}$$

Where CV is the coefficient of variation, μ is the mean streamflow [$m^3\ s^{-1}$] and σ is the standard deviation of the streamflow [$m^3\ s^{-1}$]. KGE′, r, β and γ have their optimum at unity. The KGE′ measures the Euclidean distance from the ideal point (unity) of the Pareto front and is therefore able to provide an optimal solution which is simultaneously good for bias, flow variability, and correlation. We use the following 11 calibration parameters referring to the water cycle, soils and reservoirs and lakes:

EVAPOTRANSPIRATION

1. Crop factor as an adjustment to crop evapotranspiration

SOIL

2. Soil depth factor: a factor for the overall soil depth of soil layer 1 and 2
3. Preferential bypass flow: empirical shape parameter of the preferential flow relation
4. Infiltration capacity parameter: empirical shape parameter b of the ARNO model

GROUNDWATER

5. Interflow factor: factor to adjust the amount which percolates from interflow to groundwater
6. Recession coefficient factor: factor to adjust the base flow recession constant (the contribution from groundwater to baseflow)

ROUTING

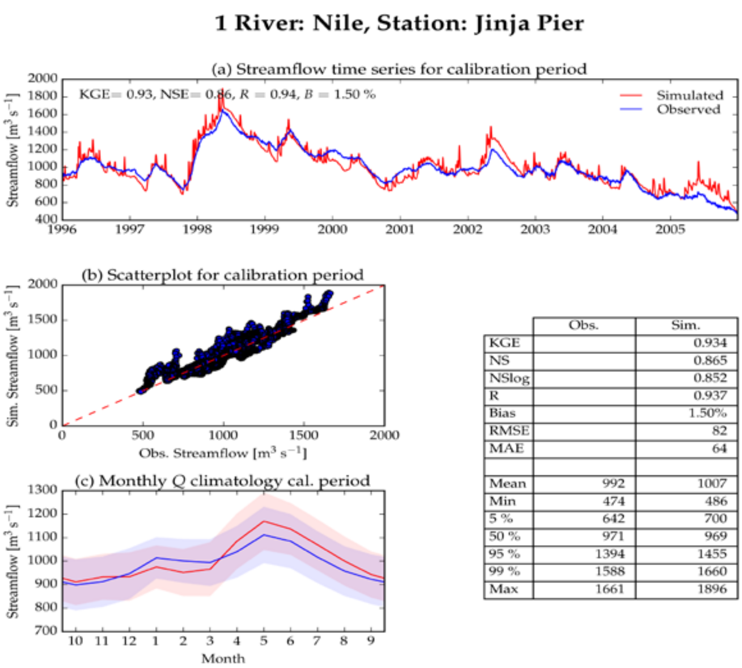
7. Runoff concentration factor: a factor for the concentration time of run-off in each grid-cell
8. Channel Manning's n factor: a factor roughness in channel routing

RESERVOIRS & LAKES

9. Normal storage limit: the fraction of storage capacity used as normal storage limit
10. Lake A factor: factor to channel width and weir coefficient as a part of the Poleni weir equation
11. Lake and river evaporation factor: factor to adjust open water evaporation

Figure 2-4 and Figure 2-5 show the calibration results for the two station Jinja and Laropi. While the station Jinja shows very good concordance between simulated and measured discharge with a KGE of 0.93 the station Laropi shows less concordance with a KGE of 0.36. This might be caused by the uncertainties of inflow and outflow into the Lake Kyoga. Still the bias of the simulated discharge is in an acceptable range. The calibrated model of the extended Lake Victoria basin now offers the benefit of not under or overestimating water availability.

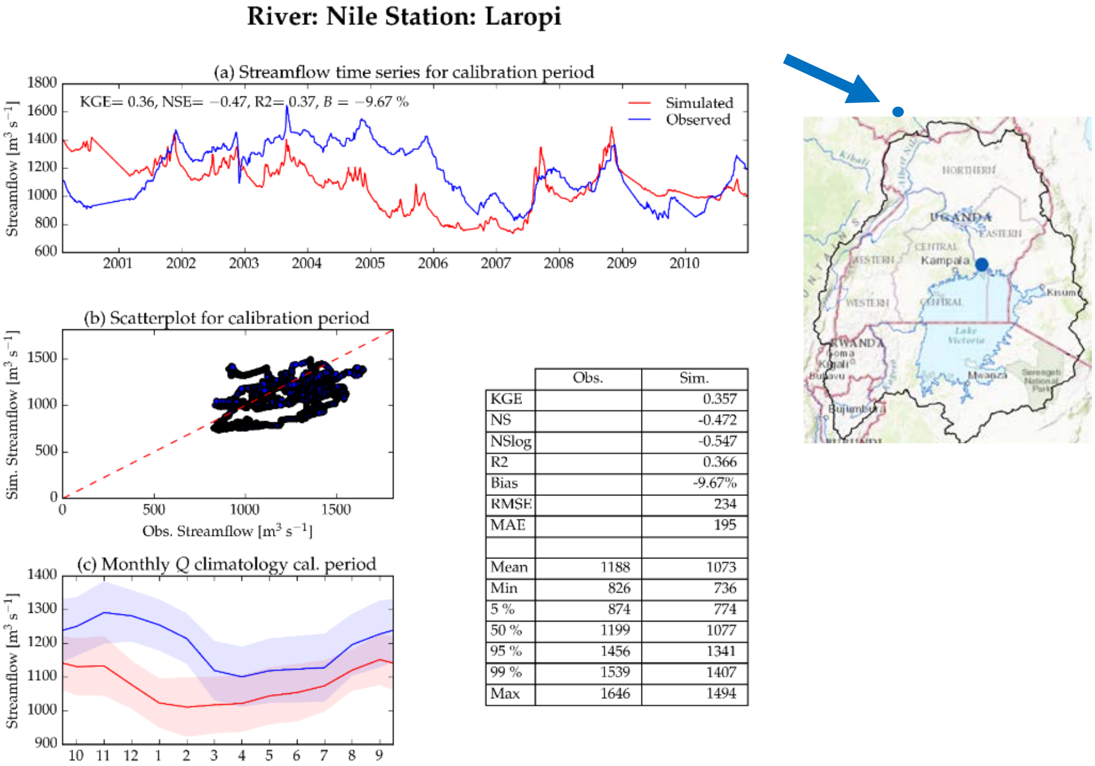
Figure 2-4. Calibration results for Jinja



	Obs.	Sim.
KGE		0.934
NS		0.865
NSlog		0.852
R		0.937
Bias		1.50%
RMSE		82
MAE		64
Mean	992	1007
Min	474	486
5 %	642	700
50 %	971	969
95 %	1394	1455
99 %	1588	1660
Max	1661	1896

Source: CWatM

Figure 2-5. Calibration results for Laropi



	Obs.	Sim.
KGE		0.357
NS		-0.472
NSlog		-0.547
R2		0.366
Bias		-9.67%
RMSE		234
MAE		195
Mean	1188	1073
Min	826	736
5 %	874	774
50 %	1199	1077
95 %	1456	1341
99 %	1539	1407
Max	1646	1494

Source: CWatM

2.4 The Hydroeconomic optimization model

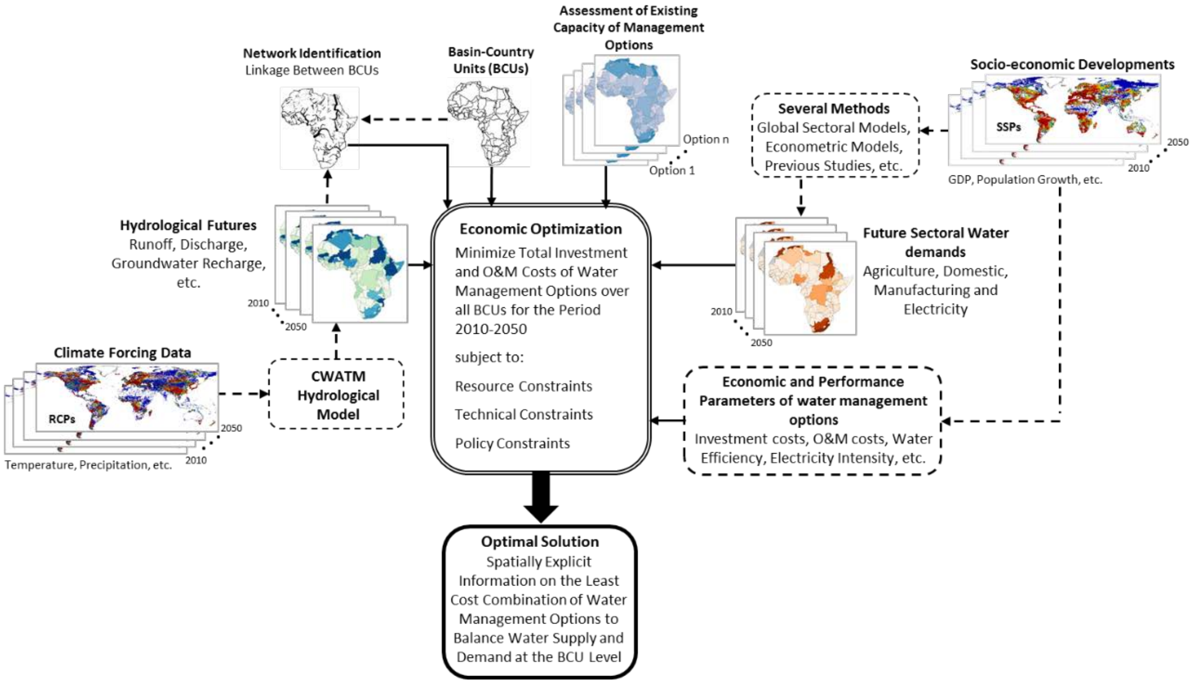
The **E**xtended **C**ontinental-scale **H**ydroeconomic **O**ptimization (ECHO, http://www.iiasa.ac.at/echo) is a bottom-up linear optimization model, which includes an economic objective function and a representation of the most relevant biophysical and technological constraints of water systems (Kahil et al., 2018). The objective function of ECHO minimizes the total investment and operating costs of a wide variety of water management options over a long-term planning horizon (e.g., a decade or more), to satisfy sectoral water demands across sub-basins within river basins.

ECHO optimization approach can be classified as a normative optimization because it goes beyond improvements in the management of existing facilities, towards projections of the capacity and activity levels of various water management options based on the assumption that water users seek to minimize the cost of water supply and demand management subject to constraints. The optimization procedure in ECHO uses a perfect foresight formulation, which provides the most optimal transition for the water system across the studied spatial and temporal ranges under anticipated future climate, socio-economic and policy changes. Figure 2-6 depicts the main features of the ECHO model including input data and outputs.

ECHO includes reasonable representations of essential biophysical and technological features at the sub-basin level. These include representations of various water supply sources (surface water, groundwater, and non-conventional water such as recycled wastewater), sectoral demands (irrigation, domestic, manufacturing, and electricity), and infrastructure (surface water reservoirs, desalination plants, wastewater treatment plants, irrigation systems, and hydropower plants). The GAMS optimization software is used for ECHO development and scenario simulations. The optimal solution generated by ECHO provides spatially explicit information on a least-cost combination of water management options that can satisfy sectoral water demands.

A diverse range of water management options are represented in ECHO, including supply and demand options that span over the water, energy and agricultural systems. The supply-side management options are surface water diversion, groundwater pumping, desalination, wastewater recycling, and surface water reservoirs. Surface water diversion, groundwater pumping, and desalination all transform raw water resources (surface water, groundwater, and seawater) into freshwater suitable for consumption within the different sectors (irrigation, domestic, manufacturing, and electricity uses). Wastewater recycling enables upgrading of wastewater originating from domestic and manufacturing sources to suitable quality for different purposes. Surface water reservoirs store water across several months for later multipurpose uses. The demand-side management options include different irrigation systems (flood, sprinkler, and drip), and various options to improve crop water management in irrigation and water use efficiency in the domestic and manufacturing sectors.

Figure 2-6. Schematic overview of ECHO modelling framework



Source: IIASA CWatM-ECHO modelling framework

2.5 Agricultural land use modelling framework

Land use and irrigated area extents are key input data for the integrated CWatM-ECHO modelling framework. This study uses estimates of future irrigated areas derived from IIASA's ecological-economic modelling framework. The modelling framework connects biophysical and socio-economic processes on a global scale and includes two main components, i) the FAO/IIASA Global Agro-ecological Zone (GAEZ) model; and ii) the IIASA World Food System (WFS) model. Due to data availability and for consistency with quantified socio-economic scenario drivers, we specify 'current' conditions based on a consistent set of data for the year 2010. Estimates of future conditions, here covering the period 2010 to 2050, follow a scenario approach in order to capture some of the key uncertainties pertaining to future developments.

Agro-ecological zones methodology: The Agro-Ecological Zones (AEZ) approach is based on principles of land evaluation (FAO, 2007) with the concept originally developed by the Food and Agriculture organization of the United Nations (FAO). Over time, IIASA and FAO have further developed and applied the AEZ methodology and supporting databases and software packages. This study uses data and calculation procedures of GAEZ version 4. For a detailed description of GAEZ methodologies, we refer to the documentation of GAEZ version 3 (Fischer et al., 2012). This most recent update uses 2010 baseline data including land cover, soil and terrain conditions, protected areas, renewable water resources, population distribution and livestock numbers. It applies climatic conditions for the historical period 1961-2010 and for a selection of future climate simulations using recent IPCC Fifth Assessment Report (AR5) climate model outputs from five general circulation models (GCMs) and for four different representative concentration pathways (RCPs). Climatic data comprises precipitation, temperature, wind speed, sunshine hours and relative humidity. These climate parameters are used to compile agronomically meaningful climate resources inventories including quantified thermal and moisture regimes in space and time.

Geo-referenced global climate, soil and terrain data are combined into a land resources database, which is assembled based on global grids, with 5 arc-minute and/or 30 arc-second resolutions. Matching crop requirements and land conditions to identify crop/feedstock specific limitations of prevailing climate, soil and terrain resources and evaluation with crop models, under assumed levels of inputs and management conditions, provides estimates of maximum potential and agronomically attainable yields for basic land resources units under different agricultural production systems defined by water supply (rain-fed or different irrigation systems) and levels of inputs and management circumstances.

Attributes specific to each particular LUT include crop/feedstock information such as eco-physiological parameters (harvest index, maximum leaf area index, maximum rate of photosynthesis, etc.), cultivation practices and input requirements, and utilization of main produce, residues and by-products. The GAEZ procedures are applied separately for rain-fed and irrigated conditions. Several calculation steps are applied at the grid-cell level to determine potential yields for individual LUTs. Growth requirements are matched against a detailed set of agro-climatic and edaphic land characteristics derived from the land resources database. Agro-climatic characteristics, including estimations of evapotranspiration and crop/feedstock-specific soil moisture balances, are used for assessments of LUT specific intermediate outputs of agro-climatic suitability and productivity. Recent national, regional and global land cover data and land use statistics have been used to produce a global land cover database consisting of a quantification by 30 arc-second grid cell of main land use/land cover shares.

World Food System Model: IIASA released a first version of the World Food System (WFS) model in 1988 in response to the energy and food crisis of the 1970s and 1980s. The WFS model has been repeatedly calibrated and validated over past time windows. Several applications of the model to international agricultural policy analysis, trade liberalization, climate-change vulnerability, and to the food vs. fuel debate have been published (Fischer et al., 2009, Fischer et al., 2005, Fischer et al., 2002, Prieler et al., 2013).

The WFS provides a framework for analysing how much food will be produced and consumed in the world, where it will be produced and consumed, and the trade and financial flows related to such activities. The WFS simulates alternative socio-economic development scenarios, to investigate impacts on cropland use, food price development and climate change impacts on food provision. It also has been used to assess the implications of alternative biofuel targets. The WFS is an applied general equilibrium model. Simply put, its framework is a world market based on a series of linked national and regional agricultural economic models. In these models, national food and agricultural components are seen as embedded in national economies, which in turn interact with each other through international trade. Although the WFS focuses on agriculture, non-agricultural economic activities are also represented in the model so that the essential dynamics among capital, labour, and land are captured.

3 The status of water use and challenges – "*Where are we?*"

In 1999, Kenya, Tanzania and Uganda signed a treaty for the establishment of the East African Community (EAC, see https://www.eac.int/), which entered into force in 2000. Rwanda and Burundi became full members as of 1 July 2007, the Republic of South Sudan joined in August 2016. The Secretariat of the East African Community, a new regional organisation, is the executive Organ of the EAC. Its mandate is to ensure that the regulations and directives adopted by the Council of Ministers are properly implemented, and provides the Council of Ministers with strategic recommendations. The EAC is widening and deepening co-operation among the Partner States in political, social and economic spheres for their mutual benefit. The EAC is considered as one of the fastest growing regional economic blocs in the world (AfDB, 2011).

The EAC has established the Lake Victoria Basin Commission (LVBC, see https://www.lvbcom.org/) as an institution focusing on the sustainable development of the Lake Victoria Basin resources. LVBC was established by the Protocol for Sustainable Development of the Lake Victoria Basin (2003) with the mandate of promoting, facilitating and coordinating actions towards sustainable development and poverty eradication within the Lake Victoria Basin. The Protocol provides a framework for the sustainable development of the Basin including water resources development, power development and trade, agriculture development and transport. The LVBC is currently implementing its Five Year Strategic Plan for the period 2016-2021 (LVBC, 2016).

The vital development concerns identified in the process of drafting the EAC Vision 2050 include: persistent poverty; unbalanced distribution of economic and social infrastructure; inadequate social cohesion; inadequacy of human capital; sub-optimal utilization of natural resources; inadequate exploitation of mineral resources; poor infrastructure base that hampers development; increasing unemployment especially among the youth; unplanned urban setting; low investment in research and development; low levels of industrialization and lack of competiveness; insufficient energy supply; and weak accountability (EAC, 2016a). In addition, workshop participants (see section 2.2) highlight the challenge of deteriorating water quality, climate change, and limitations connected to community water management systems.

3.1 Socio-economic drivers

3.1.1 Population and urbanization

According to data reported in 'EAC Facts & Figures', the population in the EAC was 149.7 million in 2015 compared to an estimated 145.4 million persons in 2014, representing a 2.9 percent growth rate. Table 3-1 shows the most recent population statistics for the EAC countries. Total fertility rate in EAC member states in 2015 ranged from 3.9 to 5.8 with Uganda having the highest and Kenya the lowest. The United Nations published higher population estimates for Kenya, Tanzania and Uganda. Therefore, the UN reported total population of 163 million for the EAC is 9 % higher compared to the estimate of the regional statistics.

Although there may be various reasons for differences in population estimates between national, regional and international data, this study cannot assess the accuracy of individual data sources. Possible reasons include differences in the use of census data or use of different demographic models and different approaches and methods for data collection. For example, the percentage of registered births among East Africa's poorest household indicate that at best, a little over half of the children born into poor families are formally 'invisible' (Eyakuze et al., 2013).

Table 3-1. Population statistics for the EAC countries, 2015, by data source

	Total population	Population growth rate 2014-2015	Fertility rate 2015	Total population
Data Source	EAC statistics	EAC statistics	EAC statistics	United Nations
	Million people	Percentage	Children per woman	Million people
Burundi	10.0	3.0	5.7	10.2
Kenya	44.2	1.3	3.9	47.2
Rwanda	11.2	2.4	4.2	11.6
Tanzania, UR	48.8	2.7	5.2	53.9
Uganda	35.5	3.0	5.8	40.1
Total EAC	**149.7**	**2.9**	**5.0**	**163.1**

Source: (EAC, 2016b) and (UN, 2017)

Today, the Unite Nations[1] report that more than one fourth of total population in the EAC lives in urban areas (Table 3-2). The rate of urbanization across East Africa is growing at the rate of between 4 and 5 per cent each year.

Despite some uncertainty, an additional 4 to 5 million people living in the EAC every year show the high population dynamics in the region. Population growth combined with an accelerated urbanization rate will increase demand for water across all sectors.

Table 3-2. Urban and rural population in the EAC at mid-year 2018

	Urban	Rural	Total	Urban share
	Million people	Million people	Million people	%
Burundi	1.5	9.7	11.2	13
Kenya	13.8	37.2	50.9	27
Rwanda	2.1	10.3	12.5	17
Tanzania, UR	19.9	39.1	59.0	34
Uganda	10.5	33.7	44.2	24
Total EAC	**48.9**	**130.2**	**178.0**	**27**

Source: (UN, 2018b)

3.1.2 Economic development (GDP)

East Africa's economy is characterized by rapid change in economic structure. In 2003, Kenya was the only regional economy where the services sector had a greater share of the economy than agriculture. Today, all East African economies are in a similar position in terms of contribution of the service sector. While a falling share of the agricultural sector in the overall economy usually characterizes developing economies, the trouble in East Africa is that the speed of change is overwhelming the capacity of the industrial and services sectors to provide the needed jobs and alternative livelihood opportunities (Eyakuze et al., 2013).

[1] The EAC statistics do not provide information on urban population.

The majority of GDP is generated by the service sector (45 %), followed by agriculture (33 %) and industry (22 %), with little regional variety across the EAC (Table 3-3). However, per capita GDP and structure in employment show significant intra-regional differences.

Both the EAC and the World Bank report GDP per capita (GDP_{cap}). In 2015, the World Bank reports a higher GDP_{cap} for Kenya and Burundi and a lower for Uganda, Tanzania UR, and Rwanda compared to the EAC statistics. Differences may be due to unrelated economic and population figures, conversion rates into US$, or GDP deflators when converting into constant prices.

Table 3-3. Sectors contribution to GDP in the EAC, 2016

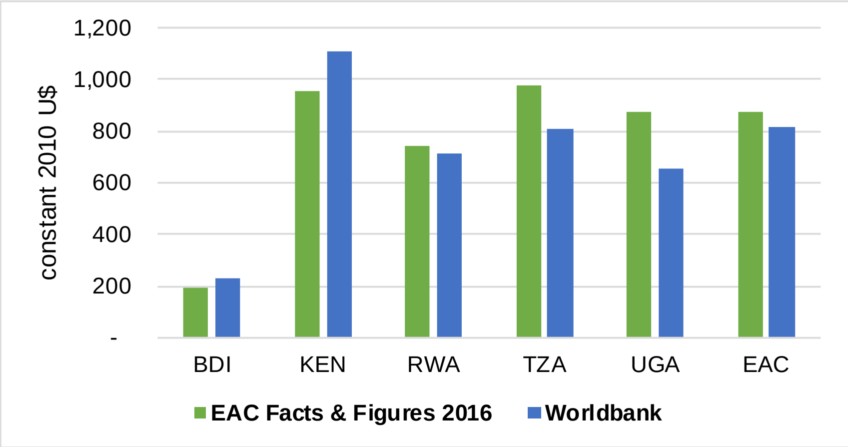
	GDP	Agriculture	Industry	Manufacturing*	Services
	[billion current US$]	[% of GDP]	[% of GDP]	[% of GDP]	[% of GDP]
Burundi	3	40	17	10	43
Kenya	71	36	19	10	45
Rwanda	8.4	32	18	6	50
Tanzania, UR	47	32	27	6	41
Uganda	24	26	22	9	52
East Africa	**153**	**33**	**22**	**8**	**45**

* Note, manufacturing is a sub-sector of industry.

Source: World Bank national accounts data

At the aggregated EAC level, GDP_{cap} is comparable with about 850 constant 2010 US$ for the year 2015 (Figure 3-1). GDP_{cap} varies across the EAC. Burundi stands out as the country with the lowest GDP_{cap} of only 200 US$, otherwise, GDP_{cap} ranges between 700 and 1100 US$.

Figure 3-1. Per capita GDP in the EAC countries, 2015



Source: (EAC, 2016b) and (Worldbank, 2018)

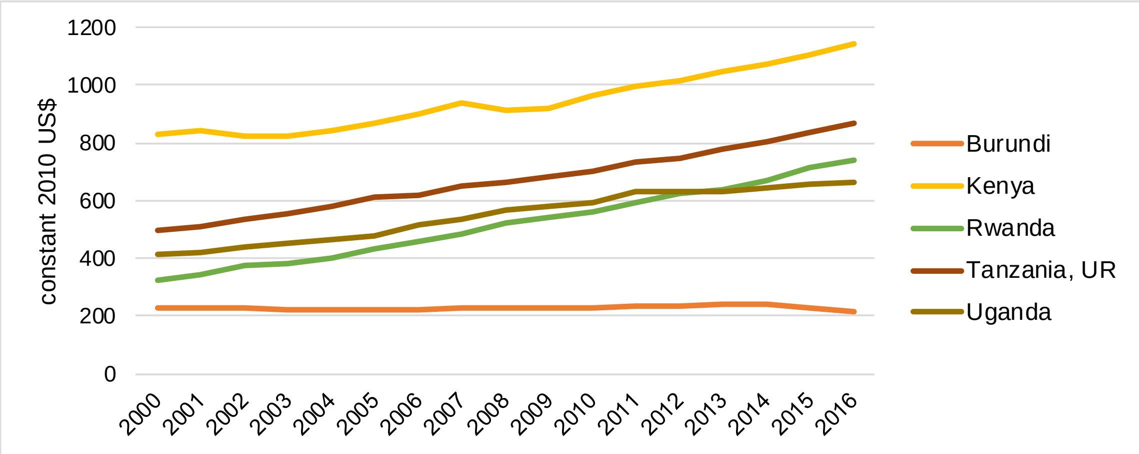
Except Burundi, GDP_{cap} increased in all EAC countries since 2000 (Figure 3-2). The growth was most pronounced in Rwanda where GDP_{cap} more than doubled (+126 %), followed by Tanzania UR (+74 %), Uganda (+61 %), and Kenya (+37 %). For the EAC as a whole GDP_{cap} increased from 550 $US\$_{2010}$in 2000 to 846 $US\$_{2010}$ in2016. This represents an average annual growth rate of 3.4 % over the 16-year period.

Despite economic growth, the EAC is still a relatively poor region, albeit with differences between countries. In 2011 the average population living below US$1.25 a day was 48.0 per cent(EAC, 2016a).

With exception of Kenya[2], the other EAC countries are still grouped into the Least Developed Countries (LDCs) (UN, 2018a).

The World Bank divides economies into four income groups: low, lower-middle, upper-middle, and high, based on GNI per capita. While it is understood that GNI per capita does not completely summarize a country's level of development or measure welfare, it has proved to be a useful and easily available indicator that is closely correlated with other, nonmonetary measures of the quality of life, such as life expectancy at birth, mortality rates of children, and enrolment rates in school. Currently, the World Bank classifies Burundi, Rwanda, Tanzania UR and Uganda as low-income countries and Kenya as low-middle income country.

Figure 3-2. GDP per capita in the EAC countries, 2000 to 2016



Source: (Worldbank, 2018)

In the EAC, almost two-thirds (63 %) of the population is employed in agriculture sector, followed by services (29 %) and industry (8%). In Kenya, almost half of people employed work in the service sector, significantly more than in the other four countries (Table 3-4).

Table 3-4. Distribution of employment by sector in the EAC, 2015

	Total population	**Employment distribution**		
	[thousand people]	Agriculture [%]	Industry [%]	Services [%]
Burundi	4,355	92	2	6
Kenya	16,066	38	14	48
Rwanda	5,880	67	8	25
Tanzania, UR	24,097	68	6	26
Uganda	14,418	71	7	22
EAC	64,816	63	8	29

Source: (ILOSTAT, 2017)

[2]Kenya is not included because in comparison to the other four countries, there is a relatively low prevalence of undernourishment in total population, a better education index and Gross National Income (GNI) per capita is higher.

3.2 Environment and biophysical conditions

3.2.1 Water resources

The EAC is endowed with adequate water resources, which are however unevenly distributed over space and time. The UN Food and Agriculture Organization (FAO) compiles 'total renewable water resources per capita per year' also known as Water Crowding Index (WCI). Broadly, it computes the annual volume of renewable water theoretically available through runoff and groundwater recharge arising from precipitation within a country, and water flowing in from, or shared with, other countries, set against population (Margat et al., 2005). Per capita TRWR is a widely used indicator for water stress, proposed by Falkenmark (Falkenmark et al., 1989) who has proposed a broad classification for different degrees of stress level, which has been further refined by FAO (Table 3-5).

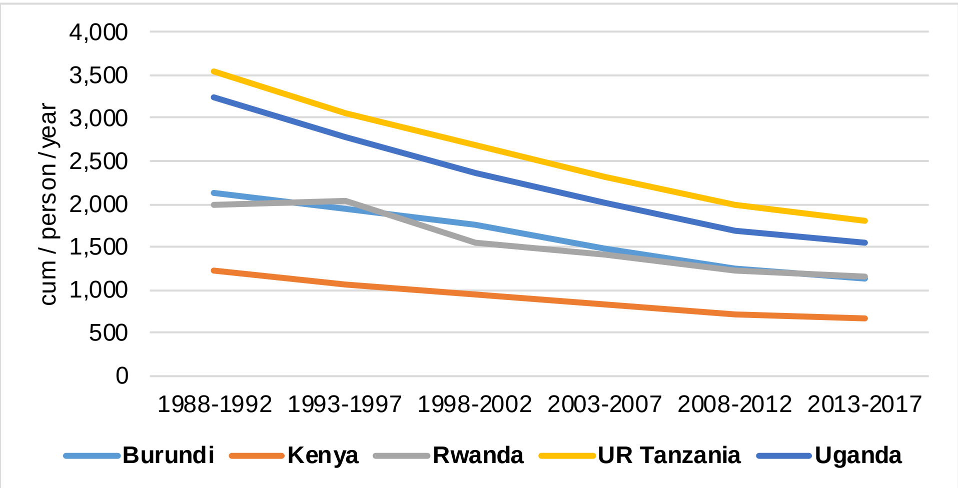
Table 3-5. Water stress index based on Total Renewable Water Resources (TRWR) per capita

TRWR (m3/person/year)	**FAO AQUASTAT[1]**	**Falkenmark (1989)**
> 5000	Abundant water resources nationally, stress possible locally	No stress
1700 – 5000	Occasional or local water stress	No stress
1000 – 1700	Water stress	Stress
500 – 1000	Chronic water scarcity	Scarcity
< 500	Absolute water scarcity	Absolute scarcity

1 This classification is used by the FAO maps depicting per capita TRWR.

The FAO's estimates of per capita TRWR changes over time. For most countries, including the EAC member states, the downward is caused by changes in population only (Figure 3-3). This is because national estimates of renewable water resources are updated by the FAO only when new information becomes available. In the 1990s, in all EAC member countries per capita TRWR was above 1700 m^3 (occasional or local water stress). Around the year 2000, Kenya has fallen below the 1000 m^3/person/year threshold indicating a chronic water scarcity. Burundi and Rwanda will follow soon. Except Tanzania, all countries are now fall in the 'water stress' category (<1700 m^3/person/year).

Figure 3-3. Total Renewable Water Resources per person in the EAC countries, 1998 to 2017



Source: FAO AQUASTAT

Many watersheds in the regions are transboundary. Depending on country, between 13 % and 35 % of renewable water resources, originates from outside the country's national boundary (Table 3-6). The installed water storage capacity is on average only 500 m^3 per capita and almost entirely confined to the natural storage of the Lake Victoria. For comparison such as the USA or Australia, water storage capacities are ten times higher at around 5000 m^3 per capita. Therefore, the EAC region is characterized by an economic water scarcity, largely due to inadequate investments in and management of water control structures and systems for effective management of water resources (EAC-Secretariat, 2011b).

The region is vulnerable to the adverse impacts of climate change. It is already experiencing increased impacts, including persistent drought and extreme weather, rising sea-level, coastal erosion and ocean acidification, further threatening food security and efforts to eradicate poverty (EAC, 2016a).

Table 3-6. Renewable water resources in the EAC countries, 2013-17

10^9 m^3 water/year	**Renewable water resources**			Surface water[3] leaving
	Internal[1]	External[2]	TOTAL	the country to other countries
Burundi	10.1	2.5	12.5	7.6
Kenya	20.7	10.0	30.7	8.9
Rwanda	9.5	3.8	13.3	6.1
Tanzania, UR	84.0	12.3	96.3	37.0
Uganda	39.0	21.1	60.1	15.6

1 Long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation; **2** Long-term average quantity of water annually entering the country through transboundary flow (rivers, canals, pipes). It includes inflows from upstream countries (groundwater and surface water), and part of the water of border lakes and/or rivers; **3** No groundwater leaves the country to other countries

Source: FAO AQUASTAT

Lake Victoria

Lake Victoria plays a major ecological, social and economic role in the EAC countries. It is the main source of water for domestic, industrial, and hydropower generation, a climate regulator, a reservoir of biodiversity, as well as a means of transport and connecting three of the EAC countries (Kenya, Tanzania, and Uganda). The lake basin also contributes significantly to nutrition and food security through agricultural production and the fishing industry (LVBC, 2016). Generally speaking, the Lake Victoria is the lifeline and livelihood of people in the basin. The hydrology of Lake Victoria and its outflow is largely dependent on direct rainfall onto the lake (Tate et al., 2004, Smith and Semazzi, 2014). The productivity of the hydroelectric dams along the Nile River (Victoria Nile, Albert Nile[3]) is largely determined by the level of the Lake Victoria (Smith and Semazzi, 2014).

[3] Currently electricity is produced from two power stations at the outlet of the Lake Victoria (Nalubaale Hydro Power Plant with 180 MW and Kiira Power Plant with 200 MW capacity) and Bujagali Hydro Power Plant (250 MW) downstream in the Nile River downstream. Two more hydropower plant are already under construction; Karuma Hydro Power Plant with 600 MW and Isimba Hydro Power Plant with 183.2 MW capacity. Further hydro power plants are under planning in the Ugandan Nile River system.

Analysis of Lake Victoria's water budget show that that rainfall and evaporation by far exceed catchment inflow and outflow. Rainfall contributes about 117 km^3 (82%) of the total inflow and evaporation accounts for 105 km^3 (76%) of the losses from the lake. In terms of water budget, the surrounding catchment areas only play a minor role (26 km^3 or 18%). Outflow from the Nile in Jinja (Victoria Nile) exceeds the inflow from the rivers into the Lake Victoria by a factor of 0.27 (Sewagudde, 2009). The same study compares mass balance components for the Lake Victoria from an earlier study Krishnamurthy and Ibrahim (1973) and identifies significant changes. Whereas evaporation remains relatively stable (5% increase), the inflow from rainfall increased by 17% and discharge from the surrounding catchment areas increased by 44% which the author attributed to deforestation in the 30 years between the two studies.

The vast ecological, economic and social functions of the Lake Victoria Basin are deteriorating rapidly due to a number of factors. Increasing population threatens the resilience of water resource uses and management through unsustainable agricultural water demands and practices that are causing eutrophication (phosphorous and nitrogen) and siltation. In addition, untreated wastewater transports pollutants into the lake, creates health risks and endangers the regionally important fishing industry. Access to safe and clean drinking water, sanitation and irrigation remains a major challenge throughout the catchment area, mainly due to economic water scarcity (LVBC, 2016).

3.2.2 Land use/cover and protected areas

The EAC covers a total surface area of 1,818 thousand km^2 and is home to about 150 million people of which about 40 million reside within the Lake Victoria Basin (LVBC, 2016). About 100 thousand km^2 of the EAC are covered by lakes, which are all part of the so-called Africa Great Lakes Region. The largest of these lakes is the Lake Victoria with a surface area of 68 thousand km^2 and a catchment area of 194 thousand km^2 (Tate et al., 2004). Hence, more than one third of the catchment area is covered by the lake itself.

The United Republic of Tanzania covers more than half of the EAC territory, followed by Kenya and Uganda. Burundi and Rwanda are comparatively small countries, albeit with high population densities of respectively 366 and 442 people per km^2 (year 2015 based on UN population figures). Population density in the other three countries amount to 166 people per km^2 in Uganda, 81 in Kenya and 57 in the United Republic of Tanzania.

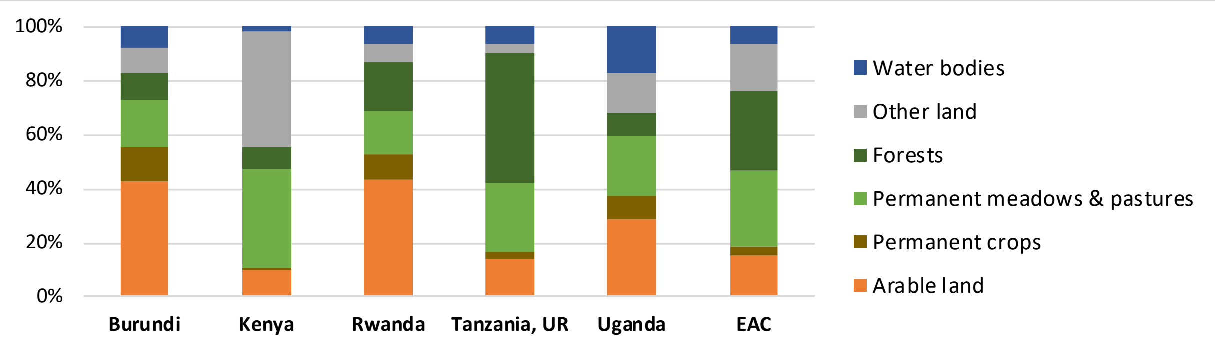
Figure 3-4 shows the distribution of main land use/cover in the EAC. Agricultural land includes arable land for the cultivation of annual crops, land for permanent crops and permanent meadows and pastures. Note the fraction of permanent meadows and pastures that is actually used by grazing ruminant livestock is not recorded. Almost one-fifth (19%) of the EAC land is cropland including 286 thousand km^2 arable land and 55 thousand km^2 permanent crops. Some 28 % are covered by 'permanent meadows and pastures'[4]. Hence, almost half of the EAC area is classified as agricultural land. Forest cover is less abundant. Just over one fourth (29 %) of the EAC area is covered by forest. The category 'other land' (17 %) includes shrub land, sparsely vegetated areas and barren land, as well as built-up land for urban and infrastructure. The remaining 7 % is inland water.

Land use/cover varies significantly across the five countries of the EAC (Table 3-7). In the densely populated countries of Burundi and Rwanda, more than half of the area is arable land and permanent crops). In Uganda, more than one third of the country area (38%) is cropland. Forestland in the EAC is concentrated in Tanzania, where 86% of the EAC forests are found. In Rwanda less than one fifth,

[4] The FAO term 'Permanent meadows and pastures' is defined as the land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild.

in Burundi and Uganda some 10% are covered by forest. 'Other land' is a dominant land use/cover in Kenya covering 42 % including large stretches of semi-arid and arid savannahs and deserts.

Figure 3-4. Distribution of land use / cover in the EAC countries, 2015



Source: FAOSTAT

Table 3-7. Land use / cover in the countries of the EAC, 2015

thousand Km²	Burundi	Kenya	Rwanda	Tanzania	Uganda	EAC
Arable land	12.0	58	11.5	135	69	286
Permanent crops	3.5	5.3	2.5	22	22	55
Permanent meadows /pastures	4.8	213	4.1	240	53	515
Forests	2.8	44	4.8	461	21	533
Other land	2.6	249	1.8	29	36	317
Water bodies	2.2	11	1.7	62	41	118
Total area	28	580	26	947	242	1,823

Source: FAOSTAT

Areas of high value for the environment

Large tracks of East Africa are subject to a designation status for environmental protection including national parks, nature reserves, wetlands, and key biodiversity areas. More than one third (38 %) or 700 thousand km² of the EAC area has some designation status for the protection of the environment. Two-thirds of these areas are located in Tanzania, UR, where almost half of the area has a designation status (Table 3-8). The main land use types with a protection status for the environment include forests, shrub- and grassland and to a lesser extent cropland (Figure 3-5).

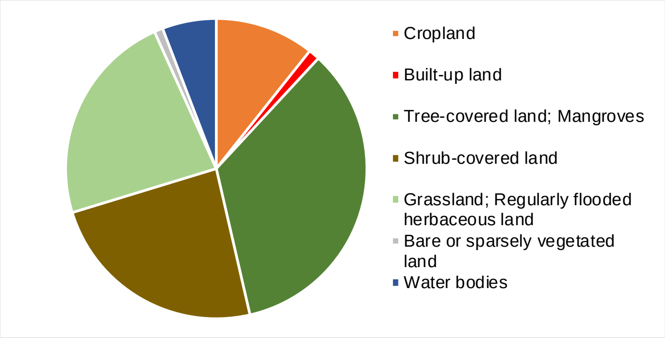
Table 3-8. Areas with designation status for the environment

1000 km²	No designation (Unprotected)	World Database on Protected Areas (WDPA)	Other (additional) designation[1]	Total area with designation	Share of designated in total land [%]
Burundi	22	1	4	5	20
Kenya	434	93	59	152	26
Rwanda	16	2	7	9	37
Tanzania, UR	490	302	155	456	48
Uganda	166	36	41	77	32
EAC	1,128	433	267	700	38

1 Additional designations include those of the Peace Park Foundation (www.peaceparks.org), the Global Wetland Database (Lehner and Döll, 2004),Key Biodiversity Areas (IUCN, 2016), and a buffer zone of one grid-cell around designated areas. Note, when areas in either of these categories overlap with WDPA areas they are included in the WDPA areas.

Source: GAEZ(IIASA, 2012) Layer on areas reserved for the environment in GAEZ version 4 based on WDPA (IUCN and UNEP-WCMC, 2016).

Figure 3-5. Land use/cover of the 700 km² designated for the environment in the EAC countries



Source: GAEZv4 layer on areas reserved for the environment (see Table 3-8)

3.2.3 Water quality

Climate change and environmental degradation have been repeatedly reported as being among the major contributors of rapidly evolving changes in the basin that seriously threaten its ecosystem functions, overall biodiversity and the livelihoods and welfare of its populations (LVBC, 2016). Soil erosion has not only chronic impacts on agricultural productivity where gullies destroy land but also cause severe eutrophication and siltation of the Lake. Consequently, treatment costs to supply potable water for domestic use increase. Wastewaters from sewage and industries in urban areas, which are often discharged untreated in the environment, are increasingly becoming a major source of nutrients, causing eutrophication of surface water bodies (Nyenje et al., 2010).

Algal blooms are unpleasant for lakeshore communities and limit the region's potential for tourism. One of the most striking indicators of poor ecological health is the rapid colonization of the Lake by water hyacinth and green and blue algae. Infestations of this invasive floating plant periodically block access to kilometres of lakeshore, preventing use of the Lake for transport and fishing, as well as posing serious health and safety risks to local inhabitants (Worldbank, 2015, MWE, 2016). Due to poor and inadequate sanitation, cases of water borne diseases have been reported in the LVB basin.

Land use/cover and water quality are closely related (Baker, 2003). Reduction or change of natural vegetation cover types increases the speed of surface runoff and reduces water and nutrient retention capacities. This can lead to high nutrient inputs into lakes, resulting in eutrophication, siltation and infestation of floating aquatic vegetation. There is mounting evidence that significant land use changes have taken place in the Lake Victoria Basin increasing the likelihood that the frequency and concentrations of chlorophyll blooms are increasing (Mugo et al., 2016).

Furthermore, intensity and type of nutrient loading to the Lake Victoria is closely correlated with agricultural activity and population density. A high nutrient load intensity, especially for nitrogen, has been observed in the basin of the Kagera, the largest river that drains into Lake Victoria (Table 3-9).

Table 3-9. Annual loads of nitrogen and phosphorus to Lake Victoria for major sub-catchments

Lake Victoria sub-catchment	**Area** [km²]	**Discharge** [m³/sec]	**Nitrogen N** [kg/km²/year]	**Phosphorus P** [kg/km²/year]
Mara	13,393	39	127	23
Grumeti / Rubana	13,216	13	42	14
Mbarageti	3,559	5	60	14
Simiyu	11,577	34	130	38
Kagera	59,682	265	491	32

Source: (Machiwa, 2003)

The basin is densely populated with an average population density of over 250 persons/km². More than half of the basin is farmland, which increased from 2.9 million hectares 1985 to 3.6 million hectares (60% of the basin area) in 2010 (Wasige et al., 2013). Causes of phosphorus enrichment include cultivation on the proximity of river channels and atmospheric deposition from biomass burning (Machiwa, 2001; Tamatamah, 2002).

Wetlands

Wetlands are critical ecosystems in the sub-region both, for maintaining water quality as well as storage function for balancing peak flows. This applies in particular to the wetlands in highland countries such as Burundi, Rwanda and Uganda (EAC-Secretariat, 2011b). One of the most important functions provided by the Lake Victoria wetlands is the ability to maintain and improve lacustrine water quality (Kansiime et al., 2007). Lake Victoria wetlands are the most productive systems in the region offering various ecosystem services which are crucial to the local and regional socio-economic development (Raburu et al., 2012).

Wetlands in the LVB have been facing serious problems of degradation and their ability to continue providing valuable ecological services is threatened (Kairu, 2001, Kansiime et al., 2007). In LVB and EAC states at large, wetlands face severe degradation caused by a range of pressures of which, the main ones include population growth, agricultural development and urbanization (Raburu et al., 2012). Encroachment of wetlands has reduced wetland coverage in LVB (Odada et al., 2009). For example, on the Kenyan side of the basin, Owino and Ryan (2007) reported 34-50% loss of wetlands fringing Lake Victoria from the year 1969 to 2000 resulting from farmland conversion. Uganda has lost approximately 11,268 km2 of its wetland from 1994 to 2009, representing a loss of 30% of the country's wetlands (WRI, 2009).

Over the last three to four decades, the limnological dynamics of Lake Victoria have been characterized by elevated nutrient concentrations and intense eutrophication regimes due to excessive pollution (Machiwa, 2003, Odada et al., 2009). This situation has partly been linked to massive encroachment of agriculture and urban land on wetlands, which in the past served as natural pollution buffer zones. The reduction in wetland cover in LVB has been occurring inevitably despite the fact that many of these wetlands not only purify water from the catchments but are also used for wastewater treatment especially where technological fixes for advanced wastewater treatment systems are deemed expensive, lacking and/or dilapidated (Bateganya et al., 2015, Kansiime and Maimuna, 1999). Wetlands play a significant role in improving water quality and hence reducing costs of wastewater treatment (Emerton et al., 1998).

3.3 Water demand

Agriculture is the dominant water user in the EAC, mainly because of irrigation in Tanzania and Kenya. One fifth of water is withdrawn for the domestic sector. There is still only a marginal quantity of water withdrawal for use in the industry sector (Table 3-10).

Table 3-10. EAC water withdrawal, by sector, 2010

10^9 m^3 water/year	**Agriculture**	**Industry**	**Municipal (Domestic)**	**Total**
Burundi	0.22	0.02	0.04	0.28
Kenya	1.91	0.13	1.19	3.22
Rwanda	0.10	0.02	0.06	0.18
Tanzania, UR	4.63	0.03	0.53	5.18
Uganda	0.26	0.03	0.53	5.18
Total (EAC)	7.12	0.24	2.15	9.50

Note AQUASTAT provides data for 5-year periods. Estimates in the table refer to the most recent period reported.

Source: FAO AQUASTAT

3.3.1 Agriculture

Agriculture is today the backbone and economic mainstay of the EAC economies. The sector contributes on average 33 % to the GDP of the region. It supports the livelihood of almost 80 % of the population. The percentage of the economically active population working in agriculture ranges from about 38% in Kenya to over 90 % in Burundi (see Table 3-3 and Table 3-4). Crop cultivation is dominated by rain-fed agriculture, which accounts for more than 95 per cent of agricultural land use in the Lake Victoria Basin (LVBC, 2016).

Almost half of the EAC territory is in some form of use for agriculture (see land use in section 3.2.1). About 286 thousand km^2 are categorized as cultivated area for the production of annual crops on arable land and permanent crops. However, only about 37% of the arable land is actually utilized due to water shortage and other factors (EAC-Secretariat, 2011b). Some 515 thousand $km^2$are permanent meadows and grassland (Table 3-7), part of which is used by grazing ruminant livestock herds.

Smallholder farmers dominate the agricultural sector of the EAC countries and produce the majority of the crop and livestock products. The key long-standing challenges of smallholder farmers is low productivity stemming from poor access to farm inputs and the lack of access to markets, credit and technology compounded by the volatile food and energy prices (EAC, 2016a). Low yields are widespread. For example, the average grain yield in rain-fed farming is about 1 t/ha for smallholders, while under similar agro-climatic conditions, on-station yield levels of grain maize reach between 5-6 t/ha, and commercial farmers generally operate at much higher yields of 7-8 t/ha. In the dry areas, yields achieved by smallholders average 0.5 t/ha (EAC-Secretariat, 2010).

Agriculture supports subsistence livelihoods and commercial production for markets. The agro-food sector is the biggest direct employer of all manufacturing industries in the region. Agro-food value chains, particularly processed fruits and vegetables, have the highest job creation potential. In addition, the agro-food sector value chains have a significant multiplier effect to boost EAC economies and enhance food (EAC, 2016a, LVBC, 2016). Irrigation is an important strategy for managing climate-related risks to reduce poverty by increasing food security, high value products and improved incomes of the rural poor (EAC-Secretariat, 2006). However, the vast majority of land is communally owned providing little incentive for permanent improvement and investments for increasing productivity.

The most important driver regarding water demand is the use of blue water[5] for irrigation. In FAO terminology, irrigation includes controlled applications of water to supplement rainfall for crop growth. Note, that in the EAC countries the definition of irrigation schemes may go beyond controlled applications. Examples include: Farmer-made traditional irrigation schemes that use temporary infrastructure; Soils may be naturally inundated in wetland irrigation schemes; Flood recession irrigation schemes grow crops on flood plain of the rivers where they are watered by the flooding of the river; or in rainwater harvesting irrigation schemes, farmers construct water retaining bunds, harvest rainwater and store the water at the foot of mainly paddy crop.

According to AQUASTAT, the EAC total area equipped for irrigation amounts to 556 thousand hectares, which represents about 16% of the irrigation potential (Table 3-11). In addition, FAO reports the area actually irrigated, defined as the area irrigation at least once in a given year. It may be significantly lower. Often, part of the equipped area is not irrigated for various reasons such as lack of water, absence of farmers, damage, land degradation or organisational problems.

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[5] Blue water refers to water withdrawn from rivers, lakes and groundwater for irrigation. In contrast, green water is the water supplied to plants from rainfall.

The Lake Victoria supports the world's largest freshwater fishery, with a total annual landed catch value estimated at around US$ 0.5 billion, supporting the livelihoods of 3 million people, providing roughly 0.5 million tons of fish to local markets and generating US$ 0.25 billion in export revenues (Worldbank, 2015). However, fish stocks are highly endangered by different forms of environmental degradations such as sediments from soil erosion and different forms of pollutants reaching the Lake either directly or through its tributaries. This is similar to the other fish resources in the entire EAC with a total annual catch of about 0.9 to 1 million tons of fish which contribute about 4 per cent of the regional GDP and support the livelihoods of 5 million people in all EAC countries (EAC, 2016b, EAC, 2016a).

Table 3-11. Irrigation in the EAC countries

	Irrigation potential [1]		Equipped for irrigation		Actually irrigated	
1000 ha	Area	% of cultivated	Area	% of potential	Area	% of potential
Burundi	215	14	21 (2000)	10	n.d.	n.d.
Kenya	1,341	21	151 (2010)	11	97 (2003)	7
Rwanda	165	12	10 (2007)	6	8 (2008)	5
Tanzania	2,132	14	364 (2013)	17	n.d.	n.d.
Uganda	567	6	11 (2012)	2	11 (2013)	2
Total (EAC)	4,420	13	556	16		

1 Irrigation potential extracted from AQUASTAT country profiles; latest assessment quoted was chosen.

Source: FAO AQUASTAT

The economic effect of lack of inadequate water control systems to balance droughts and floods are significant. This mainly affects the agricultural sector and floods damage to infrastructure besides the loss of life in severe cases. It is estimated that a meteorological drought in a 12-year period lower the GDP by 7-10% and increase poverty by 12-15% (EAC-Secretariat, 2011b).

3.3.2 Industry including energy

Unlike many industrialized countries water withdrawn for industrial uses is small. Only 2.5 % of total water withdrawn in the EAC is used in the industrial sector (Table 3-10). In industrialized countries the majority of industrial water use is for the cooling of thermoelectric and nuclear power plants. In addition, the manufacturing industry withdraws water for cleaning, cooling, and other processing steps. Typically, water intensive manufacturing industries include food processing (e.g. breweries, soft drinks, and dairy products), textile production (for dyeing or bleaching), tanneries, and pulp and paper industries and steel manufacturing. Further the mining sector requires water for leaching or drainage works.

The share of industry in the economy increased modestly in almost all East African countries. The contribution of the industry sector to the overall GDP of the EAC countries stands at 16% (in 2014). East Africa's industrial sector employed about 560,000 workers in 2012. Assuming a labour force of about 77 million in 2010, industrial employment accounted for less than one per cent of the region's total labour force. In order to reach the goal of having 2.3 million people working in manufacturing, the region's industrial sector jobs will have to expand almost five times in the next 20 years (Eyakuze et al., 2013).

Energy supply in the EAC is still characterized by low energy access, albeit with large regional differences (Table 3-12). Access to electricity is most developed in Kenya where connection to electricity accelerated in the past years. Today more than half of the population is connected to the electricity grid, up from just 27 % in 2013. Kenya has a target of universal electricity access by 2020. Per capita electricity consumption is still very low by international standards. For example, both Kenya and India are classified as lower-middle income country, while per capita electricity consumption in India in 2014 was almost five times higher than Kenya.

Table 3-12. Energy supply in the EAC

	Access to electricity % age of population in 2016			Access to clean fuels[1] for cooking	Electricity consumption[2]	Transmission and distribution losses [%]
	Total	urban	rural	*% of population in 2016*	*[kWh/per capita]*	
Burundi	8	50	2	1	23 (2011)	24
Kenya	56	78	40	13	168 (2013)	18
Rwanda	29	80	18	1	80 (2012)	23
Tanzania, UR	33	65	17	2	89 (2013)	21
Uganda	27	58	18	1	62 (2010)	23

1 Examples for clean fuels include electric stoves, liquefied petroleum gas and biogas; **2** In comparison, per capita electricity consumption in selected other countries in 2014 was: 806 (India); 2090 (Mexico); 2601 (Brazil), 3927 (China); 4190 (South Africa); 5130 (United Kingdom); 7035 (Germany); 12980 (United States).

Source: (Worldbank, 2017) for access to electricity and access to clean fuels for cooking; (REN21, 2016) for electricity consumption and transmission and distribution losses.

The available electricity production capacity is still small with about 4.5 GW total installed capacity of which about 36% originates from thermal power plants (Table 3-13). Consequently, the per capita electricity consumption is very low ranging between 23 kWh per capita and year in Burundi and 186 kWh in Kenya (compared to 480 kWh in Sub-Sahara Africa and 3,125 kWh in global average) (REN21, 2016). Transmission and distribution losses are very high amounting to 22 % of electricity generated (compared to 11.8% in Sub-Sahara Africa and 8.2 % at global average), which also leads to more water use for electricity production than necessary.

Table 3-13. Installed electricity production capacity in EAC, 2014

	Installed electricity production capacity [MW]							
	Hydro-Power	Wind	Solar PV	Biomass power	Geothermal	Thermal*	Total	Thermal electr. [%]
Burundi	34	-	-	-	-	20	54	37
Kenya	820	26	-	26	598	751	2,134	34
Rwanda	79	-	9	-	-	48	224	35
Tanzania	562	-	-	27	-	664	1,340	53
Uganda	693	-	-	58	-	136	799	15
Total (EAC)	**2,188**	**26**	**9**	**111**	**598**	**1,619**	**4,550**	**36**

Source: (EAC, 2016b, REN21, 2016)

Off-grid solutions for electricity access seem to be increasingly important for basic energy services for millions of people in rural and peri-urban areas that lack energy access including in EAC countries. Some 15-20% of households in Kenya use solar light systems in Kenya and more than half of households in Tanzania's Lake region. This is also demonstrated by the total cumulative installed solar PV installation capacity is estimated at 76.5 MW in 2014 up from 10.4 MW in 2009 (REN21, 2016). Such type of electrification strategies have low impact on water use, especially as industrial production of the solar electricity generation equipment is currently not produced in the region.

The authors have no reliable information available on the water use for the specific electricity production mix in East Africa. However, the major share of the current industrial water use of about 2.5% as indicated above is expected to be used for the cooling of the thermal and geo-thermal power plants, which account for close to 50% of the currently installed centralised electricity production capacity in the EAC. Wood fuel is currently the major source of domestic energy, especially for rural population who uses wood for cooking. Access to clean fuels and technologies for cooking such as Liquid Petroleum Gas (LPG) or electric stoves is very low in East Africa. Except of Kenya, with 13% access all other countries are at a level below 2% only. This has serious effects on health for about 138 million people in the region due to indoor air pollution leading to 60,000 premature death (EAC-Secretariat, 2006, REN21, 2016). Furthermore, this leads to major pressures on shrinking woody biomass stocks and forested areas which affect the hydrological cycle leading to faster and higher runoff.

3.3.3 Domestic water use

About one fifth of the EAC water withdrawal is municipal water withdrawal (AQUASTAT, see Table 3-10). According to the AQUASTAT definition, it refers to the quantity of water withdrawn primarily for the direct use by the population and is usually computed as the total water withdrawn by the public distribution network, and termed municipal water withdrawal. It includes domestic water uses but also industries, which are connected to the municipal network.

Municipal water withdrawal is sometimes used interchangeably with domestic water withdrawal. This can be particularly misleading in countries such as those of the EAC, where large parts of the population are not connected to centralized municipal pipe networks. Domestic water withdrawal focuses on human/household needs (drinking, cooking, cleaning and sanitation). AQUASTAT does not report specifically domestic water withdrawals, but integrates it into municipal water withdrawal.

Insufficient access to safe drinking water (72%) and improved sanitation facilities (40%) in both, rural as well as urban areas is still a wide spread phenomena in the EAC countries (EAC, 2016a). According to data from WHO/UNICEF's Joint Monitoring Programme (WHO and UNICEF, 2017), in 2015, some 112 million people (70% of EAC population) had access to an improved drinking water source. However, people, mostly woman, may need to spend considerable time on collecting safe drinking water.

For some 81 million people the collection time for improved drinking water source is less than 30 minutes, while for the remainder of 30 million people collection time exceeds 30 minutes (Table 3-14). Almost one third of the EAC population (49 million) has to rely on water from unprotected dug well or spring or even on water directly taken from available surface water resources.

Table 3-14. Indicators on access to safe drinking water and sanitation in the EAC, 2015

	Basic drinking water services				**Basic sanitation services**			
% age of population	At least basic[1]	Limited[2] (> 30 min)	Un-improved[3]	Surface water[4]	At least basic[5]	Limited (shared)	Un-improved[6]	Open defecation
Burundi	56	20	17	7	50	11	36	3
Kenya	58	9	10	23	30	21	37	12
Rwanda	57	21	15	8	62	14	22	2
Tanzania, UR	50	13	24	13	24	13	52	11
Uganda	39	38	15	8	19	14	60	6
EAC	**51**	**19**	**17**	**14**	**29**	**15**	**46**	**9**

1 Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing; **2** Drinking water from an improved source for which collection times exceeds 30 minutes for a roundtrip including queuing; **3** Drinking water from an unprotected dug well or unprotected spring; **4** Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal; **5** Use of improved facilities which are not shared with other households; **6** Use of pit latrines without a slab or platform, hanging latrines or bucket latrines.

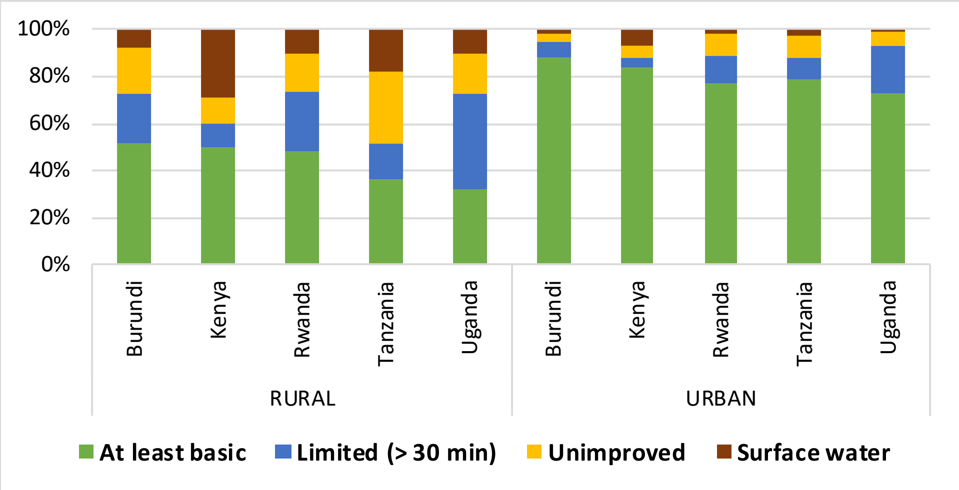
Source: (WHO and UNICEF, 2017)

The sanitation facilities in the EAC are significantly worse than in the industrialized countries, but characteristic for sub-Saharan Africa. Just over 4 out of ten people use improved sanitation facilities and only 3 out of ten do not need to share those with other households (Table 3-14).

Drinking water varies from country to country and is generally more advanced in urban areas than in rural settings (Figure 3-6). Similar, the urban population has a higher access to improved sanitation facilities Figure 3-7. From the total population of 161 million, some 78 million in rural areas and 10 million in urban areas need to rely on unimproved sanitation. Lack of access to improved water sources is due to low infrastructure investments, poor operational and maintenance services, compounded by limited and ineffective user fee charges, which cannot meet maintenance costs (EAC-Secretariat, 2011b, EAC-Secretariat, 2006, EAC, 2016a).

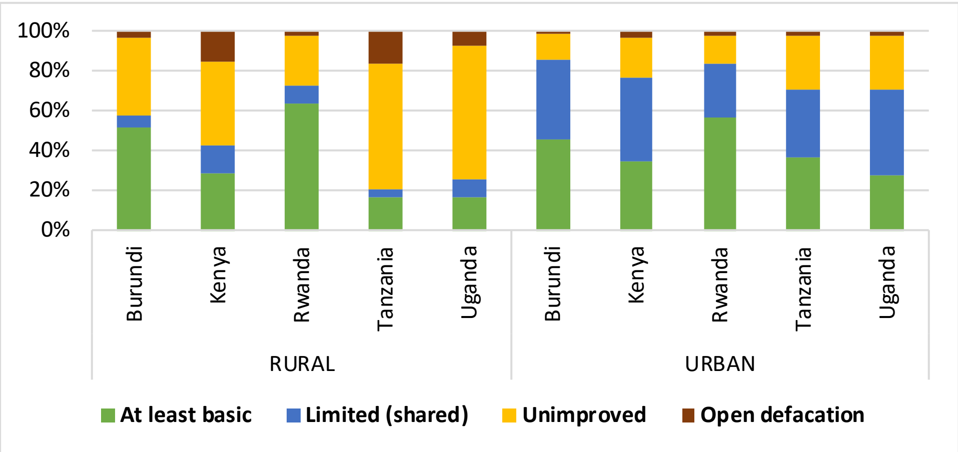
Current low access rates combined with low per capita water consumption (21.4 l/cap and day in rural areas and 46.8 l/cap and day in urban (MWE, 2013) result in low water demand in the domestic water sector.

Figure 3-6. Urban and rural drinking water services in the EAC, 2015



Source: (WHO and UNICEF, 2017)

Figure 3-7. Urban and rural sanitation water services in the EAC, 2015



Source: (WHO and UNICEF, 2017)

4 Water development target space – “*Where do we want to be?*”

4.1 Review of regional visions

4.1.1 EAC aspirations

A central element of the development visions of the EAC countries is to develop into middle-income countries by transforming their economies and shifting from agricultural dominated societies to knowledge-based economies. Therefore, infrastructure development, integration, capacity development and strengthening of institutions emerge prominently. The ambitious transition to which the EAC Member States have committed themselves in their ‘EAC Vision 2050’ (EAC, 2016a) is also reflected in a fictional picture entitled *“Graphic City of the Future Urban Infrastructure”* (Figure 4-1).

Figure 4-1. Graphic extracted from the EAC Vision 2050

Source: (EAC, 2016a)

More specifically, for the Lake Victoria Basin, EAC partner countries have declared the basin *“...as a ‘Regional Economic Growth Zone’ and an ‘Area of Common Economic Interest’ for the people of East Africa that should be exploited in a coordinated manner so as to maximize its economic and social benefits as well as take care of any environmental concerns.”(LVBC, 2016)*

This complies with the mission statement of the EAC Vision 2050, which emphasizes to widen and deepen economic, political, social and cultural integration in order to improve that quality of life of the people of East Africa. The pillars for achieving these ambitions include i) infrastructure development; ii) industrialization; iii) modernization of agriculture, food security and transforming rural economies; iv) natural resource and environment management; v) tourism, trade and services development; and vi) development of human capital (EAC, 2016a). For each pillar, a goal has been formulated. Common elements in these goals include affordable access, transformation of systems, strengthening value addition and a focus on improved quality of human resources (Figure 4-2).

Below we compile information from relevant regional vision and strategy documents on key drivers, which will shape East Africa’s future water demand and water availability.

Figure 4-2. Aspirations of the EAC vision 2050

	Aspirations					
Goals	Access to affordable and efficient transport, energy, and communication for increased regional competitiveness	Enhanced agricultural productivity for food security and a transformed rural economy	Structural transformation of the industrial and manufacturing sector through value addition and product diversification based on comparative advantage for regional competitive advantage	Effective and sustainable use of natural resources with enhanced value addition and management	Leverage on the tourism and services value chain and building on the homogeneity of regional cultures and linkages	Well-educated and healthy human resources
Pillars	Infrastructure Development	Agriculture , Food Security and Rural Development	Industrialization	Natural Resources and Environment Management	Tourism, Trade and Services Development	Human Capital Development

Source: (EAC, 2016a)

4.1.2 Demographic development

The average annual population growth rate in the five countries of the EAC was about 2.66 %[6] in 2014 and is projected to decrease to 2.04% in 2030 and 1.33% in 2050. The EAC Vision 2050 anticipates total population to increase to 184.3[7] million by 2030 and 278.4 in 2050 (EAC, 2016a). For comparison, the African Development Bank (AfDB) (AfDB, 2011)provides for East Africa, a region including 13 countries, similar future annual growth rates than the EAC Vision 2050 in their 'high-case' scenario (Table 4-1).

Table 4-1. Projections of average annual population growth rates in East Africa

Data source	Region covered	2020	2030	2040	2050
EAC Vision 2050	Five EAC countries (Burundi, Kenya, Rwanda, Tanzania UR, Uganda)	no data	2.04%	no data	1.33 %
AfDB*: low-case	Five EAC countries and Comoros, Djibouti, Eritrea, Ethiopia, Seychelles, Somalia, Sudan, South Sudan	2.30 %	1.91 %	1.58 %	1.24 %
AfDB: high-case		2.46 %	2.04 %	1.69 %	1.33 %

* African Development Bank (AfDB)

Source: (EAC, 2016a) and (AfDB, 2011)

[6] The EAC Vision 2050 contains contradicting information on current average population growth rates. Whereas Table 10 on page 37 indicates 2.66% for 2014, the document states 2.3% on page 19. The EAC Fact & Figures 2016 lead to 2.9 % growth rate.

[7] There is some contradicting information on EAC population medium term population targets (page 19 indicates 184.3 million by 2025 vis-à-vis Table 10 on page 36, which shows 184.3 million by 2030.

It is widely recognized and accepted that achieving moderate population growth rates, as projected in the *EAC Vision 2050*, depends heavily on improving the educational attainment of the population. Almost universally, women with higher levels of education have fewer children. Hence, the population outlook depends greatly on further progress in education, particularly of young women (Lutz and Samir, 2011). The *EAC Vision 2050* emphasizes, *"Well-educated, enlightened and healthy human resources are essential to facilitate development in the region."* This includes improving both the quality of education and access to education. The aim is equal access to education for all, to achieve universal primary education and secondary school enrolment and graduation rates of over 90% (Table 4-2).

Table 4-2. Educational attainment aspirations for the EAC

Percentage	2015	2030	2050
Primary school enrolment rate	95	98	100
Secondary school enrolment rate	28	65	95
Net primary completion rate	67	88	98
Net secondary completion rate	30	72	91
Adult literacy rate	69	7.9	7.5

Source: (EAC, 2016a)

Urbanisation

Population growth is considerably faster in urban areas compared to total population growth. 2.9% on average and 5% in urban areas (see section 3.1.1). According to the EAC Vision 2050, urbanisation in the EAC countries is expected to reach 51% by 2030 and 70% by 2050. This is a considerably higher urbanization rate compared to projections from the African Development Bank, albeit for a different country cohort. The AfDB scenarios expect around 33% and 46% by 2030 and 2050 respectively (Table 4-3). The AfDB scenario study suggests that the movement of working age people from rural areas to urban centres will be instrumental in accelerating economic growth. This will lead to more diversified economies, which rely less on subsistence agriculture and more on productive sectors such as manufacturing and services.

Table 4-3. Projections for urbanisation rates in East Africa

Percentage	Region covered	2020	2030	2040	2050
EAC Vision 2050	Five EAC countries (Burundi, Kenya, Rwanda, Tanzania UR, Uganda)	no data	51.0	no data	70.0
AfDB: low-case	Five EAC countries and Comoros, Djibouti, Eritrea, Ethiopia, Seychelles, Somalia, Sudan, South Sudan	26.6	32.2	38.8	46.1
AfDB: high-case		27.8	33.5	40.1	47.2

Source: (EAC, 2016a) and (AfDB, 2011)

4.1.3 Economic growth

East Africa is expected to be the fastest growing sub-region in Africa and likely to have the strongest economic growth performance, reaching 9.3 % of GDP growth in 2030. Due to high population growth, which will only show a slow decline over time, the growth rate of GDP per capita is lower, reaching a peak of 8.2% in 2040. By 2060, per capita income in East Africa will be ten times than in 2010 (AfDB, 2011).

The EAC envisages an even stronger economic growth of 10 % per annum for GDP and a per capita income growth rate ranging between 7-8 %. Accordingly, by 2050 per capita incomes will have grown ten-fold rising to US$ 10,000 thereby moving the region into the upper-middle income category (EAC, 2016a). This target is also slightly more ambitious compared to the Agenda 2063 of the African Union Commission. It intends as well to increase per capita income by at least 10 times compared to the 2013 level, however over a longer time frame (up to 2063) (AUC, 2015). Table 4-4 summarizes GDP and per capita GDP growth rates for East Africa envisioned in the EAC 2050 Vision and the AfDB study for East Africa.

Both, the East Africa Vision 2050 and the AfDB provide absolute numbers for anticipated per capita GDP for the decades up to 2050. However, because both sources do not explicitly indicate whether projections are given in current or constant US$ and to which base year they refer, absolute numbers can hardly be compared. Nevertheless, the AfDB per capita GDP projections may be less optimistic compared to the East Africa Vision 2050.

Table 4-4. Economic projections for East Africa

	2020	2030	2040	2050
Annual GDP growth rates				
EAC Vision 2050	no data	10.0	no data	9.9
AfDB: low-case	7.1	8.3	8.3	7.4
AfDB: high-case	8.4	9.9	9.8	8.8
Annual per capita GDP growth rates				
EAC Vision 2050	no data	7 - 8	no data	7 - 8
AfDB: low-case	5.0	6.6	6.9	6.3
AfDB: high-case	6.0	7.9	8.2	7.5

See Table 4-1 and 4-2 for countries included in the EAC and the AfDB study.

Source: (EAC, 2016a) and (AfDB, 2011)

4.1.4 Water availability

Climate Change will significantly affect future water availability in East Africa. EAC partner states emphasize that adaptation and mitigation to climate change represents an immediate and urgent regional priority.

Despite of mitigation efforts, the 'EAC 2050 Vision' emphasizes the need to develop the oil and gas industry. Similar aspirations are also included in the development visions of Uganda and Kenya to explore oil from Albertine Graben and Turkana oil fields. The Vision also emphasizes the need for a smooth delivery of petroleum products to avoid any adverse economic effect. At the same time the Vision commits to a green / low carbon economy including specific targets for CO_2 emissions increasing only moderately from 4.3 Million tons in 2014 to 4.7 Million tons in 2030 and 5.1 Million tons in 2050(EAC, 2016a).

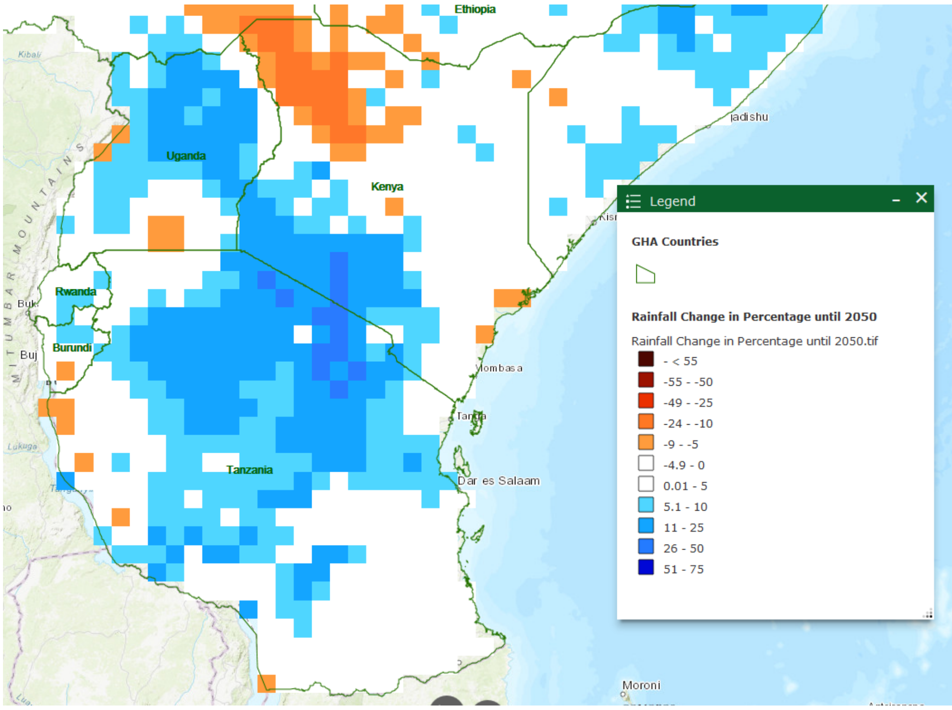
Concerning adaptation, the 'EAC Climate Change Master Plan 2011-2031'identifies water security as second priority issue after agriculture and food security. Strategic interventions concerning water and climate change include expansion of water-efficient irrigated agriculture, conservation agriculture, rainwater harvesting and storage, reuse of treated wastewater, recharge of aquifers, transboundary cooperation on water resources management, regulation and governance in distributing water for domestic, industrial / energy, and agriculture, and advance water- and climate information technology (EAC-Secretariat, 2011a).

In 2014, the total bilateral commitments of climate-related official development assistance (ODA) by members of the OECD Development Assistance Committee for the EAC region were US$ 898 million. Of this total, 41% (approximately USD 368 million) targeted climate change mitigation, 35% (USD 314 million) targeted adaptation objectives, and the remaining 24% (USD 215 million) targeted both mitigation and adaptation activities (REN21, 2016). The EAC identified costs of approximately 34 million US$ to tackle key coordination functions and funding studies related to climate change and some 2.15 billion US$ in investment costs to implement regional cross-border co-operation on climate change measures (EAC-Secretariat, 2011a). Some Integrated Water Resource Management (IWRM) strategies at the catchment level set up water user forums, which have developed catchment management plans.

By 2050, the 'EAC Vision 2050'assumes a significant temperature increase for East Africa of almost 3°C. This represents a rather pessimistic outlook of global temperature increases despite the fact that the 'EAC Vision 2050' was published after the Paris Climate Agreement of 2015, which commits to holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C(UNFCC, 2015).

Global circulation models and information published on ICPAC's web-portal suggest an increase in precipitation by 2050 for almost all of East Africa. The exception is north-western Kenya where a major decline is expected (Figure 4-3). This is likely to translate in higher water availability, albeit prone to increasing rainfall variability.

Figure 4-3. East Africa rainfall change until 2050



Source: extracted from ICPAC web portal (http://geoportal.icpac.net/)

Climate change is likely to cause increase in both lake evaporation and catchment evaporation as a direct response to temperature increase. Consequently, catchment runoff will reduce as a direct response to increased evaporation. However, lake rainfall is likely to fluctuate about the historical mean level. Increased evaporation and constant rainfall will imply to reduce net basin supply[8], leading to more prolonged droughts and reduced wetland area (Sewagudde, 2009). With reduced net basin supply, the ability of the role of the Lake Victoria as regional water source for domestic water supply, hydropower generation, water requirements for irrigation development and fisheries may be jeopardised.

4.1.5 Agricultural water use

Modernized agricultural production is widely recognized as an important driver for transforming the East African economies in line with the visions and strategies formulated at national, regional, and also continental levels (AfDB, 2011, AfDB, 2017a, AfDB, 2017b, AUC, 2015, EAC, 2016a, EAC-Secretariat, 2010). The EAC member states will therefore continue to increase their investments in the transformation of agriculture through mechanization, irrigation, improved seeds and the use of fertilizers to ensure increased productivity for food security and economic prosperity(EAC, 2016a, EAC-Secretariat, 2010).

Accordingly, the EAC will emphasize the development of the agricultural sector to achieve food security in the EAC, liberalize cross-border trade of agricultural products, harmonise agricultural policies and regulations, increase production of crops, livestock, fisheries, develop markets and marketing infrastructure, accomplish sustainable utilization of natural resources, reduce post-harvest losses, promote value addition through agro-processing, and protect human, animal, plant and environmental safety(EAC, 2016a).

The *Agriculture and Rural Development Strategy for the EAC* (2005-2030) (EAC-Secretariat, 2006) emphasizes the need to improve crop and livestock production and productivity. Means to achieve this include intensification, promotion of agro-forestry, sustainable use of land resources, increasing the availability of agricultural inputs, etc., all of which are geared towards producing higher yields in current cultivated areas. However, despite of an expected increase in intra- and inter-regional trade, cultivated land expansion is likely. Neither of these factors have been quantified for the coming decades. A few quantitative targets include i) Increase of real annual agricultural GDP growth from 4% to 8% by 2030; ii) Reduction of population below poverty line from 38% to 10%; and iii) Increase of irrigated land from 1.2% (of potential irrigated land actually irrigated) to 20% by 2028 (EAC-Secretariat, 2006).

The EAC's *food security action plan* published in 2010 indicates a target of 15% increase of production and productivity for both crops and livestock & fisheries between 2010 and 2015. Similarly, according to this action plan, per capita surface water storage and rain-water harvesting should both increase by 15% until 2015 (EAC-Secretariat, 2010).

The significant targeted irrigation expansion – according to the EAC agricultural and rural development strategy - should be backed by improved water utilization, watershed management including IWRM, developing water harvesting techniques, research in different cost effective irrigation techniques, private sector participation in irrigation and harmonization of irrigation policies across the EAC countries.

The *African Water Vision 2025 (UN-Water/Africa, 2003)*, reemphasized in the *African Water Resources Management Priority Action Program 2016-2025 (AUC-AMCOW, 2016)*, sets a target to

[8] The net basin supply (NBS) is computed by rainfall + runoff – evaporation. It is a critical determinant of the Lake Victoria's level and ideally it maintains a relatively stable level and volume of water.

increase agricultural water productivity[9] by 60% in the period 2000 to 2025, while at the same time increasing by 100% the area under irrigation.

Because agriculture is the largest user of water in Africa (and in the EAC), the anticipated expansion of irrigated areas will require well-targeted funding based on careful planning including consideration of all water use sectors.

The envisaged transformation process in the agricultural sector goes beyond improving livelihood of the existing smallholder farmers. The *EAC Vision 2050* also emphasizes the need for large-scale land based investment, while safeguarding the interests of the local population. The agro-food sector is the largest direct employer of all manufacturing industries in the region. Agro food value chains, particularly processed fruits and vegetables, have the highest job creation potential. In addition, the agro-food sector value chains have a significant multiplier effect to boost EAC economies and enhance food security (EAC, 2016a).

By 2050, a key concern of the fishery sector is to operate a single management space that covers all surface water bodies in the EAC region. Education, infrastructure and technology will be critical for the development of the industry. The Region will also cooperate with development partners towards curbing illegal and unregulated fishing. Further, the EAC Partner States have committed to invest in aquaculture to improve food security, income generation and reduce fishing pressure on inland water bodies(EAC, 2016a). To achieve these ambitions, the conservation and improvement of surface water quality is of paramount importance.

4.1.6 Industrial (including energy) water use

Industrial development is a key factor in realizing the *EAC Vision 2050*, and thus as one of the six pillars described in the vision aspirations (Figure 4-2). The Vision sets several targets for 2030 and 2050. The contribution of the industrial sector to GDP should increase considerably from a current 16% (2014, see 3.1.2) to 27% and 40% by 2030 and 2050 respectively. The share of manufactured export value in total export value should from 8.2% in 2014 to 20.3% in 2030 and 30.8% in 2050. All national development plans as well as the *EAC Vision 2050* describe value addition in the agricultural sector as an important priority sector. The EAC Vision sets a target to “raise local value addition” from a current 8.2% to 40% and 60% by 2030 and 2050. Although the nature and approach of ‘local value addition’ is not explicitly mentioned, the term is mainly used in relation to agricultural produce. In any case, the industrial sector is likely to increase its water demand significantly in the coming decades.

The SWOT Analysis conducted for the EAC Vision 2050 identified insufficient energy supply as a key weakness for East Africa. The Regions target is to transform to energy landscape to achieve “100% access to modern energy services with more than 50% supplied from renewable and clean energy sources”. All different energy sources should be developed including hydro, geothermal, natural gas, biomass, wind, solar, oil and nuclear (EAC, 2016a). Despite of the EAC’s aspirations for nuclear energy, the International Energy Agency, in their ‘Africa Energy Outlook’ foresees nuclear energy in sub-Saharan Africa confined to South Africa (IEA, 2014).

Secure and reliable supply of energy is inextricably linked with water availability and quality. Energy (mainly electricity) is needed to pump, treat, transport, and desalinate water. Conversely, significant amounts of water are needed in almost all energy generation processes. Water is used to generate electricity in hydropower plants and almost all thermal power plants (coal, nuclear, solar-thermal,

[9] Water productivity indicates the ratio of agricultural GDP and the amount of water extracted for agricultural use (US$/$m^3$).

geothermal, biomass, and natural gas combined-cycle) require large amounts of water, especially for cooling purposes. Water is also needed to extract, process, and generate fuels (Delgado et al., 2015).

The *EAC Vision 2050* sets very ambitious electricity production capacity targets of having an installed capacity of 70,570 MW by 2030 and 122,569 MW by 2050[10]. The 2050 target is based on the assumption that production can supply an assumed annual growth of 10% until 2050 up from a 3,965 MW[11] baseline total regional supply in 2014. The Vision also aims to ensure that the entire population having access to *modern* energy services and more than half of energy comes from renewable sources.

Other sources suggest more moderate growth rates of electricity demand and connected power generation capacity in the region. The *EAC Renewable Energy and Energy Efficiency Regional Status Report* expects electricity demand is to increase by approximately 5.3% annually until 2020(REN21, 2016). The most recent *Africa Energy Outlook*, published by the International Energy Agency (IEA), projects future electricity demand calculated as the total gross electricity generated, less own-use in the production of electricity, less transmission and distribution losses for the period 2010-2040. East Africa is the most dynamic region with the highest annual average annual growth rate of 7.6% compared to 4.6% for Sub-Sahara Africa (IEA, 2014).

There is a considerable potential for renewable electricity production in the EAC. An estimated 25 to 29 thousand MW can be produced from hydro-power and geothermal (Table 4-5). Further, the EAC region has one of the highest potentials for solar power globally with a year-round exploitation of between 4 and 6.5 kWh/m^2/day. There is still only limited information about the region's wind power potential. However, preliminary information suggest potential in Kenya (country's north-west and Rift Valley) and in Tanzania's Rift Valley and on its islands. In Kenya alone and estimate 1 GW could be produced(REN21, 2016).

Table 4-5. Hydropower and geothermal electricity production potential in the EAC

Megawatt (MW)	**Hydro-power**	**Geothermal**	**Total**
Burundi	300 – 1700	no data	300 – 1700
Kenya	4500	7000 – 10000	11500 - 14500
Rwanda	313	300	613
Tanzania, UR	4800	5000	9800
Uganda	2200	450	2650
Total (EAC)	12113 - 13513	12750 - 15750	24863 - 29263

Source: (REN21, 2016)

For centralized grid-based solutions, hydropower is likely to remain the main source of power generation. Geothermal energy becomes the second largest source of electricity by mid 2020s. At the same time oil is expected to increase resulting in a more diversified power mix. Despite the stated aspirations of *the EAC Vision 2050* to build nuclear power capacity, the IEA expects that nuclear energy in sub-Saharan Africa will be limited to South Africa (IEA, 2014).

The analysis of the diverse vision documents for East Africa suggest that the existing power generation mix for centralised grid-connected systems is unlikely to change significantly over the coming decades. The exception is renewable energy, which will likely account for a higher share in the total electricity mix, mainly due to geothermal and wind. Off-grid solutions for lightening and household appliances based on photovoltaic have already been increasing sharply in some of the EAC countries (see section 3.3.2). It is likely that they photovoltaic will play a key role in areas lacking

[10] Table 10 in the EAC Vision 2050 target (p.38). Apparently the 70,570 MW in 2030 would assume a higher than 10% annual growth rate.
[11] This number is lower than the 4,550 reported in other sources (see Table 3-11).

access to an electricity grid. Off-grid electricity generation will play a key role for two targets of the *EAC Vision 2050* (provide access to modern energy sources for all people, at least 50% of energy supply from by renewables).

The extractive industry, which covers a wide variety of mining products, is an important building block of the EAC vision 2050. This is likely to affect water consumption as mining is often very water intensive and poses water quality risks if not managed well.

Given the discoveries of oil and gas in the region, there is need to develop adequate petroleum production capacity in the region and to develop the petroleum supply infrastructure to meet the regional market requirements and match the expected increasing demand for petroleum products regionally. The petrochemical and natural gas industry registered the fourth highest score on attractiveness (6.75) and strategic feasibility (4.74) (EAC, 2016a).

Ugandan oil & gas industry alone is projected to consume about 44,000 m3/day for oil& gas extraction alone in full exploitation (Burtscher et al., 2018). If refining the petroleum products, additional domestic water supply for the workers in the urban centres, and irrigation for additional food production is considered about 500,000 m^3/day will be needed according to government official sources (Tenywa, 2017)[12].

4.1.7 Domestic water use

Access to safe and clean drinking water and sanitation are important dimensions for water demand and water quality in Eastern Africa.

The *EAC Vision 2050* sets a target of 81.7% and 92.9% of the population having access to safe drinking water by 2030 and 2050 respectively. These figures refer to the entire EAC, including urban and rural areas. Individual countries have higher targets, for example Uganda has set a target of 100 %. The population with access to improved sanitation is expected to be 60% in 2030 and 90% in 2050.

4.1.8 Environmental flows / Environment

The *EAC Vision 2050* emphasises sustainable land management, particularly its contribution to biodiversity, sustainable agriculture and food security, eradicating poverty, empowerment of women, addressing climate change and improving water availability. Furthermore, it suggests integrating actions of mitigating the effects of land degradation and drought, including restoring degraded lands, improving soil quality and water management, in order to contribute to improved land use in the region.

Maintaining environmental flows is also vital for achieving the ambitious targets for tourism. Today tourism contributes an estimated 9 per cent of the regional GDP (EAC, 2016a). Generally, on the African continent the contribution of tourism to GDP should be increased at least five-fold until 2063 (AUC, 2015).

Undertakings to boost tourism development in East Africa indicated in the *EAC Vision 2050* strongly focus on improving facilities, infrastructure and the quality of services in order to attract big numbers of visitors. Preserving the natural heritage (valuable ecosystems etc.) which also depends heavily on water is rather taken as a given. The aspect of environmental management is mentioned in the document and even included as a pillar in connection with natural resources. However, the

[12] https://www.newvision.co.ug/new_vision/news/1462606/oil-water-thirsty-sector

description how this should be achieved "effective and sustainable use of natural resources with enhanced value addition and management" does not include any environmental concerns but is focused on use of natural resources and value addition.

4.2 Scenario development approach

The “regional development scenario” is foremost guided by the “Vision 2050” of the EAC (EAC, 2016a) and complemented by other regional plans and strategies. The documents include

- the EAC Agriculture and Rural Development Strategy (2005-2030) (EAC-Secretariat, 2006)
- the Food Security Action Plan (2011-2015) (EAC-Secretariat, 2011b)
- the EAC Climate Change Master Plan (2011 – 2031) (EAC-Secretariat, 2011a)
- the EAC Renewable Energy and Energy Efficiency Regional Status Report (REN21, 2016).

These documents are very much in line and agreement to both the national level development visions and strategies of the EAC countries and diverse Africa-level development aspirations including the studies

- “Africa 2036. The Africa We Want” (AUC, 2015)
- “Africa in 50 Years' Time. The Road Towards Inclusive Growth” of the African Development Bank (AfDB, 2011)
- “The African Water Resources Management Priority Action Programme 2016 – 2025”(AUN, 2016).

Stakeholder Participation

In the beginning of December 2017, the Republic of Uganda (Directorate of Water Resources Management of the Uganda Ministry of Water and Environment) in collaboration with IIASA as co-hosts organized and hosted a three-day workshop in Entebbe/Uganda on the issue of achieving a water secure East Africa in 2050. The workshop was attended by over 50 participants covering a wide range of regional stakeholders engaged in governments, academia, businesses and civil society.

One day was dedicated to regional development scenarios resulting from existing visions (see section 3) and the role of water in support of these development aspirations. Key drivers for mid- to long-term water resources management options on the road towards 2050 were discussed and documented (Burtscher et al., 2018). The workshop participants were further consulted to feedback on the story line and quantification of the regional development scenario presented in this report.

The **E**ast **A**frica **R**egional **V**ision **S**cenario, henceforth termed **EA-RVS**, has been initiated in the Entebbe workshop and reflects the agreed understanding of the workshop participants (Burtscher et al., 2018). A common understanding on mid- to long-term water trajectories was achieved by incasting[13] on key determinants of development trends of water availability and demand. For this purpose, participants were grouped according to four sub-themes on i) socio-economic trends and domestic water; ii) surface and ground water resources; iii) agriculture, livestock, fishery and land use; iv) industry and manufacturing.

[13]Since the mid-1970s, the Hawaii Research Centre for Futures Studies, under the direction of Jim Dator, has been using a workshop forecasting technique that Dator named ”incasting.” In this process, participants are presented with scenarios to explore. The scenarios are deliberately written very generally, and participants are asked to add details to the scenarios, using their creative imaginations and the rule of logical consistency to the described characteristics of each scenario.

4.3 East Africa Regional Vision Scenario (EA-RVS)

4.3.1 Scenario narrative

Motivating forces: Stimulated by the United Nations Conference on Environment and Development, convened in Rio de Janeiro in June 1992 (Rio Summit), the world has been shifting toward a more sustainable path, emphasizing more inclusive human development that respects perceived environmental limits. The World Summit on Sustainable Development in 2002 in Johannesburg, South Africa, at which the "Johannesburg Plan of Implementation for Sustainable Development" (UN, 2002) was agreed upon and the Rio+20 conference in 2012 in Rio de Janeiro were further landmark events to shape the global development agenda. Started at the "World Summit 2012", this culminated in an UN-sponsored consultation process to define 'The World We Want' with tens of thousands institutional and individual participants. The consultation process has led to the Sustainable Development Goals (SDGs) unanimously adopted by the UN General Assembly in September 2015 (UN, 2015).

Many of the SDG targets are of high relevance for the least developed countries. Committed to the SDGs, the International Community progressively engages in supporting the development ambitions of the African continent. East Africa spearheads sustainable development efforts. In summer 2016, the 'Sustainable Development Goals Centre for Africa[14]' was launched in Kigali, Rwanda, a reflection of the region's early commitment to sustainable development. A series of Memorandum of Cooperation/Understanding between institutions in East African and more developed countries facilitate the promotion of innovation, knowledge co-creation and investments.

Political integration: Recognizing the value of cooperation and economic size in development and negotiations, East Africa embarks on a slow but continuous economic and political integration. The unification process is driven primarily by the founding countries of the EAC (Kenya, United Republic of Tanzania, Uganda) later extended by Burundi and Rwanda, all of which belong to the Lake Victoria watershed. To underline the importance of the common watershed, Lake Victoria is becoming a point of reference and the emblem for an integrated East Africa. In 2016, the EAC was extended to South Sudan, which is an important downstream country of the Lake Victoria basin.

Population and urbanization: In close cooperation with more developed nations and across the African continent, investments in education, accelerate across all class levels from primary to tertiary education. Teacher training targeted to address local challenges in achieving school completion of secondary level for all, small class sizes of maximum 20 pupils/students, and well-equipped schools provide a solid foundation for achieving a high educational attainment across the entire population. The close integration and cooperation with regionally important as well as emerging economic sectors is developing into a highly effective means of building up skilled labour in East Africa. High educational attainment of woman is leading to significantly lower population growth compared to the first two decades of the 21st century. The urbanization, planned and carefully managed by the local authorities, makes education and vocational training easier for many.

Economic development: East Africa's sluggish improvement in the standard of living (expressed as per capita GDP) preceding the two decades before 2015 accelerates based on the double thrust of building and strengthening national and transnational institutions together with developing human capital. The latter is realized through the rapid transition to universal access to primary- and

[14]The Sustainable Development Goals Center for Africa (SDGC/A) is an international organization that supports governments, civil society, businesses and academic institutions to accelerate progress towards the achievement of the Sustainable Development Goals (SDGs) in Africa. see https://sdgcafrica.org/

secondary education and an internationally well connected Research & Development sector. The resulting political stability and trust in governance and institutions trigger increased capital investments in the region from both, domestic and international sources.

Infrastructure: Coordinated trans-national infrastructure development plans for electricity, critical internet infrastructure, and road/railway connections between major markets develop into a reliant infrastructure and increasingly attract domestic, regional and foreign direct investments. The resulting inter-connectivity further contributes to East Africa's political stability, reinforcing trust, boosting economic development and triggering further investments.

4.3.2 Water specific elements

Raising awareness of the water sector: The growing evidence that water is both a constraining as well as enabling factor to sustainable socio-economic development raises awareness of the water sector being a crucial element in achieving development aspirations. Awareness across all sectors of society moves the region gradually, but pervasively, to prioritize integrated water resources management towards achieving water security. A shared understanding of water security facilitates the process. Water security follows the UN definition of "Reliable, sustainable and equitable access to water in adequate quantities and of adequate quality for current and future generations and for the environment." The close interrelation of water with food and energy security is a major driver for perceiving water as a pivotal enabler for achieving regional development aspirations. Overcoming economic water scarcity, which is characterised by a lack of infrastructure and capacities to access available physical water resources for human use, a widespread phenomenon in Sub-Sahara Africa, will remain the pre-occupation for the coming decades. Gradually, the EAC region can attract domestic and international infrastructure investment, partly supported by increasing trust that well-educated human capital is available in the region. The economic and political integration of East Africa greatly facilitates integrated water resources management. The Lake Victoria Basin Commission develops into a well-equipped institution that compiles data, harmonises and improves national and regional water policies, strengthens capacities and regional collaboration for sustainable management of water resources.

Surface and groundwater resources: East Africa's physical surface and groundwater resources are plentiful in principle, but unevenly distributed in space and time. Climate change will further increase the variability of water resources and changing water regimes. An increase in temperature and the number of hot days will increase water lost due to evaporation and increase water demand for the different sectors. The credibility of climate projection in terms of changes in precipitation are still highly uncertain, and the region is increasingly preparing for more frequent droughts and floods. This is achieved by adaptation strategies to enhance resilience to climate change such as rainwater harvesting at local and regional levels and increased storage capacities combined with more regulated flows. Although surface water remains the main source for human freshwater withdrawal, the groundwater is increasingly being used and subjected to comprehensive monitoring to ensure sustainable extraction rates.

Water quality plays an increasingly important role over time as urban and industrial wastewater volumes grow with population, higher per capita consumption, urbanization and industrialization. At the same time, diffuse pollution from the agricultural sector increases due to the use of higher rates of agricultural input (fertilizer and pesticides) and increasing livestock numbers.

Agricultural water uses and land use: East Africa's decision makers recognize the importance of the agricultural sector and integrated land use planning and management for achieving by 2050 the vision of food security and sustainable use of land and water resources while safeguarding the environment. Although over time the contribution of agricultural production to economic growth declines as other sectors grow stronger, agriculture remains a corner stone of the economy as supplier of growing supply chain values in agro-industries. Especially in the first decades, the sector is critically important for boosting the economy and providing employment. Against the background of three fourth of the population employed in agriculture today (2017), agro-industrial production is aggressively developed by relying on two cornerstones. First, a series of initiatives support the EAC's agricultural processing industries (food and non-food sector) and stimulate demand for crops, livestock and fish products. Second, farmers gradually increase productivity and are closing yield gaps towards achieving sustainable biophysical production potentials. Irrigation development is a key strategy to protect against climate variability. Policies perceive the agricultural sector along its entire supply and value chains. Accordingly, support and management strategies encompass all elements from 'field to consumption'. This leads to the development of agro-industries based on increasing production of crop and livestock products.

Domestic water use: Population will grow unevenly across the region due to different growth rates between urban and rural areas and migration. Although fertility rates in urban areas are generally lower compared to rural areas, this is offset by migration from rural to urban areas. Domestic water use (drinking water, sanitation and water using appliances) will increase significantly as a result of population growth and higher per-capita consumption levels of a wealthier population. The increasing use of domestic water use is inextricably linked to a higher discharge of wastewater. However, because the city development plans foster increasing population densities in urban areas, it will become more cost-effective to provide both water access and sanitation services. People in urban areas are increasingly likely to be able to afford and pay for improved water services, which allow reducing non-revenue-water to international levels. Investments in faecal sludge management systems in rural and per-urban areas and centralized wastewater treatment facilities are increasingly built in an effort to improve water quality in East Africa. In contrast to rapid changes in urban areas, rural areas are less dynamic. Although migration to urban centres can trigger some loss of indigenous knowledge in the context of sustainable management of natural resources, research aims to broaden the scope and retain part of the traditional knowledge base.

Industry including energy, manufacturing and commerce: Access to electricity will increase because of its dominant role as driver and enabler for achieving the EAC Vision 2050, in particular to improve livelihoods, create employment, increase local productivity and promote manufacturing. Electricity generation capacity will grow faster than overall economic growth. Centralized systems, in particular close to urban conglomerates together with well-interconnected electricity lines and market across the entire EAC increasingly supply affordable electricity for all and more stable power grids (no cuts, stable voltage). In addition, off-grid solar photovoltaic technologies and markets support solar home systems, solar pumping, solar powering of decentralised institutions and mini-grid solutions. Electricity and liquefied petroleum gas will largely replace woody biomass for cooking, with the joint benefit of improving health due to enhanced indoor air quality and reducing deforestation for firewood and charcoal production. After initial production for export markets, oil and gas resources in the Albertine Graben (Uganda) and Turkana oil fields (Kenya), when fully developed supply some of the region's petroleum products requirements.

Despite electricity, being produced more and more by renewable energy sources (solar, wind, geo-thermal) together with increased inter-connectivity within the EAC, thermal energy production capacities will grow in order to cover demand. Together with using regional oil and gas resource, this is likely to absorb major amounts of water both, for cooling power plants and the petroleum industry. There may be scarcity of water locally, which is compensated by diversion from other basins. Possible conflicts are dealt with proactively in accordance with the spirit of integration in the EAC.

The increased local value addition will drive agro-processing, industrialisation, manufacturing and commerce in the EAC countries leading to higher incomes, reduced imports and higher foreign exchange earnings. These developments will gradually absorb the labour force to be released in a more productive agricultural sector. Increasing competition for water across the different sectors are addressed and managed following the practices and principles of Integrated Water Resources Management (IWRM) to develop sound water allocation policies.

4.4 Global scenario narratives and data

This study integrates into the widely applied new parallel process (Moss et al., 2010) developed by the climate change community, which is characterized by a Scenario Matrix Architecture (Van Vuuren et al., 2014). The two main axes of the scenario matrix are:

1) The level of radiative forcing of the climate system as characterised by the Representative Concentration Pathways (RCPs) (Van Vuuren et al., 2011), and
2) A set of alternative plausible trajectories of future demographic and economic development described as Shared Socio-economic Pathways (SSPs) (O'Neill et al., 2015).

Each cell in the matrix combines an SSP with and RCP and represents possible scenarios that combine elements of mitigation and adaptation policy. Various Integrated Assessment Models (IAM) have been used to simulate possible combinations and to quantify resulting GHG emissions dependent on the type, degree and speed of policies implemented. For example, the emissions of an SSP2 world could follow the RCP6.0 trajectory, if only weak climate policies are implemented. With policies that are more ambitious, forcing levels of RCP4.5 or even RCP2.6 could be reached. In contrast, a combination of socio-economic development according to SSP1 in combination with RCP8.5 or RCP6.0 is not possible to occur.

4.4.1 Climate change in the Representative Concentration Pathways

Four RCPs[15] are used in the IPCC process to characterize the magnitude of future radiative forcing (climate forcing) and resulting rate of climate change. They range from a target level of radiative forcing for the year 2100 of 2.6 Wm^{-2} to 8.5 Wm^{-2} (Table 4-6).

"*Global surface temperature changes for the end of the 21st century is likely to exceed 1.5°C relative to 1850-1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6.* " Source: (IPCC, 2013)

This study makes use of existing future climate quantifications of five Global Circulation Models (GCMs) based on the four RCPs. GCM outputs were processed in the context of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Hempel et al., 2013, Warszawski et al., 2014) for bias-correction and geospatial harmonization at 0.5-degree latitude/longitude.

[15] The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). Radiative forcing or climate forcing is the difference between insolation (sunlight) absorbed by the Earth and energy radiated back to space. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy will cause warming.

Table 4-6. Characteristics of the Representative Concentration Pathways (RCPs)

Name	Radiative forcing[1]	AR5 global warming[2]	CO_2 concentrations[3] (ppm)			
		Mean change and likely range in temperature change by 2081-2100 [degree Celsius]	2030	2050	2080	2100
RCP2.6	Peak of 3 Wm^2 declining to 2.6 Wm^{-2} by 2100	1.0 (0.3 to 1.7)	431	443	432	421[4]
RCP4.5	Peak around 2040, then decline to 4.5 Wm^{-2} by 2100	1.8 (1.1 to 2.6)	435	487	531	538
RCP6.0	Peak around 2060, then decline to 6 Wm^{-2} by 2100	2.2 (1.3 to 3.1)	429	478	594	670
RCP8.5	Rising to 8.5 Wm^{-2} by 2100 and thereafter	3.7 (2.6 to 4.8)	449	571	758	936

1 Source: (Moss et al., 2010) **2** The figure provides mean change and likely range in global mean surface temperature changes for the period 2081-2100 relative to 1986-2005. The observed warming until the reference period 1986-2005 is 0.61 [0.55 to 0.67] degree Celsius from 1850-1900. Source: (Stocker (Ed.), 2014);**3** Source: (Meinshausen et al., 2011); **4** Peak before 2100 and then decline.

The RCP2.6 emission concentration pathway aims to limit the increase of global mean temperature to 2°C. These scenarios form the low end of the scenario literature in terms of emissions and radiative forcing. RCP2.6 is close the ambitions of the Paris agreement (UNFCC, 2015), i.e., to put the world on track to avoid dangerous climate change by limiting global warming to *well below* 2°C.

RCP4.5 and RCP6.0 are scenarios in which total radiative forcing is stabilized shortly after 2100 (although at different levels) and mean temperature anomalies over pre-industrial levels increase by some 1.8°C and 2.2°C respectively. While deviating from each other in 2100, these RCPs are characterized by quite similar forcing levels at mid-century in 2050. RCP8.5 is characterized by increasing GHG concentrations throughout this century (and beyond 2100), leading to the highest GHG concentration levels and global mean temperature increases of nearly 4°C in 2100.

The corresponding atmospheric concentrations of carbon dioxide in 2100 range between 420 ppm (in RCP2.6) and over 930 ppm (in RCP8.5). For comparison, the current carbon dioxide concentration in the atmosphere is at 409 ppm, up from about 300 ppm at the end of the 19th century. Thus, for the RCP2.6 pathway, CO2 concentrations in 2050 are about 30 ppm higher than current levels. For comparison, between 1959 and 2008 measurements at Mauna Loa showed an annual average growth rate of 1.4 ppm per year (Keeling et al., 2009).

4.4.2 Shared Socio-economic pathways (SSPs)

The Shared Socio-Economic Pathways (SSPs) (O'Neill et al., 2015) describe plausible trajectories of future demographic and economic development and characterize in broad terms the international setting (e.g. trade liberalization), technological progress and priorities in land use regulation. The SSPs provide a set of five storylines on possible trajectories for human development and global environmental change during the 21st century. They have been developed over several years as a joint community effort and form part of a larger set of community scenarios for analysis of climate change, global environmental change and sustainable development issues (van Vuuren et al., 2017). For each scenario quantitative descriptions for key scenario drivers such as population (Samir and Lutz, 2014), urbanization (Jiang and O'Neill, 2015), economic growth prospects (Dellink et al., 2015), have been compiled for harmonization and inter-comparability among ongoing integrated assessments, climate change impacts and adaptation studies. Quantified scenario drivers can be accessed and are available online in the SSP Web-database[16](IIASA, 2016).

This study analyses two of the five[17] SSP scenarios. Box 1 summarizes basic elements of the narratives. The 'Middle of the Road' Scenario (SSP2) largely maintains business-as-usual trends, uses a medium population growth, generates economic and food security improvements in all regions, but cannot achieve agreed climate targets. The Scenario 'Sustainability - Taking the green road' (SSP1), is the only possible pathway that can most likely meet the recently agreed Sustainable Development Goals. Elsewhere we have scrutinized each SSP narrative for developments relevant for water to indicate some implications this may have for water use in each sector(Wada et al., 2016).

***Box 1. Narrative for SSP1 and SSP2** (adapted from (O'Neill et al., 2015))*

SSP1 is a sustainability scenario ("*Sustainability – Taking the green road"*) where the world shifts gradually, but pervasively, toward a more sustainable path, emphasising more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Rapid technological progress facilitates the reduction of resource intensity and fossil-fuel dependency. Consumption is oriented toward low material growth and lower resource and energy intensity. Low-income countries grow more rapidly, inequality between and within economies falls, and technology spreads. Educational and health investments accelerate the demographic transition, leading to a relatively low population. The world has an open trade economy, associated with increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions.

SSP2 is a continuation of current trends scenario ("*Middle of the road*"), where the world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Fossil-fuel dependency decreases slowly. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth.

4.5 Quantification of scenarios drivers

This study analyses two scenarios (Table 4-7). First, the Middle of the Road scenario uses available country-level quantifications from the SSP database. Second, the East Africa regional vision scenario (EA-RVS) applies available quantifications from regional documents. Often regional projections are limited to EAC aggregate numbers or individual future years. As a rule, we use development trends from the country-level quantifications of the SSP1 (Sustainability) scenario to fill gaps required for the period until 2050.

[16] See https://secure.iiasa.ac.at/web-apps/ene/SspDb/

[17] The other three scenarios include SSP3 (Regional rivalry – A rocky road), SSP4 (Inequality – A road divided); SSP5 (Fossil-fueled development – Taking the highway)

Table 4-7. Socio-economic scenarios applied in this study

Scenario	Acronym	Data source
'Middle of the Road' scenario (SSP2) of the Shared Socio-economic Pathways	REF	Global database of Shared Socio-economic Pathways (SSP)
East Africa regional vision scenario	EA-RVS	Regional documents complemented with data from the Sustainability scenario (SSP1) of the SSP database

4.5.1 Demography (Population)

The 'Middle of the Road' Scenario uses available population projections from the SSP database. The EAC Vision scenario applies for 2010 and 2015 population figures from the EAC statistics (EAC, 2016b). The EAC Vision 2050 document assumes for 2030 and 2050 a total population in the EAC of 183 million and 278 million people respectively. Between 2015 and 2050, we adjust the country-level growth rates of the SSP1 scenario so that by 2050 the EAC will reach the 278 million adopted in the EAC Vision 2050 (Table 4-8 and Figure 4-4).

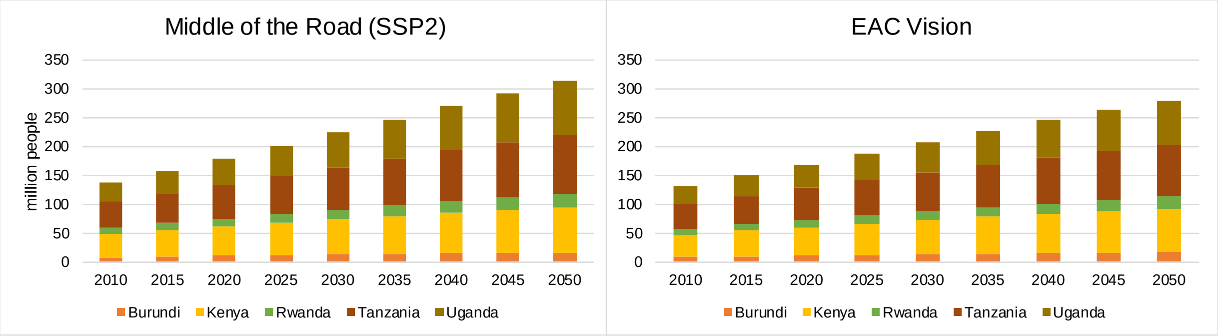
Table 4-8. Population development in the EAC for two scenarios, 2010-2050

Scenario:	Middle of the Road (SSP2)					East Africa Regional Vision (EA-RVS)				
million people	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Burundi	8	11	13	15	17	9	11	14	16	18
Kenya	41	51	61	70	78	39	49	59	68	75
Rwanda	11	14	17	20	23	10	13	15	18	20
Tanzania, UR	45	58	73	88	102	44	55	67	79	89
Uganda	33	45	60	76	93	31*	41	52	65	76
Total EAC	138	179	223	270	313	132	169	207	245	278

***** For Uganda no data were available for 2010 and we estimated 2010 population assuming an annual growth rate of 3% between 2010 and 2015.

Source: (EAC, 2016b, IIASA, 2016)

Figure 4-4. Population development scenarios for the EAC, 2010-2050, by country

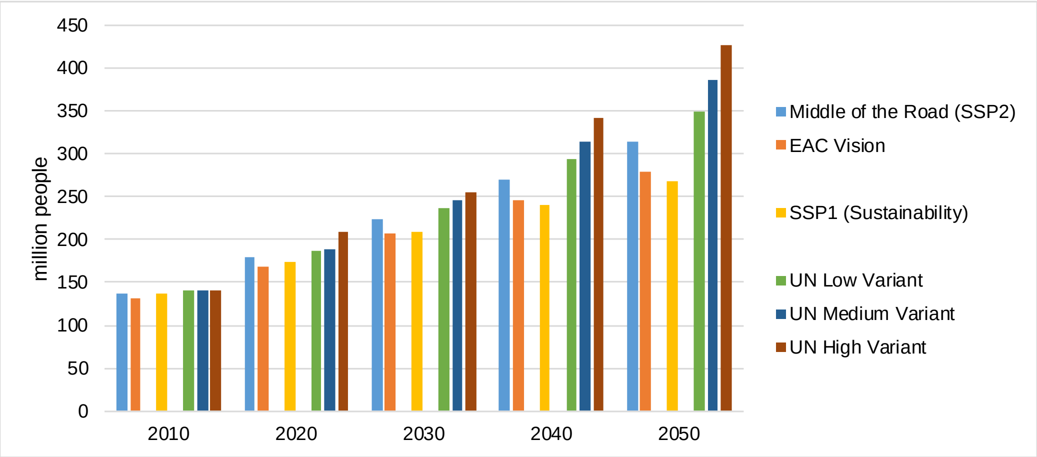


Source: (EAC, 2016b, IIASA, 2016)

In both scenarios, the EAC population more than doubles in the four decades until 2050, despite of a significant decrease in annual population growth rates over time. For the EAC, between 2010 and 2015, average annual population growth is 2.9% in the 'Middle of the Road' and 2.8% in the EAC Vision scenario. The same figures for 2045-2050 amount to 1.5% (Middle of the Road) and 1.2% (EAC Vision). The low future annual growth rates imply a strong decline in fertility rates, closely correlated with a strong increase in educational attainment of woman. Lower population figures in 2010 and lower annual growth rates result in 34 million people less in the EAC Vision scenario compared to the 313 million people in the 'Middle of the Road' Scenario.

The UN provides another source of population projections. Figure 4-5 shows a comprehensive summary of the projections used in this study, SSP2 and EAC Vision, and those projected by UN and SSP1 (Sustainability in the SSP). The UN projects for all its variants higher population figures for the EAC compared to both scenarios used in this analysis.

Figure 4-5. Population development scenarios for the EAC, 2010-2050, by data source



Source: (EAC, 2016b, IIASA, 2016, UN, 2017)

4.5.2 Economics (GDP per capita)

The EAC Vision 2050 articulates the dreams and aspirations of the Eat African people. A key rational for the Vision 2050 is to provide a catalyst for the region to enhance transformation for growth and development and move East Africa to an "***upper-middle income region*** *within a secure and politically united East Africa based on the principles of inclusiveness and accountability" (EAC, 2016a)*. According to most recent data of the World Bank (June 2017[18]), Burundi, Rwanda, Tanzania and Uganda are low-income countries, and Kenya has reached the status of a lower middle-income economy. Some 31 countries are grouped in the low-income category. Except Afghanistan and Haiti, all are located in sub-Saharan Africa. Over 50 countries grouped into lower-middle income countries are found throughout the world. Another more than 50 countries have reached today the status of the EAC envisioned upper-middle income status. They include Mexico, South Africa, Turkey, Brazil, or Russia, to name a few.

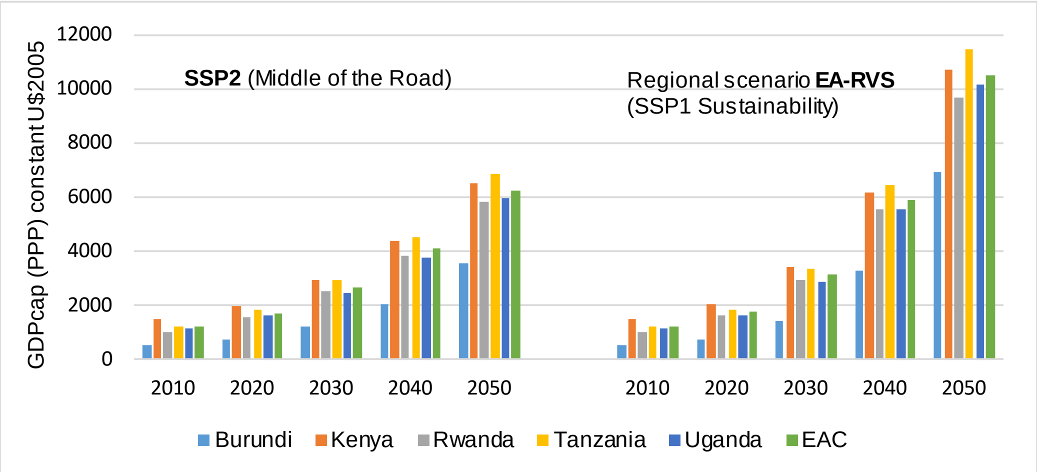
[18]For operational and analytical purposes, economies are divided among income groups according to 2016 gross national income (GNI) per capita, calculated using the World Bank Atlas method. The groups are: low income, US$1,005 or less; lower middle income, US$1,006–3,955; upper middle income, US$3,956–12,235; and high income, US$12,236 or more.

The aspiration to become an upper-middle income region is expressed quantitatively by setting targets for per capita GDP in the EAC for 2030 and 2050[19]. GDP per capita (GDP_{cap}) is expected to increase from 1014 US$ in 2014 to 10,000 US$ in 2050(EAC, 2016a). Though not stated explicitly we may assume that GDP_{cap} for 2030 and 2050 refer to GDP at constant prices (i.e. real GDP) measured in 2014 US$. Therefore, the 8.9 fold increase in GDP_{cap} over the 36-year period, indicates an annual increase of 6.56%.

Water demand models are forced by GDP_{cap} measured in purchasing power parity (PPP[20]). GDP (PPP) and population are reported in the SSP scenario database (see 4.3.2). Between 2015 and 2050, GDP_{cap} in the Sustainability Scenario of the SSP database grows at an annual rate of 5.85 % for the EAC, only somewhat lower than the 6.56 % in the Vision 2050. Because the Vision 2050 document does not provide country-level GDP_{cap} and the annual growth rates in GDP_{cap} are very similar, we apply the SSP1 GDP_{cap} for the regional EA-RVS scenario.

Figure 4-6 summarizes GDP_{cap} development until 2050 for the two scenarios analysed in this study. Kenya and Tanzania are leading the growth path, followed by Rwanda and Uganda. Burundi's GDP_{cap} grows from the lowest level in 2010 by a factor of 7 (SSP2) and 13 (EA-RVS) in the 40 years until 2050. However, the country remains the poorest economy, even by 2050.

Figure 4-6. GDP per capita (PPP) for the EAC countries, 2010-2050 by scenario



Source: (Dellink et al., 2015, O'Neill et al., 2015, IIASA, 2016)

Note that scenarios on GDP_{cap} growth are subject to uncertainties not only related to the general challenge of forecasting economic development but also to uncertainties related to inflation and ratios of purchasing power parities. Trends in individual countries may also diverge from assumed development pathways with effects in both directions. For example, catastrophic events or war may disrupt positive development paths. On the other hand, (unforeseen) institutional reforms towards high trust and stability may help countries improving their socio-economic performance faster than anticipated.

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[19] Table 10 in Vision 2050 lists GDP per capita for 2014 (US$ 1,014), 2030 (US$ 3,000), and 2050 (US$ 10,000).
[20] Purchasing Power Parity (PPP) is measured by finding the values (in USD) of a basket of consumer goods that are present in each country (such as pineapple juice, pencils, etc.).If that basket costs US$ 100 in the US and US$200 in the United Kingdom, then the purchasing power parity exchange rate is 1:2.

4.5.3 Agricultural sector

The expansion of irrigated area is the most influential factor for the estimation of agricultural water use. Based on the regional irrigation targets described in section 4.1.5, two approaches can be derived for estimating areas actually irrigated by 2030 (Table 4-9). One of them, according to the EAC's 'Agricultural and Rural Development Strategy (2005-2030)', is to assume for each country that 20% of the irrigation potential will be actually irrigated. The second approach is to increase the extents of irrigated areas by 100%, as specified in the 'African Water Vision 2025'. The base year for both studies is not explicitly mentioned, but likely around the year 2000. Here we assume however the most recent data on area equipped for irrigation of the FAO country facts sheets as base year conditions. Furthermore, we propose to use the higher of the two values to estimate the area actually irrigated by 2030 (5th column in Table 4-9). By 2050, we simply assume a further doubling of the 2030 extents of irrigated areas.

Table 4-9. Projections for irrigated area in EAC countries

in 1000 ha			**Area actually irrigated**			
			by 2030			**by 2050**
	Irrigation potential[1]	Area equipped for irrigation[2]	20% of potential	100% increase of 2000 status	**Max. Value**	**doubling of 2030**
Burundi	215	21	43	43	**43**	**86**
Kenya	1,341	151	268	301	**301**	**602**
Rwanda	165	10	33	19	**33**	**66**
Tanzania	2,132	364	426	727	**727**	**1,454**
Uganda	567	11	113	22	**113**	**227**
Total (EAC)	4,420	556	884	1,113	**1,218**	**2,435**

1 Irrigation potential extracted from country profiles **2** According to country fact sheets of most recent years, i.e. between 2000 (Burundi) and 2013 (Tanzania);
Source for 1 and 2: FAO AQUASTAT.

Water demand estimations require areas *actually* irrigated. Though FAOSTAT includes the item 'actually irrigated areas', country data are scarce and incomplete. Often countries do not report actually irrigated areas.

For comparison, except Burundi, all EAC countries have developed water or irrigation master plans. Some of them include physical areas of future irrigated land. Kenya's National Water Master Plan 2030[21] follows the Kenya Vision 2030[22] target to increase the irrigation area to 1200 thousand hectares. The 'Project on the Revision of the National Irrigation Master Plan in the United Republic of Tanzania' (JICA, 2018) projects for 2025 and 2035, irrigable areas of 672 and 1017 thousand hectares respectively. The 'National Irrigation Master Plan for Uganda (2010-2035) (MWE, 2011) projects some 233 thousand hectares to be developed for irrigation by 2035.

Others, like the Rwanda Irrigation Master Plan (Maimbo et al., 2010) focuses on potential irrigation areas rather than presenting plans for future irrigated areas. In this plan, the estimated national irrigation potential amounts to almost 590 thousand hectares. However, this potential refers to areas of water resources including lake water resources (100 thousand ha) and marshlands (219 thousand ha), rather than agricultural areas that could potentially be irrigated.

Irrigation water demand depends in addition to the extents of irrigation areas, as well on climate specific crop water deficits and irrigation efficiency. While crop water deficits are calculated endogenously in CWATM-ECHCO, the modelling system requires assumptions on irrigation efficiency. Irrigation efficiency measures the effectiveness of irrigation, which takes into account losses during

[21] Kenya: National Water Master Plan 2030, see https://wasreb.go.ke/national-water-master-plan-2030/
[22] Kenya Vision 2030, see https://vision2030.go.ke/about-vision-2030/

water application in irrigation systems (flood, sprinkler, and drip) and management practices at plot level.

The current irrigation efficiency level and irrigation system distribution in each sub-basin for the base year (2010) are assumed similar to the corresponding country-level data as reported by the AQUASTAT database (FAO online resource[23]). The maximum theoretical efficiency of irrigation systems at plot level is taken from Phocaides (2007), and further adjusted in order to match with the current overall irrigation efficiency in each sub-basin. For the period 2020-2050, changes in irrigation efficiency are projected based on exogenous assumptions from the study of Hanasaki et al. (2013), which quantified water efficiency improvements under the SSP scenarios. The assumptions are translated into the ECHO model as a 0.15% per year improvement in efficiency in the REF scenario, and a 0.30% per year improvement in the EA-RVS scenario.

For livestock, we assume livestock water demand equals consumption. Lacking development trends of livestock herds, we assume as a first approximation that future livestock numbers grow in relation to scenario specific population growth.

4.5.4 Energy sector

The EA-RVS scenario assumes the 7.6% annual electricity growth rates for East Africa published by the International Energy Agency (see section 4.1.6). The IEA indicates this growth rate for the period of 2010 to 2040. It is assumed that there is no change of this trend for the last decade to 2050. The same growth rate is applied for both, the projection of the installed electricity generation capacity and also for the per capita consumption.

Table 4-10. Installed electricity generation capacity in the EA-RVS Scenario

Megawatt [MW]	2010	Status (2014)	2020	2030	2040	2050
Burundi	40	54	84	175	364	757
Kenya	1,592	2,134	3,311	6,888	14,329	29,808
Rwanda	167	224	347	722	1,501	3,123
Tanzania, UR	1,000	1,340	2,080	4,326	9,000	18,722
Uganda	596	799	1,239	2,578	5,363	11,156
Total EAC	**3,394**	**4,550**	**7,061**	**14,689**	**30,557**	**63,567**

Table 4-11. Per capita electricity consumption in the EA-RVS Scenario

[kWh/per capita]	2010	**Status** (2010-2013)	2020	2030	2040	2050
Burundi	21	23	44	93	192	400
Kenya	135	168	281	584	1,214	2,526
Rwanda	69	80	144	299	622	1,294
Tanzania, UR	71	89	149	309	643	1,338
Uganda	62	62	129	268	558	1,161
Total EAC	**82**	**102**	**170**	**354**	**737**	**1,533**

[23] http://www.fao.org/nr/water/aquastat/data/query/index.html

5 Scenario results – "*What can models tell us?*

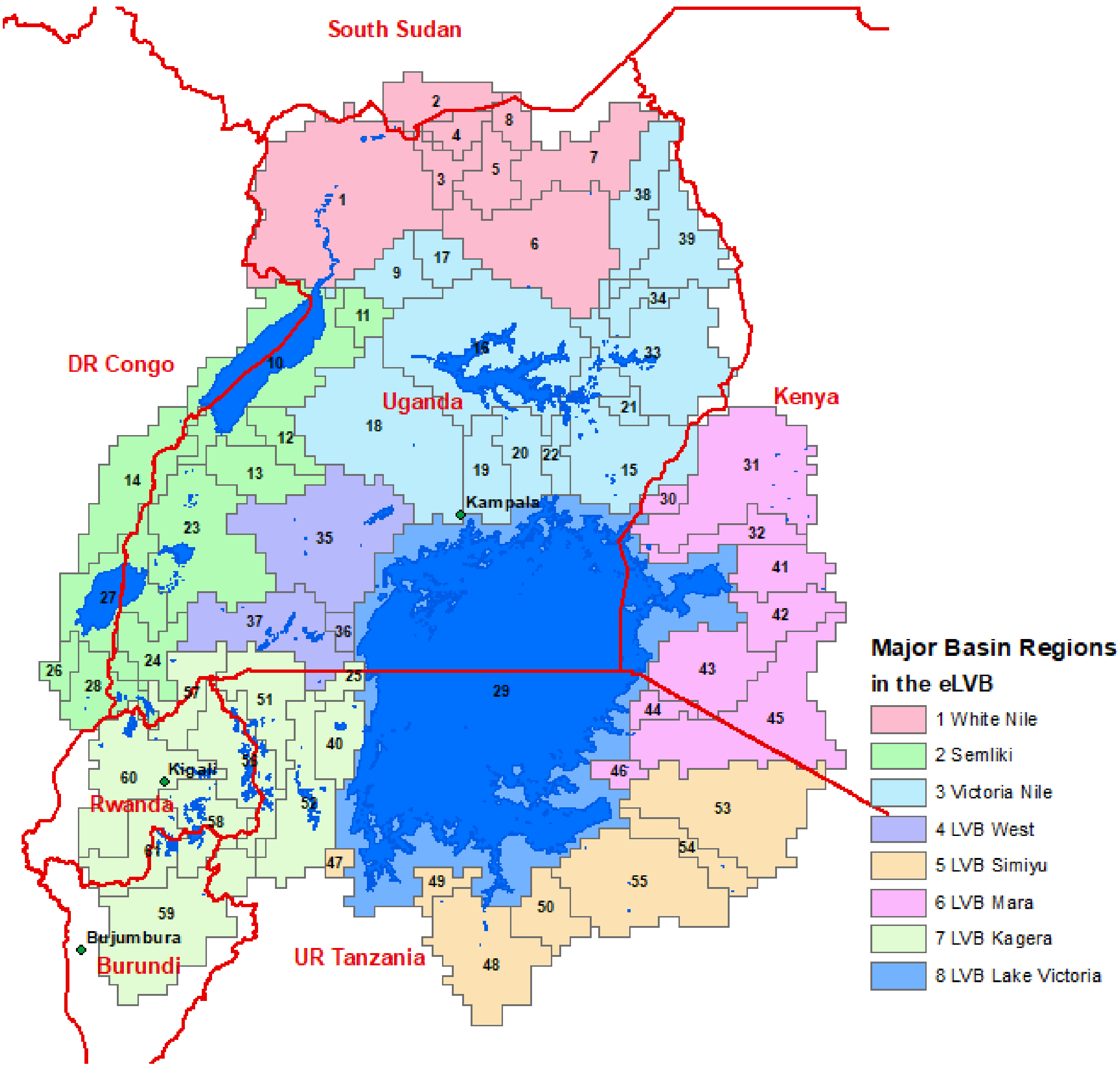
5.1 The extended Lake Victoria Basins (eLVB)

5.1.1 A transboundary basin in the tropics

The study area of the extended Lake Victoria Basin (eLVB) is a transboundary basin in the tropics. It encompasses the upper Nile Basin of the African Great Lakes region and includes an area of over 460 thousand km^2. The equator crosses the region approximately in the middle of the eLVB just south of Kampala. The eLVB includes the source of the Nile, major lakes in East Africa, foremost Lake Victoria, Lake Albert, Lake Edward and Kyoga Lake.

Using a detailed digital elevation model, the eLVB has been subdivided into 61 interconnected sub-basins. According to the water flow regime, we have aggregated the 61 basins to eight major basins shown in Figure 5-1. All but one are named after large rivers. Figure 5-2 shows the interconnection of the 61 sub-basins and indicates the aggregation to the eight major basins.

Figure 5-1. The 61 sub-basins of the eLVB and their aggregation to 8 major basin regions



Four of the eight major basin regions, namely the 'LVB West' (Uganda), 'LVB Mara' (Kenya), 'LVB Simiyu' (Tanzania), and 'LVB Kagera' (Burundi, Rwanda, Tanzania) drain into the Lake Victoria. Together with LVB Lake Victoria, these form the Lake Victoria Basin (LVB). Each of the sub-basins in LVB West, LVB Mara and LVB Simiyu drains into Lake Victoria. The 'LVB Kagera' is the largest single inflow into Lake Victoria and flows into the Lake at the southern fringe of Uganda. The source of the Kagera River is Lake Rweru, into which the river Nyabarongo (Rwanda) flows. The Kagera River flows out of the lake along Rwanda's and later Tanzania's border until it joins the Ruvubu River.

Close to Jinja, located on the northern shores of Lake Victoria, the source of the White Nile, the river flows through Lake Kyoga to the outlet of the sub-basin 'Victoria Nile' at the northern shores of Lake Albert. The Victoria Nile outlet joins here the outlet of the Semliki sub-basin with its headwaters in the DR Congo. Semliki sub-basin includes Lake Edward and Lake Albert. The 'White Nile' covers the northernmost downstream sub-basin of the eLVB including a smaller area in South Sudan. It includes the outlet of the entire eLVB, located at Laropi, a gauging station in the White Nile close to the border of Uganda and South Sudan.

Figure 5-2. Water flow connection of the 61 sub-basins in the eLVB

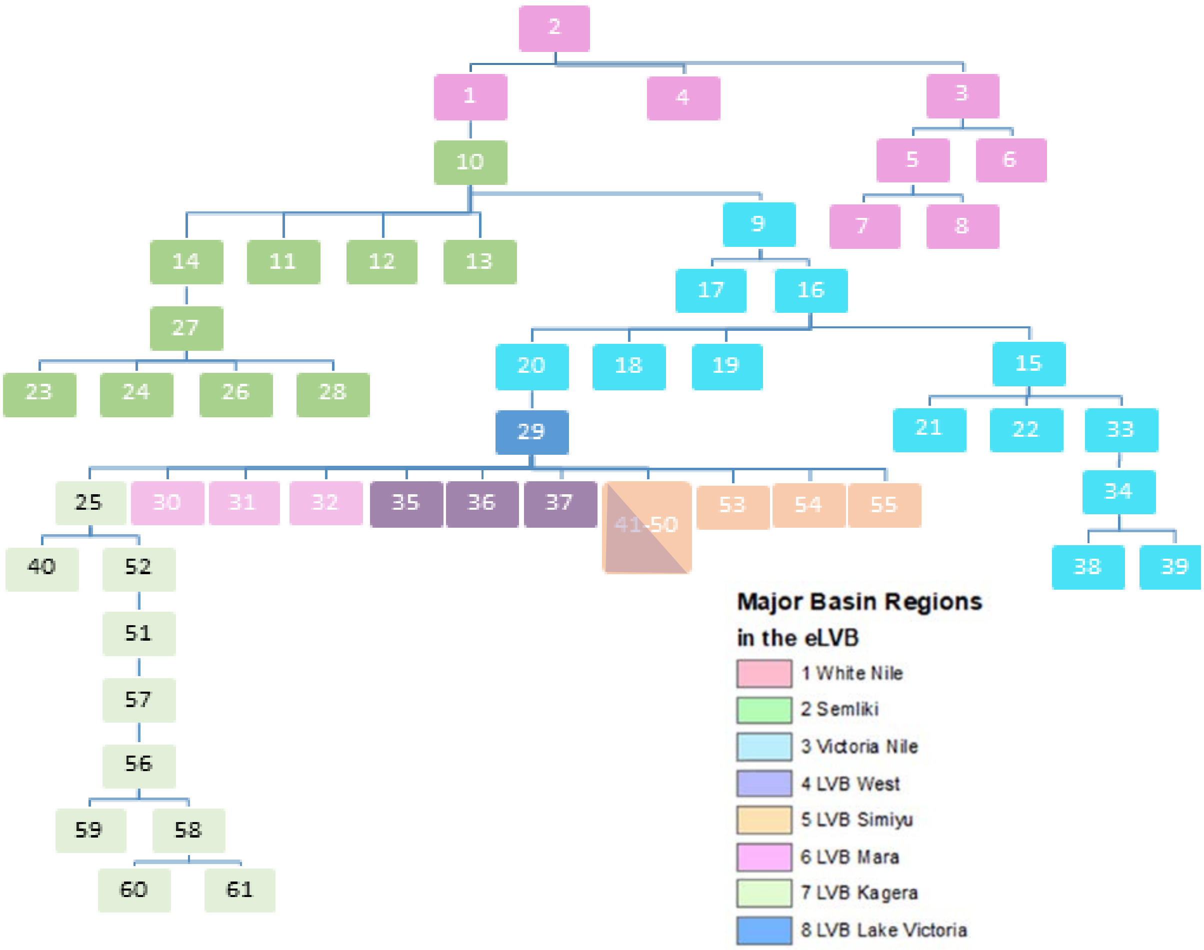
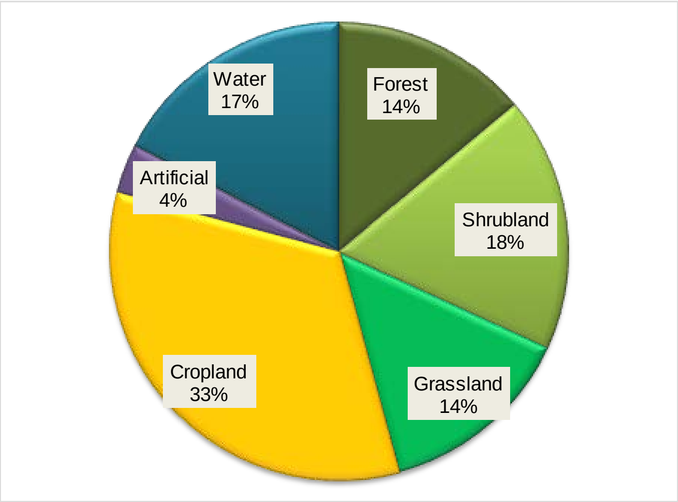


Figure 5-3 and Table 5-1 show the distribution of land use in the eLVB. Water bodies account for almost one fifth (17%) of the land cover (Figure 5-3) in the eLVB including Lake Victoria, the third-largest fresh water lake in the world by area, Lake Albert, Lake Edward. Lake Kyoga, a large shallow lake, is part of the Great Lakes system, but not considered a great lake. Table 5-1 shows the distribution of land use for the eight major basin regions.

Natural vegetation ranges from rainforest to savannah grasses. An estimated 65 thousand km^2 (14%) are covered by forests. In only one fifth of the 61 sub-basins of the eLVB the forest area exceeds 25% of the land area. Half of the sub-basins have a forest cover of less than 15%. Shrub land and grassland cover one third of the area, some of which is used for livestock grazing. Some 4% are artificial areas including urban, residential, infrastructure and industrial areas.

Figure 5-3. Current land cover / use in the eLVB, 2010



Source: GAEZv4 based on GLCCS

Table 5-1. Land cover / use in the eLVB, per major basin, 2010

1000 km^2	Forest	Shrub land	Grassland	Cropland	Artificial	Water	Total
While Nile	6.7	15.3	9.0	21.2	1.4	0.2	54
Semliki	15.8	8.9	4.7	18.0	2.1	8.1	58
Victoria Nile	12.3	18.8	11.5	36.7	3.3	3.4	86
LVB West	3.3	3.6	4.3	10.2	0.9	0.4	23
LVB Simiyu	4.4	11.7	6.0	12.6	1.0	0.2	36
LVB Mara	12.1	7.1	8.0	17.5	2.5	0.1	47
LVB Kagera	4.6	12.6	15.8	26.7	3.6	0.9	64
LVB Lake Victoria	5.3	5.5	4.8	11.7	1.6	67.2	96
Total eLVB	64.5	83.5	64.1	154.7	16.3	80.4	464

Source: GAEZv4 based on GLCCS

One third of the eLVB is cultivated cropland, a dominant land cover of 155 thousand km^2 (15 million hectares). Cropland in the eLVB is intensely cultivated including some areas with two harvests per year. Crop rotations include fallow periods for soil fertility management. However, on average, across the eLVB some 94% of the cropland is harvested (Table 5-2). Only a small fraction of cropland is equipped for irrigation, in total some 500 km^2, mainly for the production of rice, sugarcane and some fruits.

Table 5-2. Cropping intensity in the eLVB, 2010

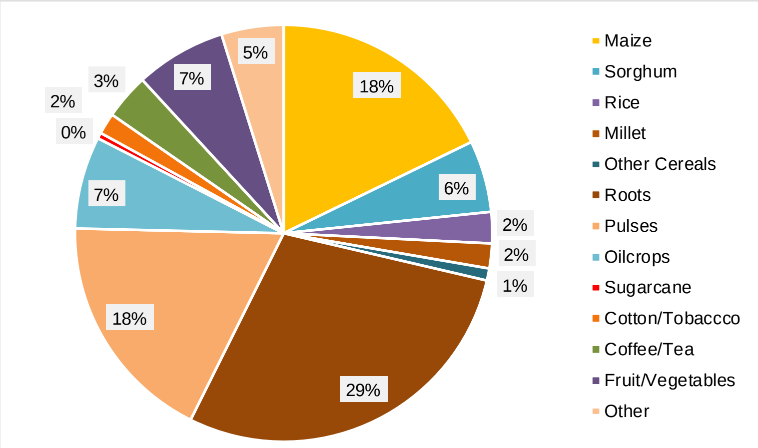
	Cropland	Irrigation	Harvested	Multi-cropping	Share of cropland in total area
	[km^2]	[km^2]	[km^2]	Ratio[1]	[%]
While Nile	21,240	4	17,071	0.80	39
Semliki	18,046	14	16,261	0.90	31
Victoria Nile	36,673	94	30,458	0.83	43
LVB West	10,203	2	8,813	0.86	45
LVB Simiyu	12,591	35	12,972	1.03	35
LVB Mara	17,506	141	19,012	1.09	37
LVB Kagera	26,718	166	29,510	1.10	42
LVB Lake Victoria	11,735	62	11,568	0.99	12
Total eLVB	154,709	518	145,662	0.94	33

1 Ratio of harvested area over cropland

Source: GAEZv4

In 2010, in the eLVB some 146 thousand km^2 were harvested including a wide range of crops (Figure 5-4). About one third of harvested area is for the production of cereals, mainly maize, followed by sorghum, rice and millet. Almost half is harvested for the production of roots (potatoes, cassava, and other) and pulses, main staple foods. Oil crops (mainly groundnuts), fruits, vegetables, coffee, tea and sugarcane are other important crops.

Figure 5-4. Harvested areas in the eLVB, by crop, total = 2010



Source: GAEZv4

Livestock is a key component of the agricultural sector. Livestock breeding in the eLVB include cattle, sheep, and goats, usually grazing on grassland and other herbaceous crops. Chicken is an important source for eggs and meat. Some pigs are raised, mainly Pigs and chicken are important food sources. Table 5-3 lists estimates for number of livestock in the major eLVB sub-basins.

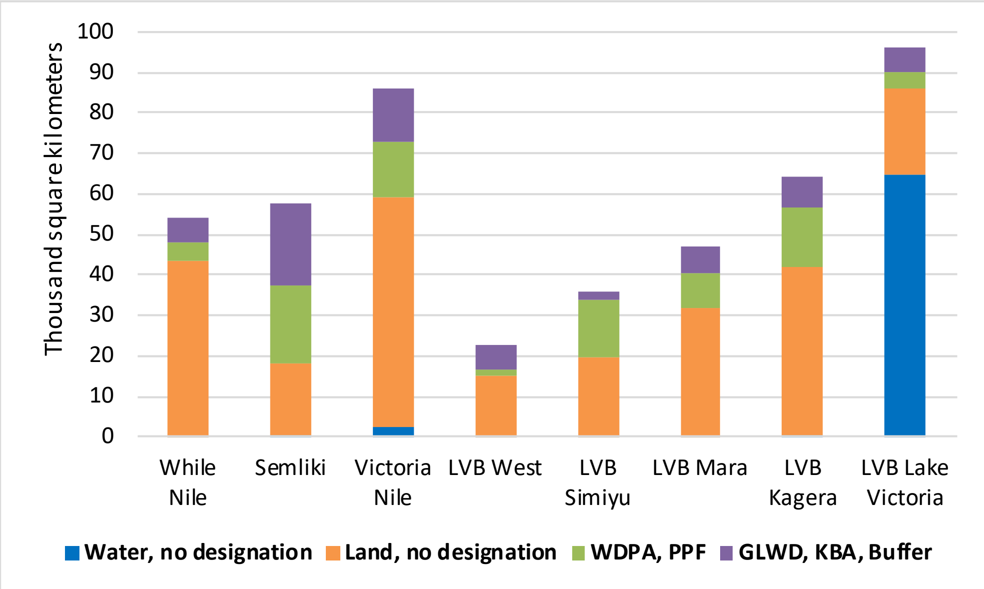
Table 5-3. Livestock in the eLVB, 2010

million heads	Cattle	Sheep	Goat	Pigs	Chicken
While Nile	1.1	0.3	2.0	0.3	5.1
Semliki	4.1	0.8	5.1	0.5	6.5
Victoria Nile	5.6	0.8	4.8	1.2	21.8
LVB West	2.3	0.3	1.5	0.2	3.8
LVB Simiyu	1.3	0.3	0.4	0.0	0.4
LVB Mara	6.1	2.7	2.4	0.1	12.9
LVB Kagera	2.5	1.0	4.5	0.9	7.2
LVB Lake Victoria	5.2	1.1	8.0	0.4	31.3
Total eLVB	27.9	7.2	28.8	3.7	89.0

Source: GAEZv4

The eLVB includes large areas of high environmental value. More than one third (37%) of the land area, i.e. excluding water bodies, is subject to various types of designation and protection zones. This includes areas designated by the World Database of Protected Areas (WDPA), the Peace Park Foundation (PPF), the Global Wetland Database (GLWD), Key Biodiversity Areas (KBA), and smaller extents of buffers around WDPA and PPF. Figure 5-5 shows the distribution of areas designated for the protection of the environment. More than one third (37%) of the eLVB land area is of high value for the environment including numerous designated areas. In Semliki and 'LVB Simiyu' half or more than half of the area is of high importance for the environment.

Figure 5-5. Areas with designations for the protection of the environment in the eLVB, 2010



Designations include WDPA: World Database on Protected Areas; PPF: Protected areas reported by the Peace Park foundation; GLWD: Global Wetland Database; KBA: Key Biodiversity Areas; Buffer: 1km buffer around WDP and PPF.

Source: (Fischer et al., 2019)

5.1.2 Scenario overview and the eLVB 61 sub-basins database

Following the scenario development process (section 4), we have analysed two possible development scenarios for the eLVB (Table 5-4). Each scenario combines a plausible socio-economic development pathway with climate change impacts calculated for the GHG concentration pathway RCP6.0 (i.e. medium climate change).

A Reference Scenario (REF) applies the storyline and quantification of one of the IPCC's Shared Socio-economic Pathways (SSP), the 'Middle of the Road' scenario (SSP2). The East-Africa Regional Vision Scenario (EA-RVS) portrays the vision of the region, as expressed in several vision studies and the first stakeholder workshop of this study. For details on the scenario development process and scenario narrative we refer to section 4.2 (scenario development approach), 4.3 (East Africa Regional Vision Scenario) and 4.4 (Global scenario narrative and data).

The spatially detailed assessments operate on a geospatial grid of 5 by 5 arc-minute resolution (about 9 x 9 km). Selected input data are available on a higher spatial resolution of 30 by 30 arc-second (about 0.9 x 0.9 km). This includes the digital elevation model used to delineate the 61 sub-basins, determine flow directions and coursed of rivers. For 2010 only, high-resolution land use data were available for the tabulation of land use, protected areas and crop production.

Table 5-4. Development scenarios analysed for the eLVB

Scenario	Acronym	Socio-economic development	Climate change
Reference Scenario	**REF**	The 'Middle of the Road' (SSP2) scenario of the Shared Socio-economic Pathways	Ensemble of two Global Circulation Models (MIROC5, HadGEM2-ES) calculated for the emission pathways of RCP 6.0 (i.e. medium climate change)*
East Africa Regional Vision Scenario	**EA-RVS**	Details described in section 4.3; many aspects similar to SSP1 'Sustainability'	

* Note, the database includes as well results for RCP2.6 (lower end of the range of future climate change scenarios).

For presenting results, we tabulate for 61 sub-basins, which were aggregated to eight major sub-basin regions (Figure 5-1). Depending on variable and item, models operate from daily (e.g. hydrology) to monthly (e.g. optimization in hydro-economic) temporal scales. Results are generally presented from 2010 to 2050 in 10-year averages. Thus, results for 2010 represent the period 2005-2014, for 2020 the period 2015-2024, etc.

Results presented in this paper focus on development trends of the eLVB and its eight major sub-basins. In addition, we've compiled a large database including additional results for all 61 sub-basins of the eLVB. It includes numerous bio-physical and socio-economic variables of the eLVB water system aggregated from the CWatM-ECHO scenario model runs. Further, selected variables for land use and agriculture were compiled for the base period 2010.

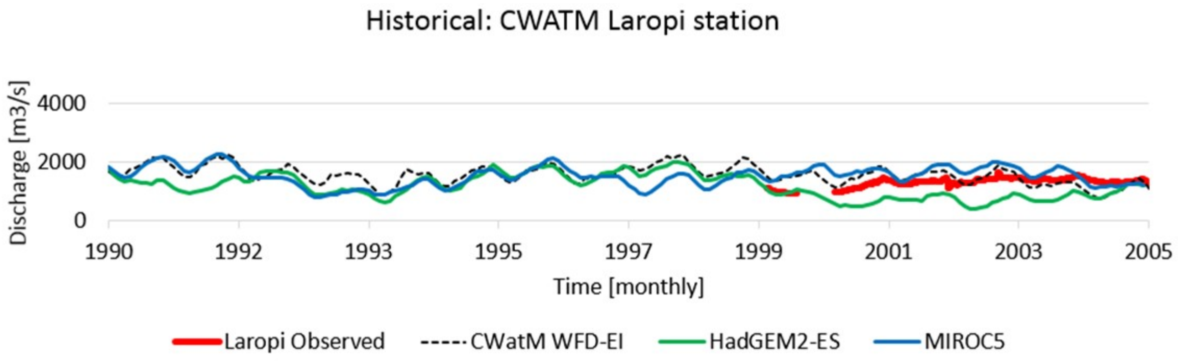
For reasons of readability, we present here only results for one emission pathway scenario, RCP6.0, which refers to a medium range of future climate change scenarios. Using the CWatM hydrological model component, we have also calculated results for RCP2.6, the most ambitious emissions pathway scenario that assumes a significant reduction of greenhouse gases. Both, RCP2.6 and RCP6.0 results are included in the eLVB 61 sub-basins database. A sensitivity analysis of the two emission pathways has been included in the 'joint learning component' of the second stakeholder workshop (Burtscher et al., 2019).

5.2 Climate change impacts on hydrology

As a first step of the analysis, we focus on the impacts of climate change on the eLVB water cycle. We have chosen the Representative Concentrate Pathways RCP6.0 as the most plausible future for East Africa and the two General Circulation Models (GCMs) HadGEM2 and MIROC5 as the most feasible ones. The GCMs GFDL and IPSL were rejected because the precipitation and discharge results for the historical runs showed a large discrepancy to the historical measurements.

Figure 5-6 compares measured discharge at Laropi (red line) with CWatM simulations for discharge forced by historical meteorological data (dotted black line). It reveals for the time period 2000 till 2005 (the time period with discharge measurements) a good fit of modelled and measured data. Further, the blue and green lines display CWatM calculations using climate forcing from the historical runs of the GCM's (HadGEM2 and MIROC5). The deviation between the GCM runs and the measured discharge is greater than that of CWatM, triggered by measured meteorological data, but still acceptable for use in further investigations.

Figure 5-6. Comparison between different meteorological forcing for the eLVB



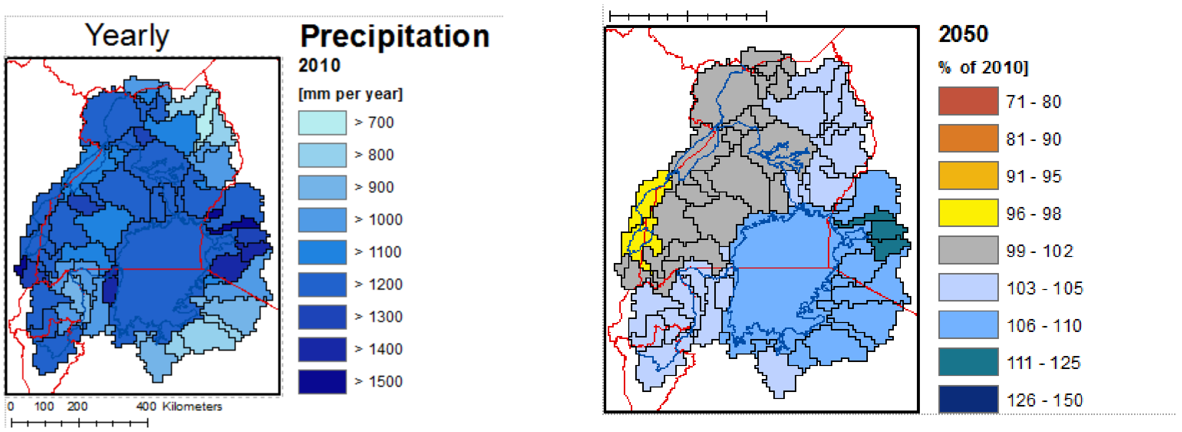
Source: CWatM

5.2.1 Precipitation

To assess the changing pattern of precipitation two time periods are compared. The time period 2010 represents average precipitation for the time span 2005 to 2014 for two GCMs and the second period 2050 is average of the period 2045 to 2054. For reasons of readability and to emphasis the spatial inhomogeneity we have aggregated the gird-cell data to average precipitation for each of the 61 sub-basins.

Figure 5-7 is showing the average precipitation of the period 2010 (left part) and the difference in percentage to the time period of 2050 (right part). Less than 100 percent indicates that precipitation is declining, more than 100 percent indicate increasing precipitation. In the coming decades annual precipitation changes hardly in the eLVB. Compared to 2010, by the 2050s, there is only a slight decline in precipitation in eastern Uganda and Congo and a small increase at the eastern and southern parts of the eLVB.

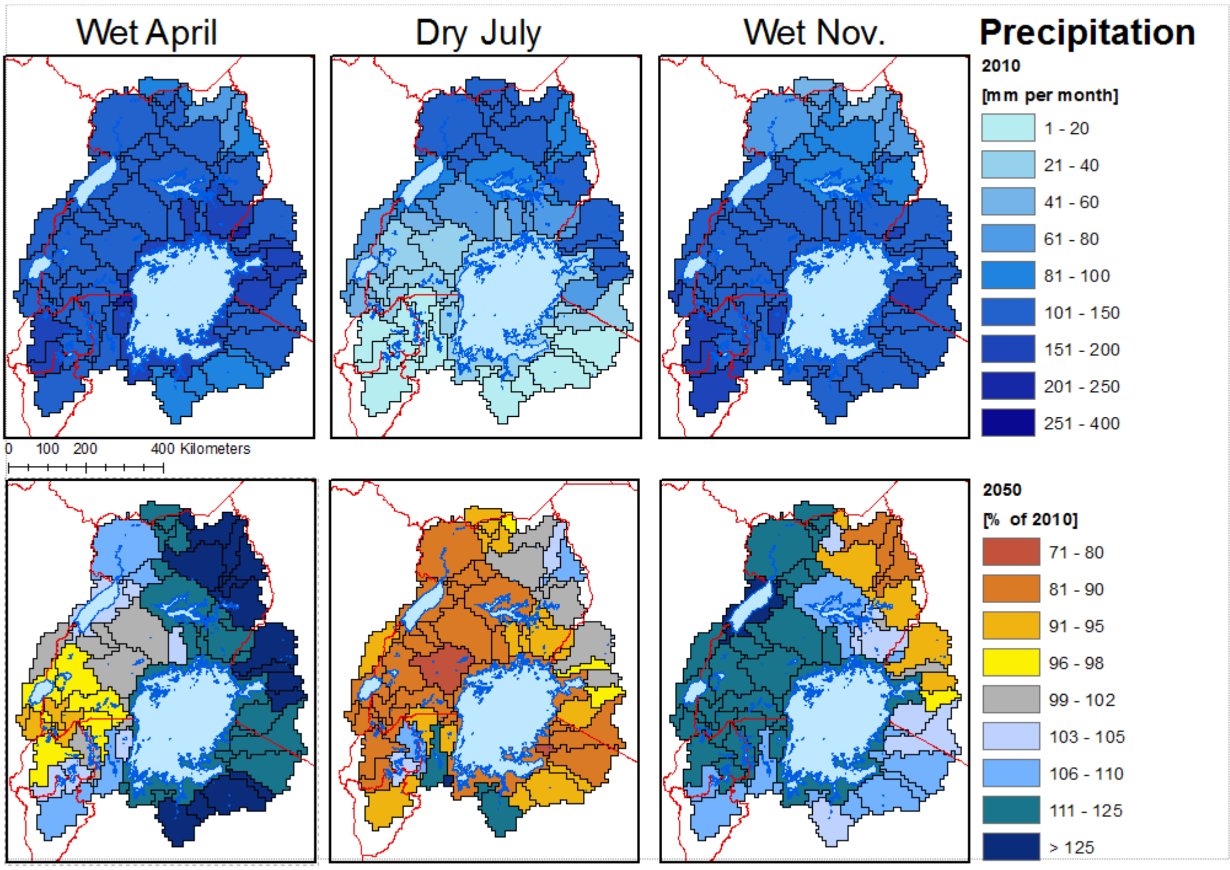
Figure 5-7. Change of yearly precipitation pattern from 2010 to 2050



Source: CWatM

Changes become more pronounced for monthly precipitation. The seasonal pattern in Figure 5-8 shows a wetter first rainy season for the eastern part and a drier rainy season for the south-western part. The dry season (around July) will be dryer for the whole region. The second rainy season (around November) will be dryer in the north-east but wetter in the rest of eLVB. An analysis of daily precipitation highlights that the rainy season tends to start later in the year. By the 2050s the onset of precipitation will have shifted by around 5 to 10 days.

Figure 5-8. Change of seasonal precipitation pattern from 2010 to 2050



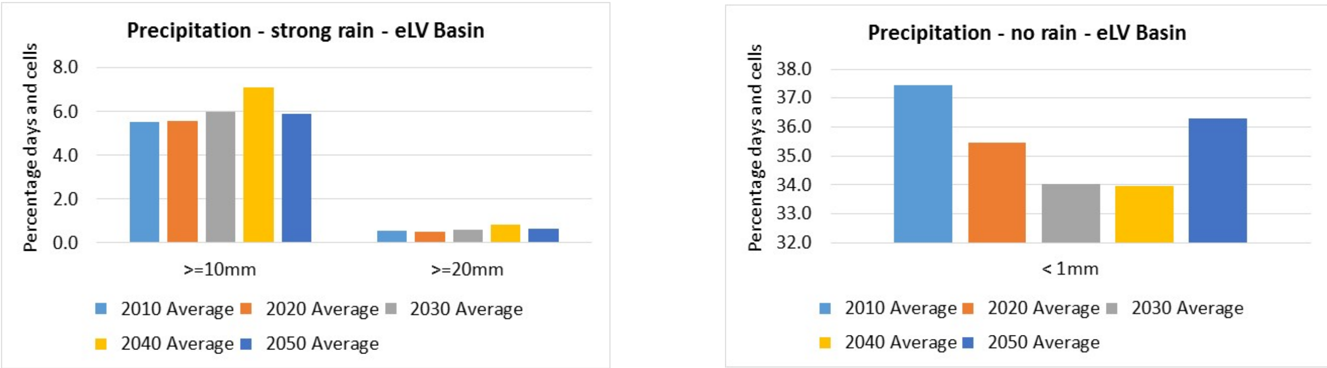
Source: CWatM

Analysis of strong rain and no rain days

To assess whether flood or drought events may be changing between 2010 and 2050, we calculate an indicator for 'strong rain' and 'no rain' as follows. We first represent the sum of all possible events in each of the 61 sub-basins by multiplying the number of grid-cells with the number of days over a ten-year period. Then we count the grid cells in the same time period with rainfall > 10mm, > 20 mm or less than 1mm per day and divide it by the sum of all possible events. For example, 10 percentage days and grid-cells with rainfall events > 10 mm means that in a particular sub basin, on average, in 10% of all days and grid cells rain exceeds 10 mm rainfall. If the number of rainfall events larger than a threshold is increasing from 2010 to 2050 this might be an indicator for increasing flood probability. If the number of days/cells with less rain than 1 mm is increasing, this is an indicator for the region getting dryer.

Figure 5-9 is showing the projection for the entire eLVB until 2050 forced by two GCMs. Until the 2040s, strong rain events (> 10 mm or > 20 mm) increase while low rain events decrease. After 2040, the trend reverses and strong rain events decrease and no rain event increase. This shows that the natural precipitation variability in the lower latitudes is superimposing the effect of climate change.

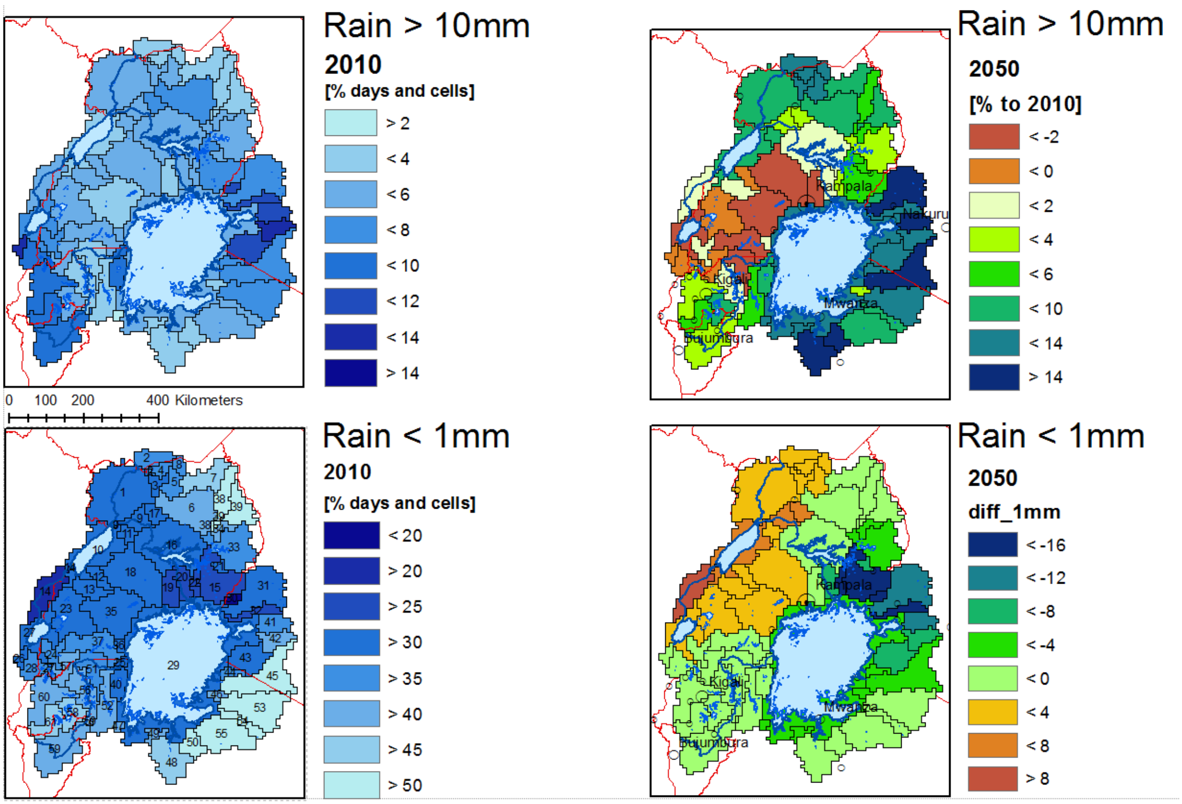
Figure 5-9. Change of days with strong rain and no rain for the eLVB, 2010 to 2050 for RCP6.0



Source: CWatM

Therefore, there is no general trend throughout the eLVB that climate change will lead to an increase or decrease in rainfall. However, But Figure 5-10 highlights that the spatial distribution across the 61 sub basins is changing relatively independent of natural variability. In the eastern eLVB, especially the southeastern part, the probability of strong rainfall events will increase. In the southwestern part including Kampala the chance of strong rainfall events will decrease. For potential drought conditions, between 2010 and 2050, no rainfall events in the eastern part of the eLVB will decrease, indicating a lowering of potential drought. By contrast, in eastern Uganda, the number of 'no rain' days will increase and the risk of droughts will rise.

Figure 5-10. Change of days with strong rain and days with no rain from 2010 to 2050

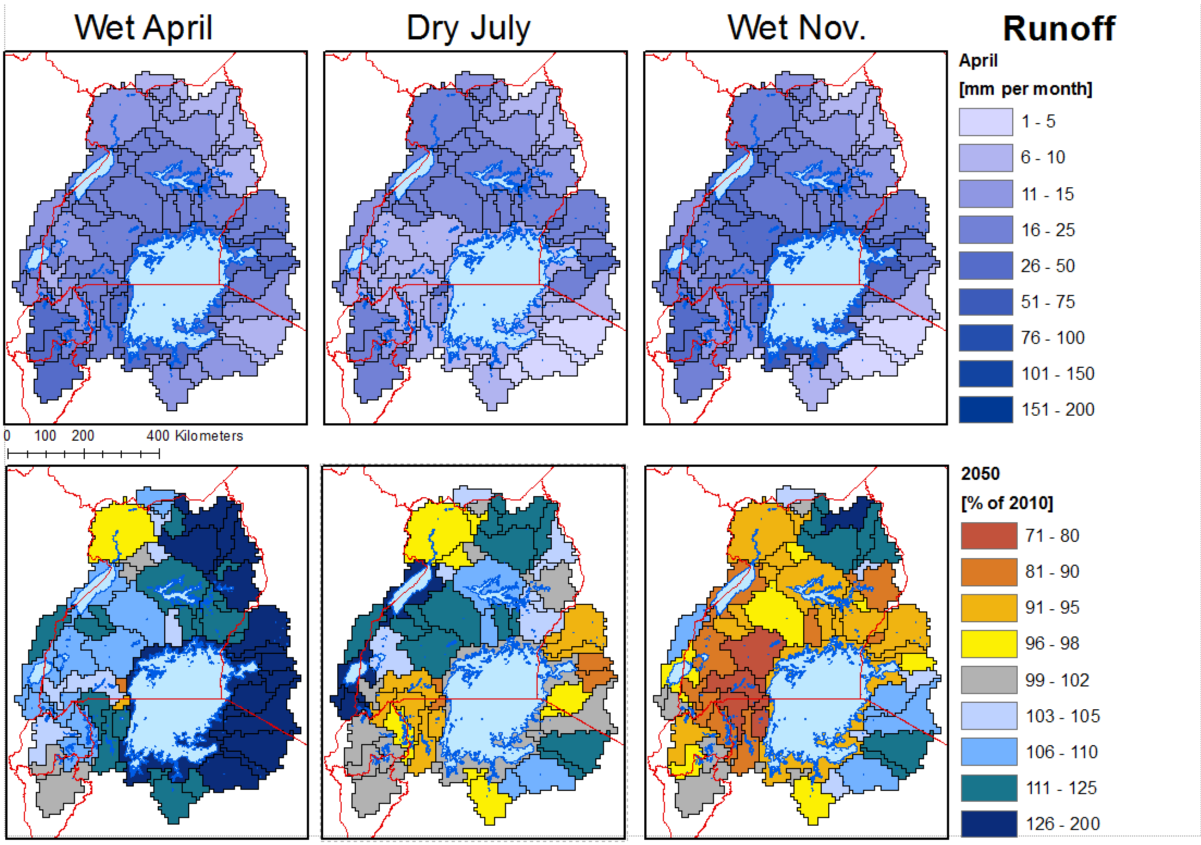


Source: CWatM

5.2.2 Runoff

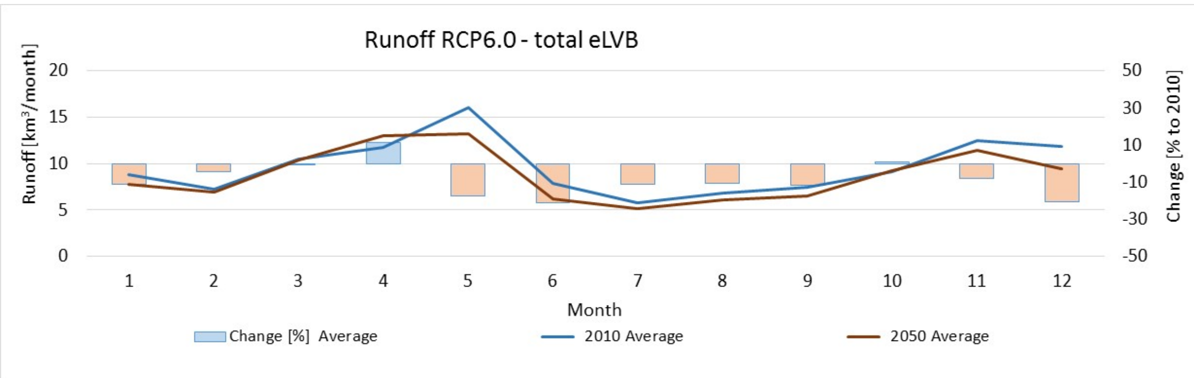
The spatial pattern of change from 2010 to 2050 follows the change in precipitation pattern which means more runoff in the Eastern part for the first rain season. But from May onwards, higher temperatures trigger higher rates of evapotranspiration. As a result runoff is decreasing. Especially the second rainy season will contribute less runoff almost throughout the whole eLVB (Figure 5-11 and Figure 5-12).

Figure 5-11. Change of seasonal runoff pattern from 2010 to 2050



Source: CWatM

Figure 5-12. Change of monthly runoff pattern from 2010 to 2050 for the eLVB



Source: CWatM

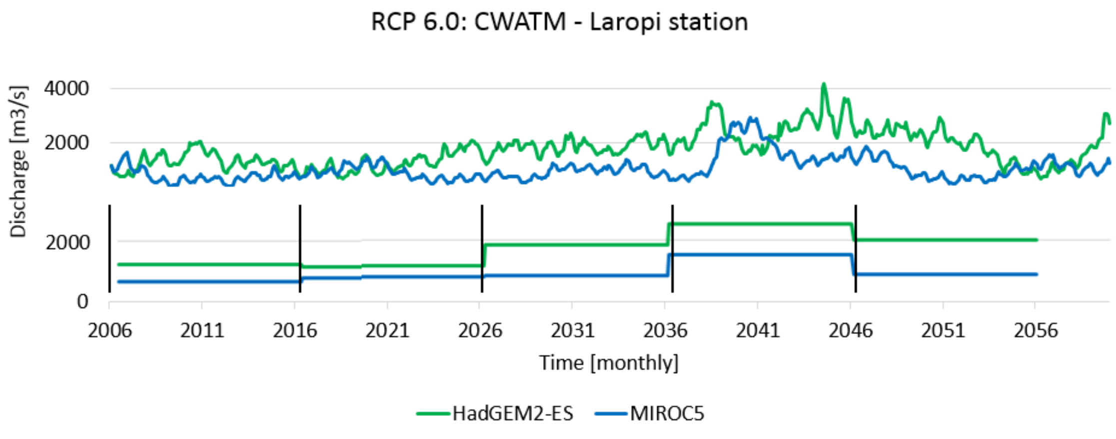
5.2.3 Discharge

Precipitation of one year is relatively independent of the previous year apart from supra-national phenomenon like El Niño effects or stable circulation pattern. Runoff is already depending on different storage conditions like soil moisture and groundwater. These storages show some memory of past conditions e.g. after a dry period it needs some time to replenish the soil storage and even long time to replenish the groundwater storage.

Discharge is the variable which incorporates all the meteorological and hydrological processes in a basin and also encloses all the storage components in a basin i.e. soil, groundwater, lakes and reservoirs, etc. Especially with the large lakes in the basin, discharge in eLVB has a long memory of past conditions.

The two GCM's used here (HadGEM2-ES and MIROC5) as meteorological forcing show both independently a peak discharge in the 2040s (see Figure 5-13). Even if precipitation and runoff in the 2050s is at the same level or lower than in the 2010s, discharge in the 2050s will remain high due to the memory effect of the different storage systems.

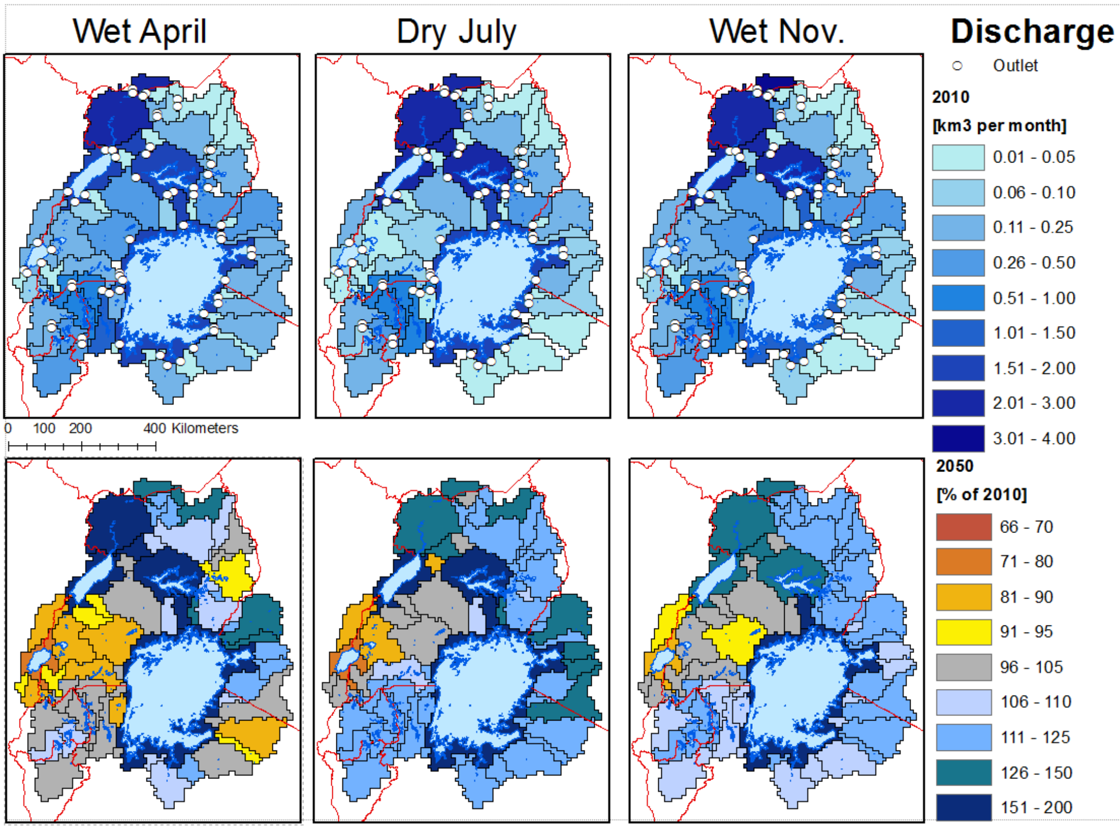
Figure 5-13. Discharge at Laropi station with met forcing from HadGEM2-ES and MIROC5



Source: CWatM

The seasonal pattern of discharge in Figure 5-14 shows more discharge in the river system from Lake Victoria onward. This is due to a wet period in the two GCMs from 2038 to 2049 and the strong memory effect of groundwater and the lakes. It also show the big influence of inter-annual variability in the eLVB. Even if a general trend of less runoff can be detected, still long lasting periods of wetter condition can superimpose this trend. South-western Uganda shows drier conditions. The western part of eLVB shows wetter conditions.

Figure 5-14. Change of seasonal discharge pattern from 2010 to 2050



Source: CWatM

Key messages for climate change impacts

The impact of climate change on the eLVB water cycle is dominated by increasing intra-annual variability in precipitation combined with increasing temperature leading to higher evapotranspiration. Precipitation: Until the 2050s, average annual rainfall remains almost unchanged. However, climate change suggests a seasonal shift in precipitation resulting in more pronounced dry and wet periods. However, there are regional differences in the timing of the seasonal shift. By the 2050s, the dry season (July) will be dryer for the entire eLVB. The rainy season in April will become wetter in the eastern eLVB but drier in the south-western eLVB region. This trend is reversed for the second rainy season in November. Runoff: Consideration of temperature and precipitation change only, i.e. excluding land use changes, suggests that by the 2050s annual average runoff will be lower compared to 2010. This effect is especially pronounced from May onwards when higher temperatures trigger higher rates of evapotranspiration. Discharge: Large lakes in the eLVB store significant amounts of water. Discharge calculations consider in addition to meteorological and hydrological processes, all water storage components (lake, reservoir, groundwater, soil). Compared to today, by the 2050s, climate change will cause a tendency of lower discharge (drier) in the western eLVB and higher discharge (wetter) in the eastern eLVB. Further, there is a shift of a few days towards later discharge peaks in general. However, the high inter-annual climatic variability in precipitation, runoff and discharge in these latitudes is superimposing climate change effects.

5.3 Socio-economic drivers of water demand

Country-level quantifications of socio-economic development, notably demography, economic growth (GDP) (see section 5.2) were downscaled to the 5 x 5 minute resolution eLVB (about 10x10 km). This was achieved by allocating country-level data to available global high-resolution grid-level data of population including urbanization (Jones and O'Neill, 2016) and GDP (Gidden et al., 2018). The resulting rural and urban population and GDP throughout the eLVB were fed into the CWatM-ECHO modelling system to calculate the water demand of the domestic and industrial sector.

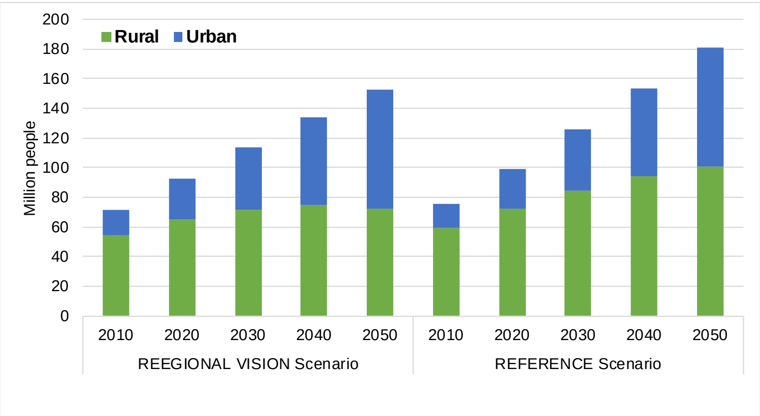
Agricultural water demand includes irrigation and livestock drinking water. Similar to population and GDP, irrigated areas in the eLVB for the base year 2010 were downscaled from the land use model (MAgPIE) (Popp et al., 2014, Stevanović et al., 2016). Increases in irrigated areas until the 2050s were estimated using 5x5 minutes grid-cell data from the WFS-GAEZ modelling system (section 2.4). As a general rule we use SSP2 for REF and if no other data are available SSP1 quantifications for the EA-RVS scenario. Accordingly the WFS-GAEZ model runs for SSP2 and RCP6.0 are used to represent irrigated areas in the REF scenario. For the EA-RVS scenario, the quantifications shown in Table 4-9 are spatially distributed according to the WFS-GAEZ SSP1 and RCP2.6 estimates.

Livestock water demand is estimated for each grid-cell and livestock type as a function of daily drinking requirements and air temperature (Wada et al., 2011, Wada et al., 2014). The distribution of cattle, buffalo, sheep, goats, pigs and poultry were obtained from available grid data for the year 2000 from the FAO (Robinson et al., 2014, Steinfeld et al., 2006). Using the distribution of year 2000 livestock densities, we apply historic livestock statistics (FAO, 2012) to downscale livestock density for the period 1979-2010. Future livestock numbers are estimated in relation to scenario specific population growth and following the spatial distribution of the base year period.

5.3.1 Demography

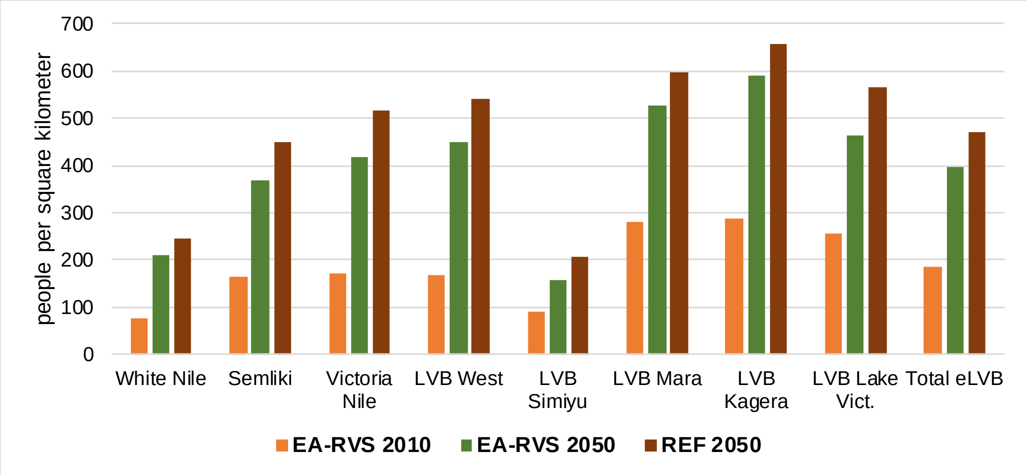
Population is a key driver for human water withdrawal. Between 2010 and 2050, the total population in the eLVB more than doubles. The increase is less pronounced in EA-RVS compared to REF (Figure 5-15). Potential reasons for the lower population number in 2010 in the EA-RVS (75 million) compared to REF have been discussed above (see section 4.1.2). Accordingly, population density in the EA-RVS is already lower in 2010 (154 people per km^2).

Figure 5-15. Demographic development 2010 to 2050 in the eLVB, by Scenario



By 2050, total population in eLVB increases to 153 (EA-RVS) and 181 (REF) million people. Population density increases to between 329 (EA-RVS) and 390 (REF) people per km^2 (Figure 5-16). Increasing population density may increase pressure on the environment. In 2010, some 16 million people live in areas classified as high value for the environment.

Figure 5-16. Population density in the eLVB, 2010 and 2050, by Scenario



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

The base-year urbanization rate of just over 20% increases significantly in the coming decades. The less pronounced population growth in the EA-RVS is associated with a high level of urbanization, which will reach 52% in 2050. Demographic characteristics in terms of urbanization and population density vary by scenario and across the eLVB (Table 5-5 and Table 5-6). The most urbanized watersheds today, LVB Simiyu and LVB Lake Victoria will reach by 2050 urbanization rates of 87% and 72%. Urbanization appears to be especially pronounced in LVB Mara, where the urban population will almost double by the 2050s.

Table 5-5. Demographic development in the eLVB, Regional Vision Scenario

	2010			2050		
	Total population	Population density	Urban population	Total population	Population density	Urban population
	1000 people	Person / km²	%	1000 people	Person / km²	%.
White Nile	4,110	76	12	11,251	209	24
Semliki	8,232	166	27	18,216	368	53
Victoria Nile	14,250	173	21	34,500	418	47
LVB West	3,728	167	3	10,057	450	30
LVB Simiyu	3,827	115	56	6,522	195	87
LVB Mara	13,218	281	20	24,858	528	64
LVB Kagera	16,549	257	16	33,883	529	51
LVB Lake Vict.	7,366	255	45	13,380	463	72
Total eLVB	71,281	186	23	152,666	398	52

Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Table 5-6. Demographic development in the eLVB, Reference Scenario

	2010			2050		
	Total population	Population density	Urban population	Total population	Population density	Urban population
	1000 people	Person / km²	%	1000 people	Person / km²	%
White Nile	4,502	84	10	13,263	247	22
Semliki	8,841	178	25	22,302	450	44
Victoria Nile	15,438	187	18	42,544	515	40
LVB West	4,132	185	3	12,083	540	20
LVB Simiyu	3,746	113	52	8,613	261	87
LVB Mara	13,991	297	18	28,173	598	52
LVB Kagera	17,158	267	14	37,650	584	42
LVB Lake Vict.	7,508	260	41	16,359	566	62
Total eLVB	75,316	197	21	180,989	472	44

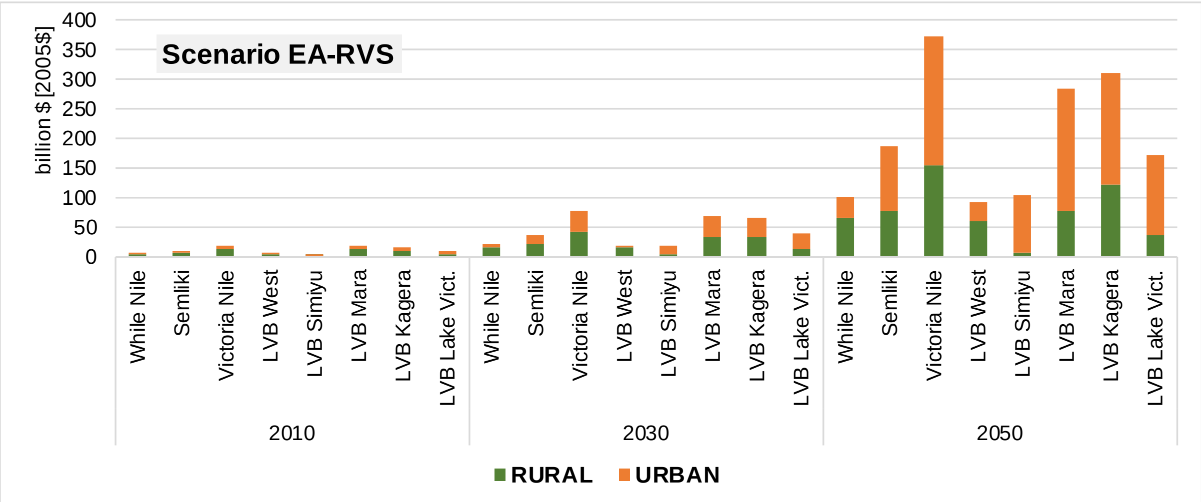
Source: IIASA WFaS East Africa (CWatM-ECHO model system)

5.3.2 Economic development

East Africa's vision of moving the region to an upper-middle income region will increase people's water needs. Higher access rates to drinking water and sanitation will increase domestic water demand. There will be more industries that require water withdrawals for their production processes. A wealthier population will change their diets towards a higher share of livestock protein causing additional demand for agricultural products.

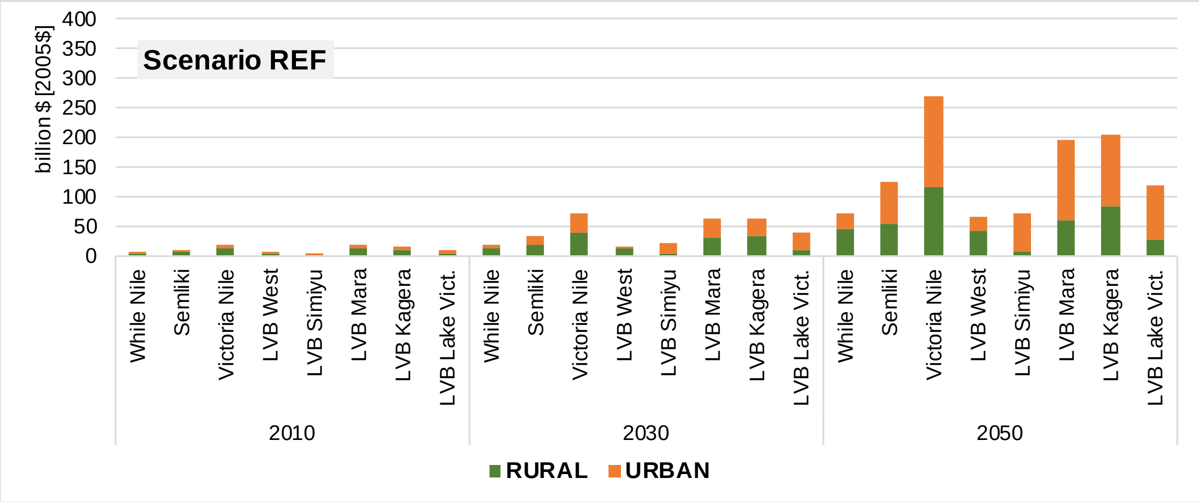
Economic growth in the eLVB is expected to accelerate after the 2030s. This is more pronounced for the EA-RVS scenario (Figure 5-17) compared to REF (Figure 5-18). Over time the urban contribution to GDP increases from about one third (34%) in 2010 to almost two-thirds (61% in REF and 63% in EA-RVS) in the 2050s.

Figure 5-17. Rural and urban GDP development in the eLVB, Scenario EA-RVS



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

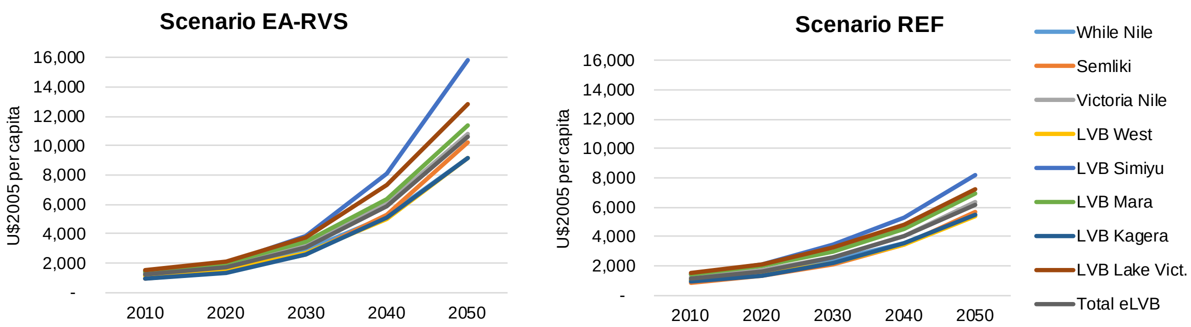
Figure 5-18. Rural and urban GDP development in the eLVB, Scenario REF



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Over the four decades income, expressed as per capita GDP, increases significantly, more in scenario EA-RVS than in REF. In the eLVB as a whole, GDP_{cap} increases almost tenfold for EA-RVS and fivefold for REF. The sub-basin 'LVB Simiyu' shows the most pronounced growth in income, followed by 'LVB lake Victoria' and 'LVB Mara' (Figure 5-19).

Figure 5-19. GPD per capita, 2010 to 2050, by Scenario

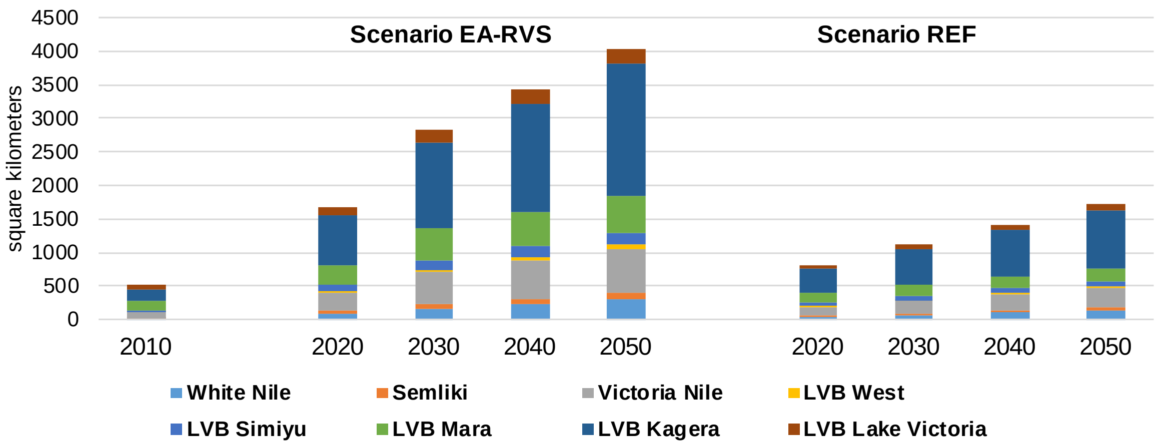


Source: IIASA WFaS East Africa (CWatM-ECHO model system)

5.3.3 Irrigated areas

Expanding irrigation areas are key drivers for increases in human water withdrawal. Current irrigated areas of just over 500 km^2 are expected to expand significantly (Figure 5-20). The more than tripling in Scenario REF, up to 1719 km^2 by 2050, is an estimate based on the agricultural economic modelling system for the global SSP2 scenario (Middle of the Road). Expansion of irrigated areas result from the combined impact of food demand growth, food price development and the potential of farmers to invest in irrigation infrastructure. In Scenario EA-RVS, we closely follow the aspirations of the East Africa's vision documents, which aim to increase agricultural productivity and explicitly point out that the expansion of irrigated agriculture should play a key role. Thus, we assume for EA-RVS, higher increases in irrigated areas, up to over 4000 km^2 until the 2050s.

Figure 5-20. Development of irrigated areas in the eLVB, 2010 – 2050, by Scenario



Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

Key messages socio-economic drivers of water demand

Population and economic growth together with expectations on irrigation expansion are key drivers for future water demand in the eLVB. Combined with strong urbanisation, the total population of the eLVB will at least double between 2010 and 2050. By 2050, about half of the population is expected to reside in urban areas. During the same period the expanding economy is expected to increase per capita GDP significantly, especially after the 2030s and due to urban GDP. Depending on scenario and region, per capita GDP will increase between three- and eight-fold. The wealthier population will change diets towards more livestock protein consumption causing additional demand for agricultural products. A significant expansion of the currently almost negligible cultivated land with irrigation infrastructure is an important development priority. Although uncertain in scope and location, the current irrigated area is assumed to increase from 500 km^2 in the eLVB to about 2000 km^2 (Scenario REF) to 4000 km^2 (Scenario EA-RVS) by the 2050s.

5.4 Increasing water demand

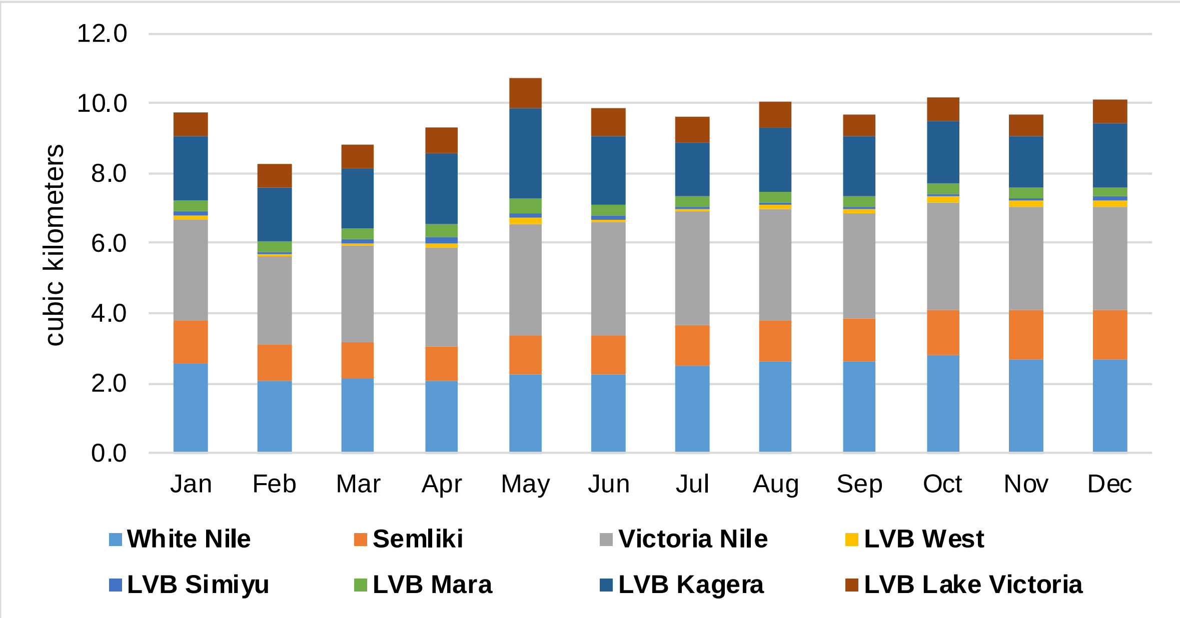
Socio-economic development leads to increases in demand for water resources for agriculture (irrigation, livestock), domestic uses (drinking water, sanitation) and industries (cooling and processing). At the same time, environmental flows must be preserved to support vital river ecosystem services. Below we first quantify environmental flow requirements, a constraint for human water withdrawal in the CWatM-ECHO modelling system. Then we present the total human water demand and its sectoral composition.

5.4.1 Environmental flow requirements

Environmental flow requirements (EFRs) describe the quantity, and timing of water flows required to sustain freshwater ecosystems and the human livelihoods that depend on these ecosystems. We determine EFRs as a percentage of 'pristine' undisturbed mean monthly river flow following the methodology of (Pastor et al., 2014). It employs the Variable Monthly Flow method to account for seasonal EFRs variation by distinguishing high-, intermediate- and low-flow regimes based on different proportions of mean monthly river flow and mean annual flow of long-term average 'pristine' conditions. EFRs are forced by two historic climate runs, HadGEM2-ES and MIROC5, for the period 1971 to 2005.

Throughout the eLVB, we estimate that annually at least 116 cubic kilometres should be secured for EFRs with amounts varying over time and watershed. Monthly EFRs are lowest in February (8.2 km^3) and highest in May (10.7 km^3). More than half of the EFRs in the eLVB are due to EFRs in two sub-basins, the Victoria Nile (36%) and the White Nile (29%). Other basins with high EFRs include LVB Kagera and Semliki (Figure 5-21).

Figure 5-21. Environmental flow requirements in the eLVB, by major basin



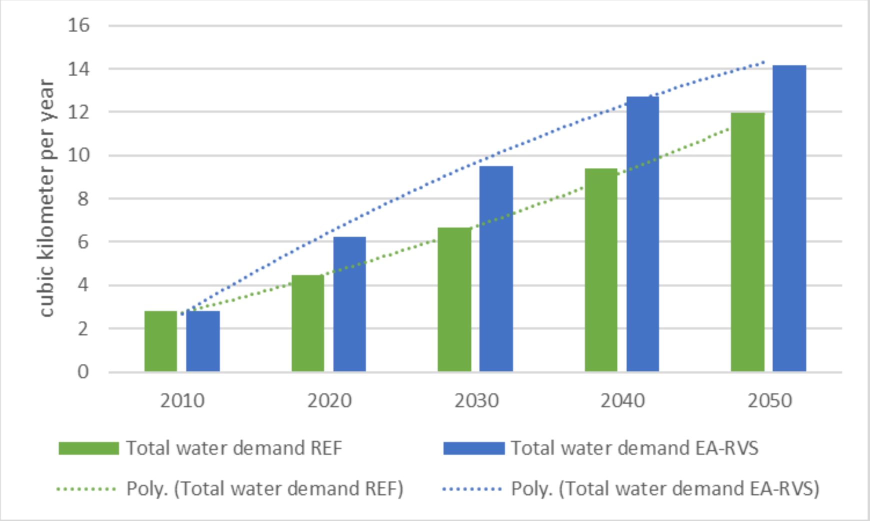
Source: CWatM

5.4.2 Total water demand

Starting from a low level of water withdrawal in the current situation (2010), both scenarios show a very strong increase in water demand in the extended Lake Victoria Basin (eLVB). The more ambitious socio-economic development targets of the EA-RVS (e.g. higher GDP per capita, more cropland under irrigation etc.) require higher water withdrawals, which need to be satisfied mainly form surface water or ground water sources (re-use of treated waste water is likely to play a minor role – see section 5.5.1).

The trend lines of total water demand for the two scenarios show different characteristics. While for the REF scenario we have an increasing growth trend over the scenario period, for the EA-RVS we can observe a sharp increase of water demand in the first two decades which then slows down for the remaining time up to 2050 (Figure 5-22).

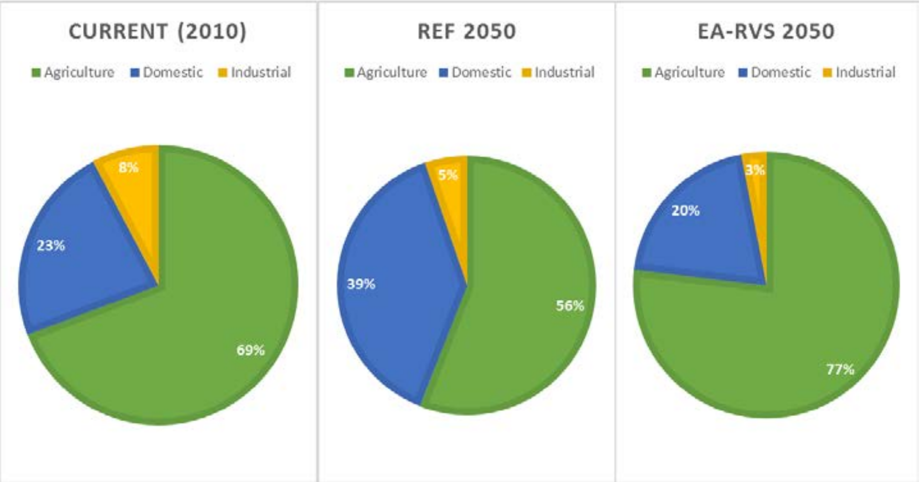
Figure 5-22. Human water withdrawal for the eLVB, 2010 to 2050 including polynomial trend line



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

The distribution of total water demand among the three key sectors (agriculture, domestic, industry) is very different for the two scenarios (Figure 5-23). By 2050, agricultural water demand (irrigation and livestock) clearly dominates human water withdrawal with 77% of water withdrawn for the agricultural sector in case of the EA-RVS whereas about 17% go for livestock and 83% for irrigation (Table 5-7). The REF scenario is characterised by both, a higher share and also higher absolute withdrawal of domestic water. Furthermore, livestock consumes about one third of the agricultural water demand in the REF scenario. In comparison to other regions in the world, water withdrawal for the industry sector is relatively small currently and remains low. In the coming decades the industrial share in total demand decreases over time, and more so in the EA-RVS than in REF.

Figure 5-23. Sectoral distribution of human water demand, 2010 and 2050



Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

The following sections look at the specific characteristics of water demand in the agricultural, domestic and industry sectors.

Table 5-7. Water demand per sector for the eLVB, 2010 – 2050, Scenario REF and EA-RVS

	2010		2020		2030		2040		2050	
	REF	EA-RVS	REF	EA-RVS	REF	EA-RVS	REF	EA-RVS	REF	EA-RVS
Agriculture	1.95	1.95	3.02	5.09	4.20	7.74	5.58	10.12	6.68	10.89
Domestic	0.65	0.65	1.17	0.91	2.07	1.45	3.34	2.24	4.64	2.85
Industrial	0.22	0.22	0.28	0.25	0.37	0.30	0.48	0.37	0.63	0.43
Total	2.82	2.82	4.47	6.24	6.65	9.49	9.40	12.73	11.94	14.16
agric. irrigation	1.02	1.02	1.81	3.90	2.68	6.31	3.73	8.47	4.53	9.04
agric. livestock	0.93	0.93	1.22	1.18	1.53	1.43	1.84	1.65	2.15	1.85

5.4.3 Agricultural sector

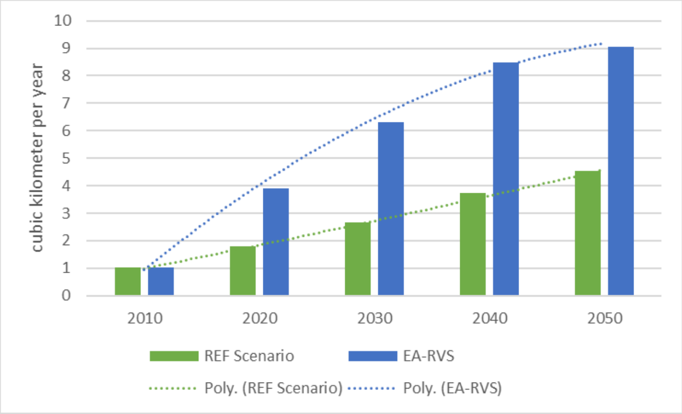
Agricultural water demand includes water withdrawal for irrigation activities in the basin and livestock water needs. Rain fed crop requirements are simulated as part of the hydrological modelling in CWatM with impacts on discharge and river levels. Monthly irrigation water demands for the period 2010–2050 at sub-basin level are estimated in ECHO using irrigated crop area and monthly gross irrigation requirements per unit area of crops. The projection of the area under irrigation is based on a combination of data from MAgPIE (Popp et al., 2014, Stevanovic et al., 2016) for current conditions and IIASA's GAEZ-WFS framework (see section 2.5) for future conditions. The EA-RVS scenario includes regional targets for the expansion of irrigation land.

Net irrigation water requirements of crops are estimated using the crop coefficient method (Allen et al., 1998), which relies on data available either at the local level or where necessary, from global sources. This method involves estimating total monthly crop evapotranspiration and available monthly water supply (or effective precipitation). Monthly crop evapotranspiration is calculated by combining a crop coefficient per crop development stage with a monthly reference (potential) evapotranspiration for the period 2010–2050. Crop-specific calendars, growing season lengths and crop coefficients are obtained from the MIRCA2000 dataset (Portmann et al., 2010).

Potential evapotranspiration and effective precipitation are calculated by the CWatM hydrological model using climate-forcing data from various climate models. Net irrigation water requirements each month are computed subsequently as the difference between crop evapotranspiration and effective precipitation. Lastly, gross irrigation water requirements are calculated per unit crop area and at sub-basin level as the ratio between net irrigation requirements and irrigation efficiency.

The need for irrigation water increases significantly in both scenarios, starting from a rather low level, as irrigation activity in the basin is currently very limited amounting to about 5 thousand hectares irrigated areas. The irrigated crop area for the EA-RVS is assumed to grow much faster (in line with the ambitions expressed in various policy documents explained in section 4) which leads to higher irrigation water demand compared to the REF scenario despite an assumed higher improvement of irrigation efficiency in the EA-RVS. By 2050, total irrigated area in the EA-RVS is assumed 400 thousand hectares compared to 172 thousand hectares in REF. Accordingly irrigation water requirements increase from about one km^3 per year in 2010 to 4.5 km^3 in REF and over 9 km^3 in EA-RVS (Figure 5-24).

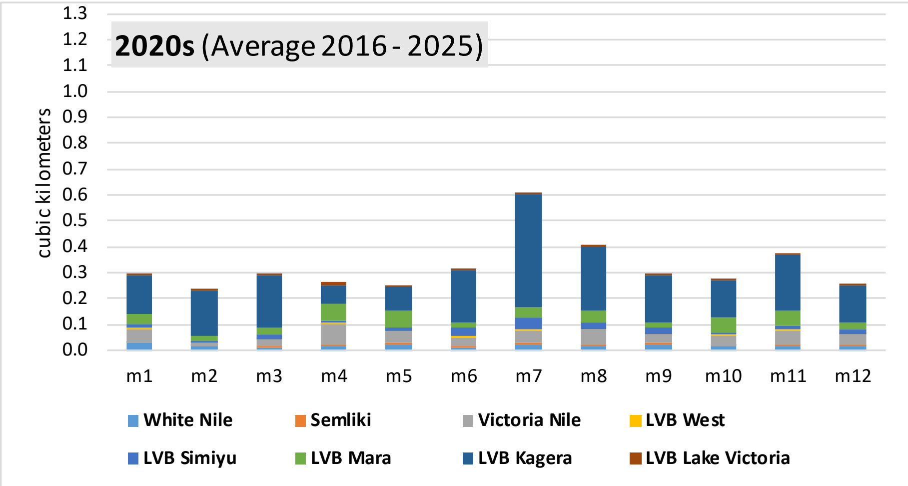
Figure 5-24. Irrigation water requirements for the eLVB, 2010 – 2050 incl. polynomial trend line

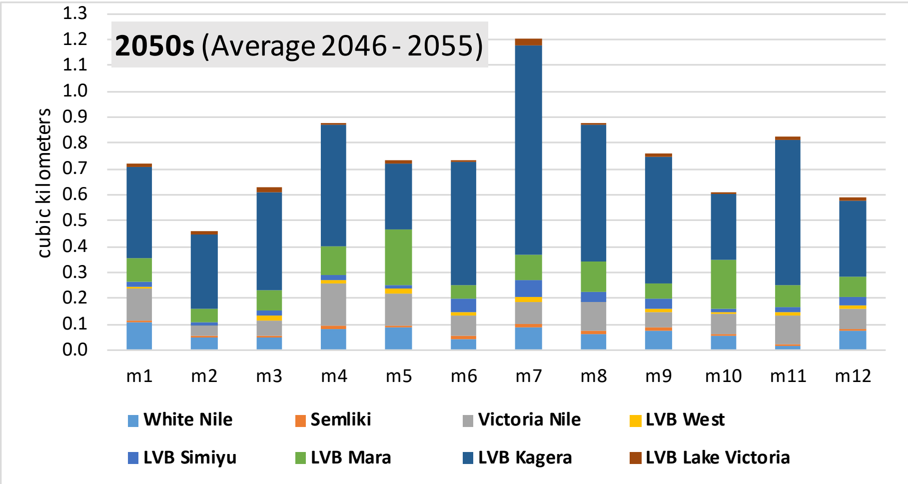


Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

While the other dimensions of human water demand (domestic and industrial) show little seasonal fluctuations, the demand for irrigation water varies greatly throughout the year. The seasonal variability is increasing from 2020 to 2050 with a strong peak in July and smaller peaks in April, November and January (Figure 5-25).

Figure 5-25. Monthly irrigation water withdrawal, Scenario EA-RVS, 2020 and 2050



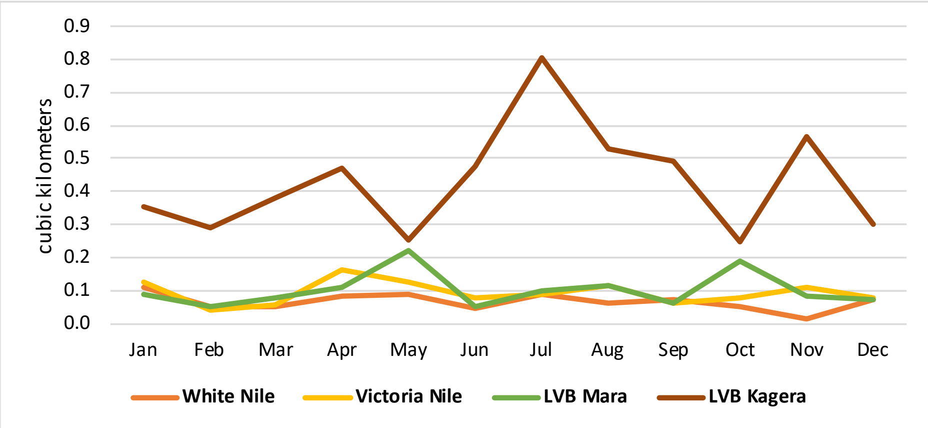


Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

With only small amounts of irrigated areas in the base year 2010, livestock water is almost as high as water demand for irrigation. Over time livestock water demand approximately doubles in both scenarios. In our scenarios, however, the increase in demand for irrigation water is significantly higher. Therefore, by 2050 the share of livestock in the total agricultural water demand is 17% in EA-RVS and 32% in REF (Table 5-7).

The seasonable variability may be very different in each of the sub-basins of the eLVB. The strong peak of irrigation water demand observed for July in the Kagera catchment is not mirrored in the other catchments with major irrigation water demand requirement (Mara and Victoria Nile) (Figure 5-26). This is crucial for decisions on appropriate water management options, as they have to fit to the local conditions.

Figure 5-26. Monthly irrigation water withdrawal in 2050, selected sub-basins, Scenario EA-RVS



Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

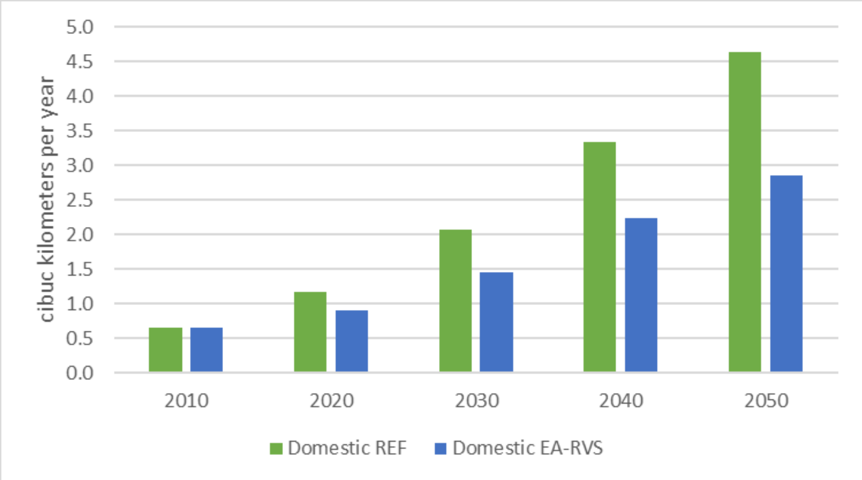
5.4.1 Domestic sector

Domestic water demand was estimated multiplying the number of persons in a grid cell with the country-specific per capita domestic water withdrawal. We consider the daily variation of household water demand over the year. The country per capita domestic water withdrawals in 2000 were taken from the FAO AQUASTAT data base[24], which were multiplied with water use intensities to account for economic and technological development (see also section 5.5.2 on "Industrial Water Demand"). Gridded global population for the study area is based on SSP 2 for the REF scenario and based on a scaled SSP 1 distribution to fit the EA-RVS population projection as described in section 5.3.1.

Domestic water requirement in this study is expressed as potential demand. This means that demand for the domestic sector is computed based on the assumption that everybody living in the study area is entitled to use water for household and personal needs. Hence, it does not take into account limited access, which is especially affecting the current situation as it, overestimates the actual withdrawal for the domestic sector. However, as in both scenarios (REF and EA-RVS) full access is assumed at least by 2050, the future projections for the last two decades should represent fairly accurately the actual situation. Future domestic water use is mainly driven by population growth and efficiency of water use. Figure 5-27 shows, that the EA-RVS results in a much lower domestic water demand as population growth is assumed to be more moderate and in this scenario with stronger socio-economic development water use efficiency is assumed to be higher.

[24] See http://www.fao.org/nr/water/aquastat/main/index.stm

Figure 5-27. Domestic water demand for the eLVB, 2010 – 2050, by Scenario



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

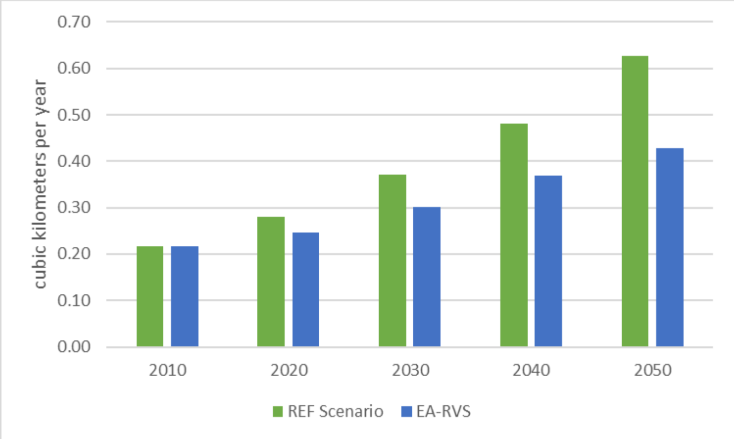
5.4.2 Industry sector

Industrial water demand data for 2000 was obtained from the combination of reported and modelled information (Shiklomanov, 1997, Vörösmarty et al., 2005). Due to limited available data in order to identify the seasonal trends, daily industrial water demand was kept constant over the year. However, in reality daily industrial water demand likely fluctuates over the year, although the seasonal amplitude may not be large.

To calculate historical and future time series of industrial water demand, we multiplied the industrial water demand for 2000 with water use intensities. This calculates country-specific economic development based on four socio-economic variables: Gross Domestic Product (GDP), electricity production, energy consumption, and household consumption. Associated technological development per country was then approximated by energy consumption per unit electricity production, which accounts for industrial restructuring or improved water use efficiency.

Industrial development dynamics and associated water use in the Lake Victoria Basin are still at a relatively low fairly level. Water withdrawal for industry is expected to remain moderate in the coming decades, especially compared to other sectors of water demand (domestic, agriculture/irrigation). The industrial water demand will be increasing in both scenarios with a sharper increase in the case of the REF scenario, mainly because of a lower water use efficiency assumed for this scenario (Figure 5-28). However, as the demand in other sectors is increasing at a much faster pace, the proportion of industrial water demand decreases to only 3% in the case of the EA-RVS and to 5% in the case of the REF scenario (Figure 5-23).

Figure 5-28. Industrial water demand for the eLVB, 2010 – 2050 for Scenario REF and EA-RVS



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Key messages water demand development

Both scenarios show a strong increase in water demand. The current low level of the eLVB annual water withdrawals of some 3 km³ will increase by 2050 to 12 - 14 km³ depending on scenario. Today about one third of water demand is for irrigation, one third for livestock, one fifth for domestic sector and less than ten percent for industrial use. In the coming decades the sectoral composition of water demand depends on scenario. By 2050 in Scenario EA-RVS, the agricultural sector is the dominant water user, mainly because of expanding irrigated areas. This is less pronounced in Scenario REF where higher population numbers are causing a relatively high share of water needs for the domestic sector. Industrial water demand is relatively low compared to water needs of the agricultural and domestic sector.

5.5 Social-ecological water system characteristics

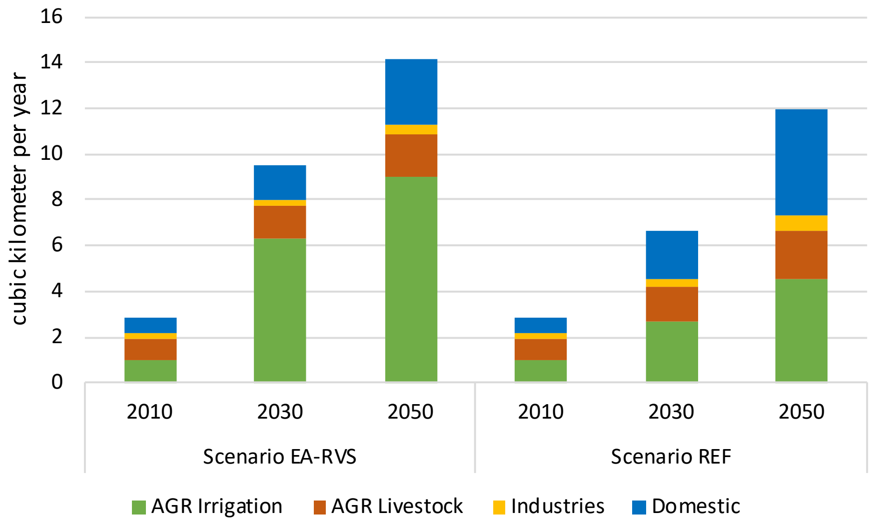
The analysis presented in this chapter combines the biophysical drivers, notably climate change impacts and land use changes, with increasing demand for water across different economic sectors.

5.5.1 Cost-efficient water withdrawal by sector and source

Depending on costs water withdrawn for human demand may be supplied by surface water, groundwater or waste water recycling. When demand is high and supply is tight, investments are made in the most expensive option, waste water recycling. Pumping of renewable groundwater consumes energy and is usually the second most expensive option. If sufficient surface water is available after the need for environmental flows has been met, surface water diversion is the most cost-effective technology and is therefore selected for water supply.

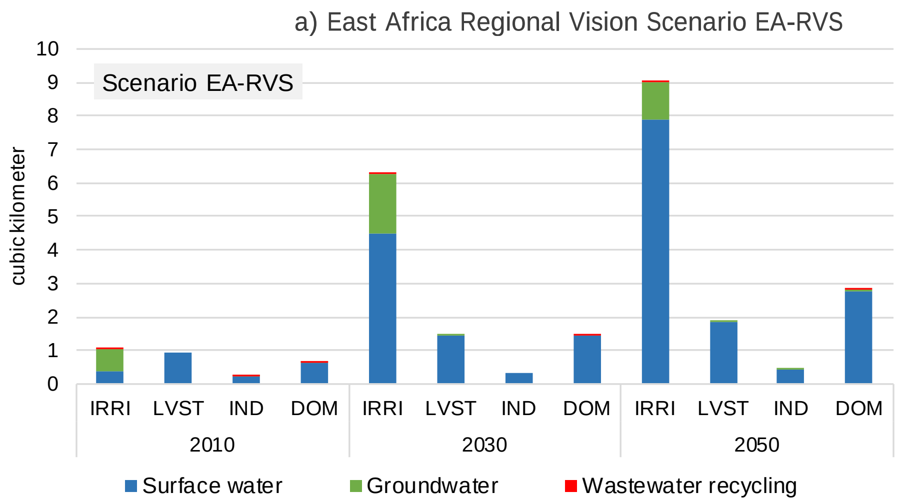
As discussed above in more detail EA-RVS total withdrawal amounts to 14.2 km^3 compared to 11.9 km^3 in the REF scenario. The higher demand in EA-RVS is entirely due to the assumed expansion of irrigated areas. Water demand in the domestic and industry sector is lower in EA-RVS compared to REF, mainly due to lower population numbers (Figure 5-29). Figure 5-30 presents a comprehensive picture of water withdrawal development until 2050 in the two scenarios.

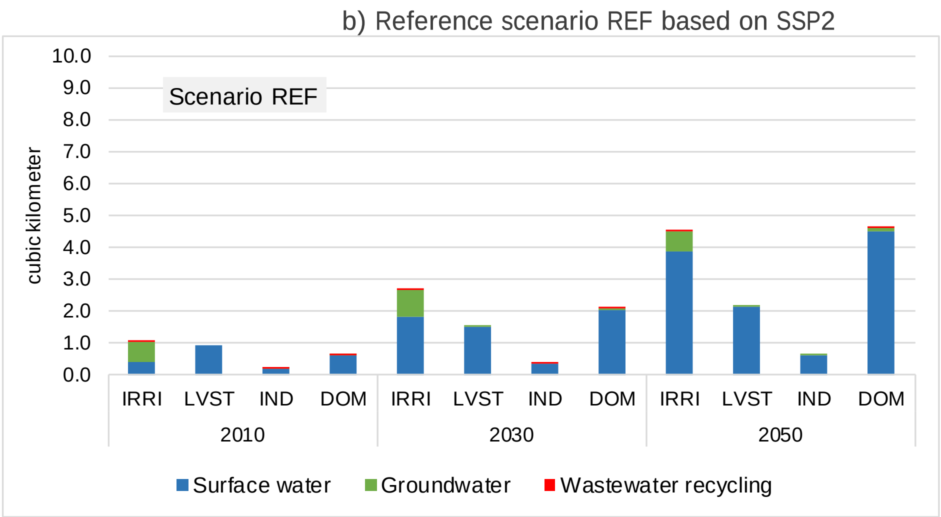
Figure 5-29. Water demand in the eLVB 2010 – 2050, by scenario and sector



Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

Figure 5-30. Water withdrawal development in the eLVB, by use sector and water source





Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

By 2050, surface water can satisfy the bulk of future human water demand in the eLVB, 91% or 12.9 km^3 in EA-RVS and 93% or 11.1 km^3 in REF. The higher overall water demand in EA-RVS results in more and a higher share of water required from pumping groundwater (9% or 1.2 km^3). In REF, groundwater pumping as a source of water, needs to supply0.8 km^3 (7% of total).

Cost-optimization suggests that some marginal quantities of water from wastewater recycling need to be provided to meet demand in all 61 sub-basins throughout the year. Total amounts are very low amounting to less than 0.11 km^3. Taking into account some uncertainties in model estimates, it may be concluded that these low amounts can be replaced by cheaper water source options.

Key messages socio-ecological water system characteristics

The CWatM-ECHO model estimates least cost options of water withdrawal for satisfying demand across the eLVB. It takes into account the monthly water resources and demand as well as environmental flow requirements in each of the eLVB's 61 sub-basins. The majority of future water needs can be supplied from comparatively cheap surface water sources. However, for irrigation during certain months, demand can only be satisfied when groundwater is tapped as well. In a few basins in the south eastern region of the eLVB, small amounts of waste water recycling would be required to satisfy demand throughout the year.

5.5.2 Waste water discharge and treatment

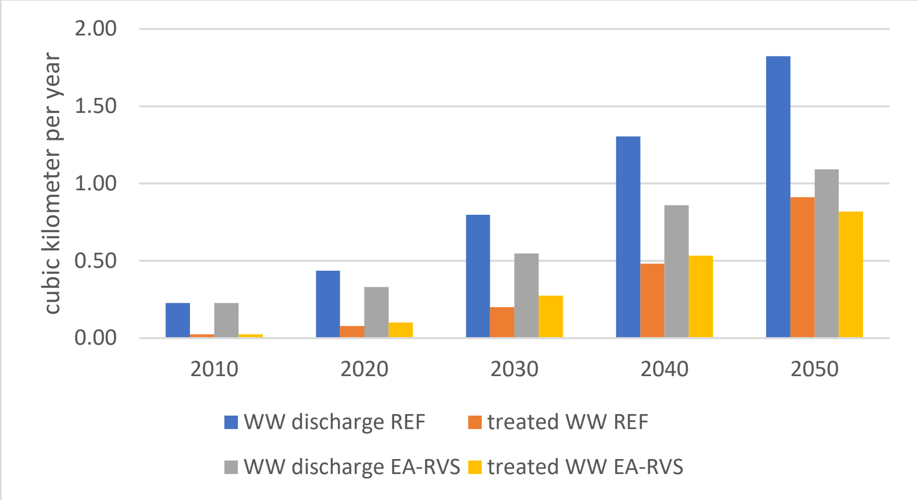
This increasing water demand in the domestic sector is the main reason for higher wastewater (WW) discharge in the eLVB. In addition, smaller amounts of water generated by industry generate wastewater. However, only partially wastewater will be treated. Depending on scenario we assume the wastewater treatment rates listed in the fourth row in Table 5-8.

Table 5-8. Domestic water demand, wastewater discharge and treatment in the eLVB, 2010–2050

	2010		2020		2030		2040		2050	
Scenario	REF	EA-RVS	REF	EA-RVS	REF	EA-RVS	REF	EA-RVS	REF	EA-RVS
Domestic demand [km^3/y]	0.65	0.65	1.17	0.91	2.07	1.45	3.34	2.24	4.64	2.85
WW discharge	0.23	0.23	0.44	0.33	0.80	0.55	1.30	0.86	1.82	1.09
treated WW	0.02	0,02	0.08	0.10	0.20	0.27	0.48	0.53	0.91	0.82
% of WW treated	11	11	18	30	25	50	37	62	50	75
WW treatment costs [mio USD]	2.56	2.56	2.26	2.26	2.20	2.29	2.38	2.75	2.04	3.46

Because of relatively low water withdrawals from the industrial sector compared to domestic water withdrawal, the bulk of wastewater treated refers to the domestic sector. Figure 5-31 and Table 5-8 summarize wastewater discharge and treated amounts aggregate for the entire eLVB. Lower domestic water demand for the EA-RVS combined with higher water use efficiency also lead to lower wastewater discharge. Wastewater treatment levels for the EA-RVS of 75% by 2050 is considerably higher compared to 50% by 2050 only in the REF scenario. In order to achieve this, more ambitious target of wastewater treatment a higher allocation of resources is required which increases from about 2.5 million USD in the current situation to about 3.5 million USD in 2050 in the EA-RVS whereas the allocations remain more or less unchanged in the REF scenario.

Figure 5-31. Wastewater (WW) discharge and treated wastewater in the eLVB, 2010–2050



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

5.5.3 Energy – Water Nexus

The services to cover the increasing water demands across all sectors (domestic, industrial, irrigation) including treatment of wastewater will require substantial amounts of electricity. Table 5-9 shows estimates for the electricity requirements for the EA-RVS and balances these against the projected hydropower production for the major power plants located within the basin which are either already operational or will become operational over the coming decades. For the current situation (2010) hydroelectric stations of Nalubaale (180 MW), Kiira (200 MW), and Bujagali (250 MW) are taken into account.

Table 5-9. Electricity needs for water services and estimated hydroelectric power production in the eLVB, Scenario EA-RVS

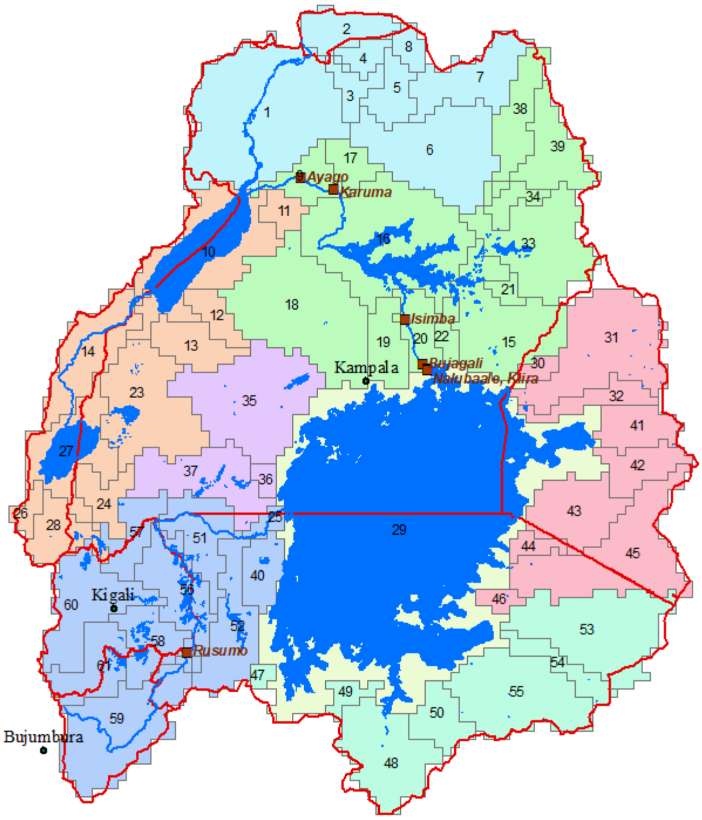
in MWh	**2010**	**2020**	**2030**	**2040**	**2050**
Electricity required for water services	549.573	964.690	1.625.197	2.340.178	3.048.132
Hydro-electric power production	3.136.739	12.806.405	14.464.434	16.948.167	13.571.731
%age used for water services	18%	8%	11%	14%	22%

Source: IIASA WFaS East Africa (CWatM-ECHO model system)

From 2020 onwards, we assume capacity to be boosted by three hydropower stations under construction, Isimba (183 MW), Karuma (600 MW), and Rusumo (80 MW). Further, we consider as of 2020 operation of another large proposed power station, Ayago (600 MW). With the exception of Rusumo, a power station in the Kagera River, all hydropower plants are located in the Victoria Nile (Figure 5-32). Although there are plans for further smaller-scale plants, we only consider these larger plants for the calculation of hydropower production here.

Without considering the hydroelectric power exports outside the basin, currently about 18% of this production is used for water services. The water service share declines to 8% in 2020 as more hydropower plants get online. Assuming no further additional hydro-power plants, by 2050, the increasing demand result in about similar levels of relative electricity requirements for covering water services as today (22%).

Figure 5-32. Hydro-power stations included in the CWatM-ECHO modelling framework



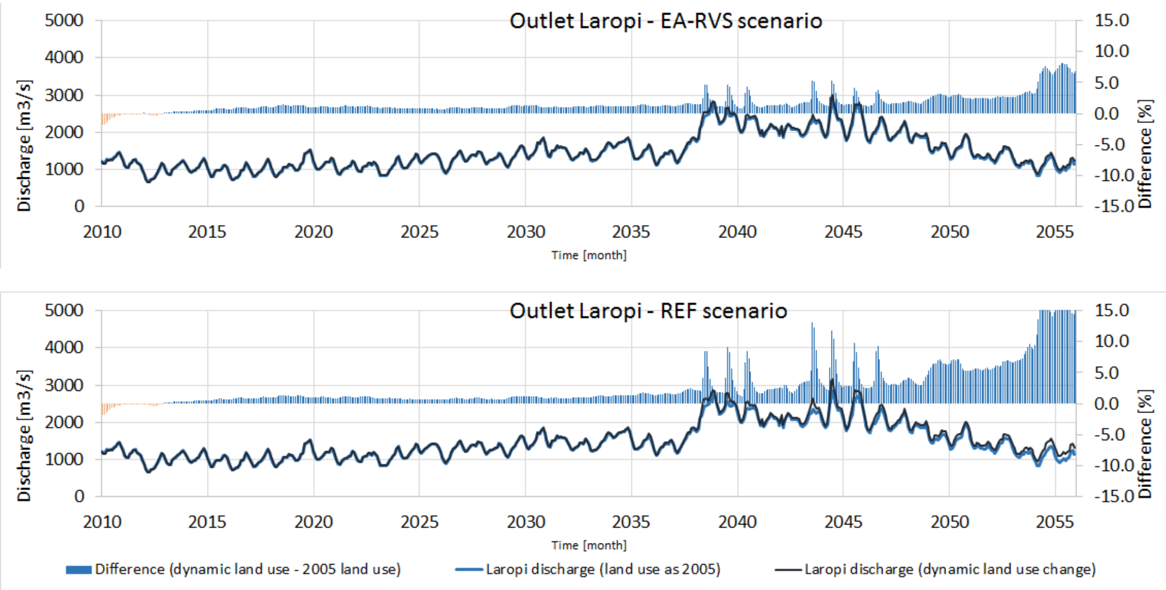
5.5.4 River streamflow development

The CWatM-ECHO modelling framework is able to address the different land use and human water withdrawals scenarios and calculates discharge at the outlet of each of the 61 sub-basins. Section 5.3 was looking at the climate change aspect only. Here land use change and water use change under a changing climate will be discussed using the two scenarios EA-RVS and REF.

Effect of changes in land use: Land use change till 2050 in both scenarios will lead to more sealed areas, because of growing population and higher urbanization, more area for intense agriculture and less forest. In general this will increase runoff and decrease evapotranspiration and lead to higher discharge. Figure 5-33 shows the effect of changing land use for the entire eLVB for the scenarios EA-RVS and REF by looking at the discharge time series at Laropi station. The figures shows two time series of discharge, one with the assumption of keeping the land cover constant as of the year 2005 and the other one with a dynamic land cover change till 2055 under the scenario assumption. Because the two time series cannot be distinguished from each other (only for REF in the late 2050s) the blue bars show the difference in percent.

Comparing no land use change versus land use change we see an increase of discharge up 7.5% (EA-RVS) and up to 15% (REF) with dynamic land use change. During high discharge periods the difference is higher than during low flow periods. This can also lead to a vulnerability to flooding. Effect on the low-flow indicator Q90 (90% of discharge are higher than this threshold) will be a 6% (EA-RVS) and 12% (REF) increase due to land use changes.

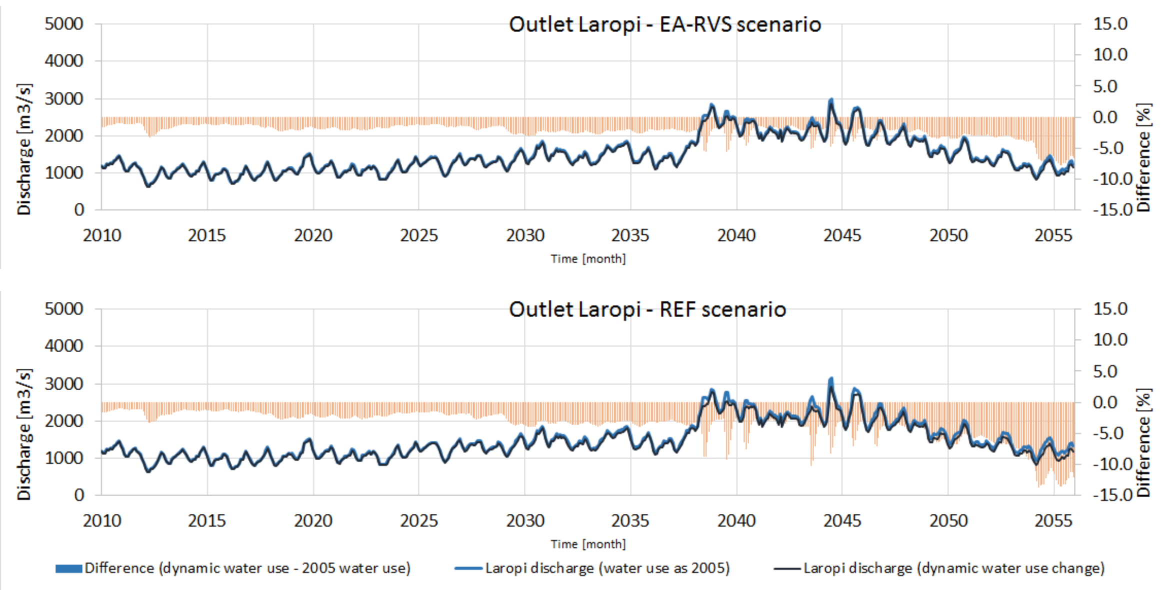
Figure 5-33. Discharge at Laropi, impacts of climate and land use change (excl water use)



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

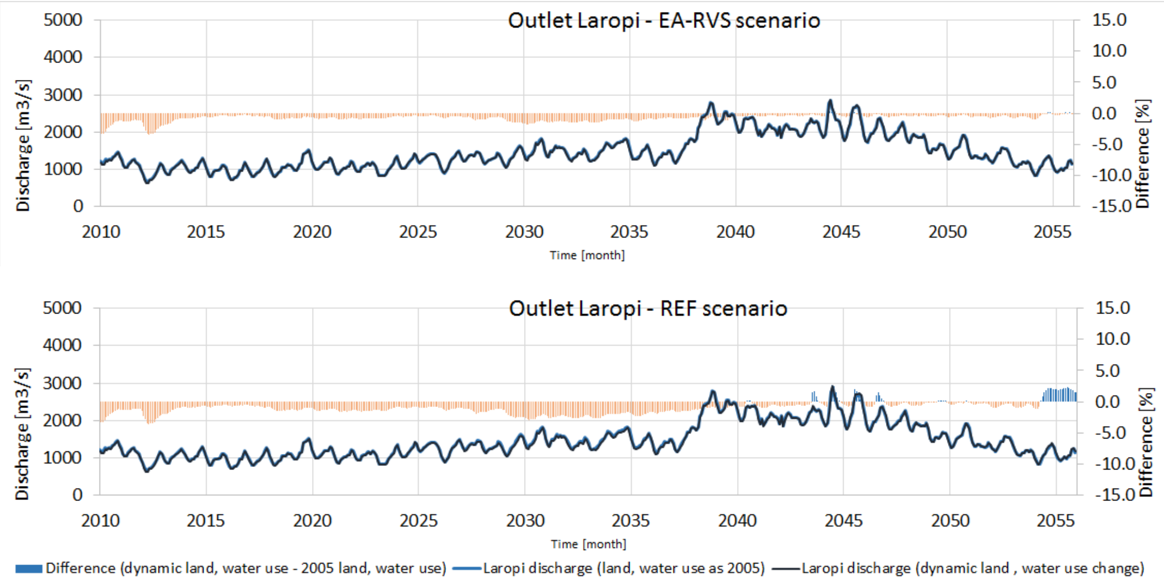
Effect of changes in water use: Looking at changing water use only which includes water withdrawal, water consumption and return flows from different sectors, we can see the opposite effect. Figure 5-34 shows a simulation with constant water use of 2005 versus a dynamic change of water use till 2055 for the scenarios EA-RVS and REF. Including water use results in up to 7.5% (EA-RVS) and up to 14% (REF) water at station Laropi. Effect on the low-flow indicator Q90 will be a 6% (EA-RVS) and 10% (REF) decrease due to water use changes.

Figure 5-34. Discharge at Laropi, impacts of climate and water use changes (excl land use)



Combined effect of changes in land use and water use: Figure 5-35 shows the effect of combining land use change and water use change. Here a simulation with constant land use and water use as of 2005 is compared to dynamic change of land use and water use for the EA-RVS and REF scenario. As both effects are of similar magnitude but opposing each other, they almost nullify each other. The water withdrawn is used up as water consumption and is compensated by the increased runoff and discharge due to changes in land cover at Laropi station. Effect on Q90 will be a no change (EA-RVS) and 1% (REF) increase due to land use and water use changes.

Figure 5-35. Discharge at Laropi, combined impacts of changes in climate, land use and water use



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Key messages for river stream flow development: Over time, the increasing runoff and discharge caused by land use change will be compensated by loss of water due to increases in water consumption resulting from human water withdrawal.

5.5.5 Water scarcity indicators

Per capita water resources (Water Crowding Index)

Available water resources per capita (the Water Crowding Index (WCI) or also called the Falkenmark Indicator) is one of the most widely used measures of water stress (Falkenmark, 1989). Based on the per capita water availability, the water conditions in an area can be categorized in different categories of stress expressed either in m³ of water available per capita and year:

Category	m³ per capita per year
no stress	> 1700
Stress	> 1000-1700
Scarcity	> 500 - 1000
absolute scarcity	<= 500

In some reports, the range between 1700 and 2500 m^3/cap/year is described as vulnerability range (WWAP 2015). In this study, the total renewable water resources in a sub-basin are not restricted to the local available freshwater (i.e. per sub-basin), but it includes also the water resources originating from upstream sub-basins. This equals the discharge based on the RCP6.0 climate scenario of each of the sub-basins and the discharge of the total eLVB respectively under natural conditions, hence without human intervention and as computed in CWatM. The population figures stem from the population projections for the REF and EA-RVS scenarios, respectively.

Table 5-10 shows the WCI values for 8 major basins and 61 sub-basins respectively, and comparing the situations of 2010 and 2050s. While the table includes a comparison of the index values based on REF and EA-RVS projections the map in Figure 5-36 is only based on the REF scenario. Both, the map as well as the detailed figures in the table show that there is a clear increase in water scarcity. For the eLVB as a whole, currently (year 2010) annual renewable water resources amount to 460 m^3 per capita. By 2050, this amount has decreased by 43% to 260 m^3 per capita in scenario REF and 33% to 308 m^3 per capita in scenario EA-RVS. The decrease is most pronounced in LVB West, followed by LVB Kagera and LVB Simiyu.

Table 5-10. Water Crowding Index in the eLVB

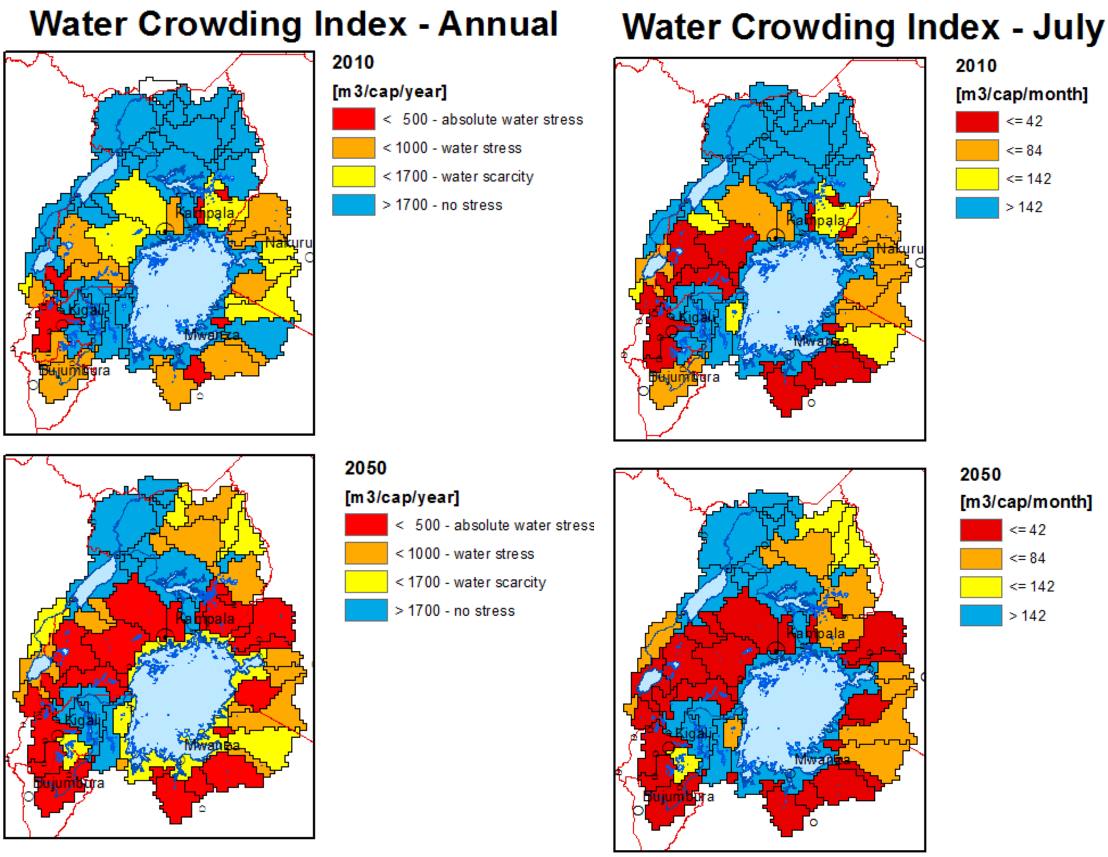
	Current (2010) [m^3/cap/year]	**Scenario 2050** [m^3/cap/year]		**Percentage change 2010-2050**	
Major basin	Current	REF	EA-RVS	REF	EA-RVS
White Nile	7976	3549	4183	-56%	-48%
Semliki	3000	1712	2096	-43%	-30%
Victoria Nile	1826	929	1145	-49%	-37%
LVB West	1004	310	373	-69%	-63%
LVB Simiyu	781	391	516	-50%	-34%
LVB Mara	711	431	488	-39%	-31%
LVB Kagera	718	353	393	-51%	-45%
LVB Lake Vict.	2402	1827	2234	-24%	-7%
Total eLVB	**460**	**260**	**308**	-43%	-33%

Source: IIASA WFaS East Africa (CWatM-ECHO model system)

While in the current situation (2010), about half of the sub-basins are exposed to some level of water scarcity with some view basins indicating absolute water scarcity, in 2050 almost all sub-basins which are neither directly crossed by the River Nile nor adjacent to a lake, experience stress or scarcity, many of them absolute water stress.

Stress levels are generally higher in the REF scenario compared to the EA-RVS which is mainly linked to the higher population growth of REF. The WCI calculated for the entire study area of the extended Lake Victoria Basin (eLVB) shows that larger parts of the basin is already under absolute water stress which is aggravating strongly for both, the REF scenario as well as the EA-RVS.

Figure 5-36. Water Crowding Index based on RCP 6.0 and EA-RVS



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Water scarcity - Imbalance between water availability and demand

A key output of this project is to assess current and future imbalances between water availability and demand. We employ the Water Resources Vulnerability Index (Raskin et al. 1997) also known as Water Exploitation Index (WEI) (EEA 2005), defined as the ratio of total annual withdrawals for human use to total available renewable surface water resources. Regions are considered water scarce if annual withdrawals are between 20-40% of annual supply, and severely water scarce if withdrawals exceed 40%.

Table 5-11 shows the water exploitation index for the eLVB. The WEI for the entire study area (eLVB) amounts to only 4.4% in 2010. The water resource availability for this index is based on RCP 6.0 climate scenario and includes the effect of human consumption and effects of land use change up to 2050. There is a strong increase of the water exploitation up to 2050. The water exploitation ration reaches 25.1 % and 30.2 % for the REF scenario for the EA-RVS respectively. Therefore, the basin slips into water scarcity in both scenarios. One of the major sub-basins (LVB Kagera) will jump from currently no water scarcity, immediately into the severely water scarce category for the EA-RVS by 2050 with water withdrawals exceeding 50%. This is of particular importance as this area is already densely populated and will be even more so in 2050.

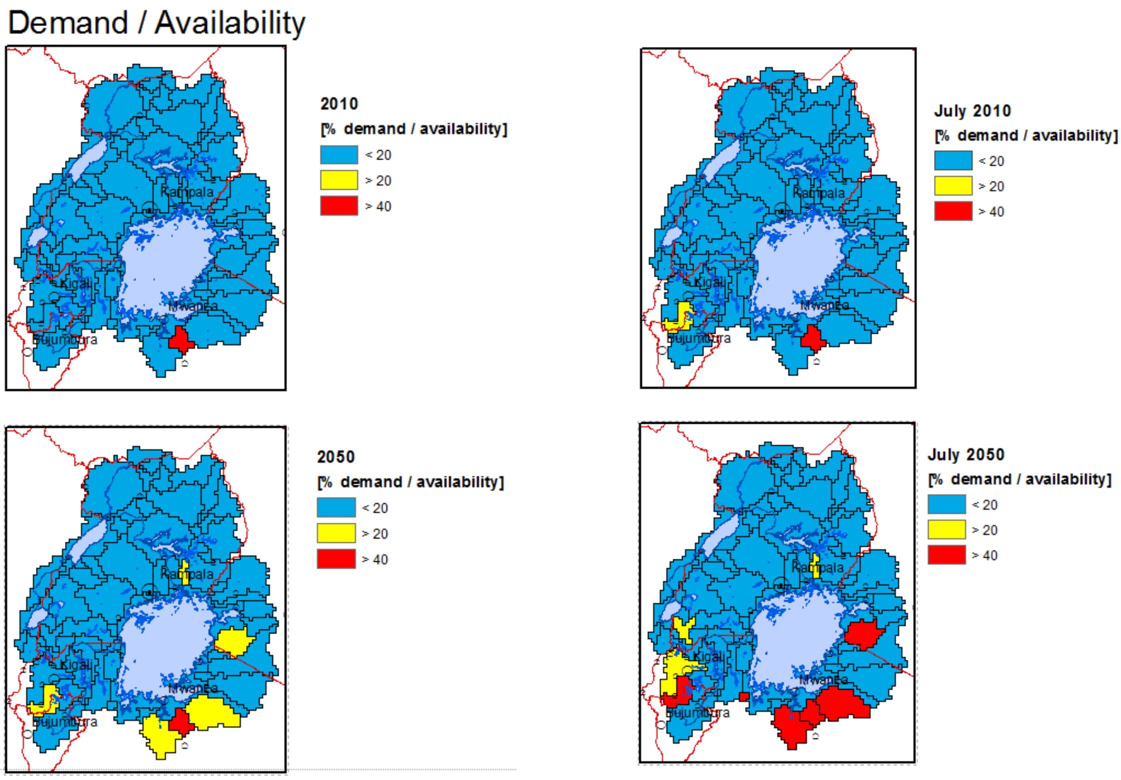
Figure 5-37 shows as well the WEI, however, based on 61 sub-basins and for the annual average as well as the driest month July. It reveals that - if the WEI spread of the year - 6 out of 61 sub-basins within the extended Lake Victoria Basin will slip into water scarcity by 2050. Looking at this index for the month of July only, it shows that many more sub-basins are likely to experience water scarcity and even severe water scarce situations by 2050 under the EA-RVS scenario. Such sub-basins are mainly located at the south and south-eastern shores of the Lake Victoria and in densely populated areas of Rwanda and Burundi.

Table 5-11. Ratio of water withdrawal over water availability, 2010 and 2050 based on RCP 6.0

Major basin	Current (2010)			Scenario REF (2050)			Scenario EA-RVS (2050)		
	Withdr.	Avail.	Ratio	Withdr.	Avail.	Ratio	Withdr	Avail	Ratio
White Nile	0.068	43.06	0.002	0.743	47.55	0.016	1.036	46.97	0.022
Semliki	0.060	44.54	0.001	0.642	48.61	0.013	0.494	47.96	0.010
Victoria Nile	0.333	37.87	0.009	1.876	42.29	0.044	2.034	41.52	0.049
LVB West	0.037	3.90	0.009	0.457	3.92	0.117	0.440	3.92	0.112
LVB Simiyu	0.426	3.02	0.141	1.115	3.40	0.328	0.958	3.40	0.282
LVB Mara	0.221	9.43	0.023	2.027	12.17	0.167	2.445	12.17	0.201
LVB Kagera	0.495	12.67	0.039	4.083	12.41	0.329	5.958	11.25	0.530
LVB Lake Vict.	0.254	72.87	0.003	1.000	77.80	0.013	0.797	76.76	0.010
Total eLVB	1.895	43.06	0.044	11.945	47.55	0.251	14.162	46.97	0.302

Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Figure 5-37. Water Exploitation Index for 61 sub-basins of the eLVB based on RCP 6.0 and EA-RVS scenario; left for annual demand and availability, right for July only



Source: IIASA WFaS East Africa (CWatM-ECHO model system)

Comparison of Water Crowding Index (WCI) and Water Exploitation Index (WEI)

Interestingly, the WEI shows a much lower signal of water scarcity for the study compared to the WCI. The WCI, expressed as per capita water availability per year or people per on million m³, is based on the underlying assumption that, regardless of the socio-economic conditions, every person on the globe has the same "water demand entitlement" or the same "water right". The Water Exploitation Index is based on the in situ situation and balancing changing water availability (mainly due to climate change effects but also human withdrawals) and water demand (determined by actual assumed demand patterns in domestic, industrial/energy, and agricultural sectors driven by GDP per capita, irrigation requirements etc.). Hence, WEI is computed based on the actual assumed local water availability and water demand.

The fact that both indices show a rather different picture, this might be interpreted as an indication for economic water scarcity. The situation of low economic development for the study area may still prevail in 2050 (at least compared to the then global average). This is the main reason for the relatively low actual water demand compared to global averages and therefore relatively low water scarcity signal for WEI compared to WCI.

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Key messages water scarcity indicators

Results of two commonly used water scarcity indicators describe different aspects of water scarcity. The per capita based water crowding index (Falkenmark) points to high levels of water scarcity in the coming decades. In contrast, the development of the ratio of water demand and water availability, as expressed in the water exploitation index, indicates a more optimistic development of water scarcity in the eLVB. There is a high spatial variability in water scarcity development trends. By 2050, water scarcity will be most pronounced in Kagera, Mara and Simiyu sub-watersheds.

5.6 Cost estimates for growing water demand

The objective function of ECHO minimizes the total investment and operating costs of a wide variety of water management options over a long-term planning horizon (e.g., a decade or more), to satisfy sectoral water demands across sub-basins. The assumption in the cost optimization is that water users seek to minimize the cost of water supply and demand management subject to constraints. The optimal solution generated by ECHO provides spatially explicit information on a least cost combination of water management options that can satisfy sectoral water demands looking at water, energy, and land sectors. Results show the most cost-efficient solution for the entire eLVB considering all water flows between sub-basins and safeguarding sufficient water for river ecosystems.

Costs incur annually for operations and management (O&M) and energy needs of the water sector. Between 2010 and 2050, the annual costs for operations, management and energy will quadruple in the EA-RVS scenario. The increase is almost six-fold in scenario REF, mainly due to a higher population size compared to EA-RVS. The largest part of the annual O&M costs stem from water supply including diverting and treating water from rivers and lakes for human consumption (Table 5-12).

Table 5-12.Annual water sector costs (operations & management, energy) in the eLVB, by scenario

million US$	2010	2020	2030	2040	2050
*SCENARIO **EA-RVS***					
Energy costs	29	48	76	103	128
Operational & management[1] costs for:					
Surface water reservoirs	0	4	5	5	6
Waste water treatment (Recycling)	3	12	29	55	82
Surface water withdrawal (diversion)	395	554	854	1247	1478
Groundwater withdrawal (pumping)	18	17	16	16	37
Wastewater re-use	11	11	11	9	10
TOTAL annual costs	455	645	991	1436	1741
*SCENARIO **REF***					
Energy costs	29	47	77	117	159
Operational & management[1] costs for:					
Surface water reservoirs	0	2	3	3	6
Waste water treatment (Recycling)	3	9	22	50	90
Surface water withdrawal	394	684	1171	1795	2318
Groundwater withdrawal pumping	18	20	13	11	64
Wastewater re-use	11	11	10	10	10
TOTAL annual costs	426	726	1218	1869	2488

1 Annual O&M costs excluding energy costs

Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

In addition, there are costs for investments to build infrastructure to meet the additional water demand of the agriculture, households and industry. Concerning the domestic sector, many people in the eLVB today still have no access to safe drinking water and improved sanitation facilities (see section 3.3.3 for details). Note, the investment need to connect the entire current population to improved drinking water and sanitation facilities, would require additional analysis. Water demand for the industrial sector is a function of GDP and energy use. Assumption for increases in irrigation water demand have been described in section 5.3.3.

Table 5-13 shows investment costs of all investments that are necessary over a 10-year period in order to build the necessary infrastructure. The total investment costs for the additional water infrastructure until 2050 are estimated at almost 4 billion U$ in the EA-RVS scenario. They are only slightly lower in the REF scenario at 3.7 billion U$. In both scenarios, the major part of the investments are for the construction of water supply infrastructure.

Table 5-13. Investment costs for additional water infrastructure in the eLVB, by Scenario

million US$	**2010**	**2020**	**2030**	**2040**	**2050**
SCENARIO ***EA-RVS***					
Investment costs[1] for:					
Domestic & Industry sector[2]	0	86	82	78	234
Reservoirs	0	40	5	0	15
Irrigation systems	30	99	166	183	232
Water supply[3]	0	260	578	783	1055
TOTAL Investment	30	486	831	1044	1536
SCENARIO ***REF***					
Investment[1] costs for:					
Domestic & Industry sector[2]	0	62	59	56	382
Reservoirs	0	20	6	0	33
Irrigation systems	30	48	60	70	86
Water supply[3]	0	168	405	843	1378
TOTAL Investment	30	298	530	969	1879

1 Costs arising over the 10-year period; **2** Investments in improving efficiency in the domestic and industry sector (e.g. reduce leakage; demand management such as information campaigns; upgrade in-houses devices; **3** Building infrastructure for withdrawal of surface-, ground- and recycled wastewater.

Source: IIASA WFaS East Africa (CWatM-ECHO-GAEZ-WFS model system)

Key messages cost estimates for growing water demand

In the coming four decades, annual water sector costs for operations and management including energy costs are estimated to increase by a factor of 4 to 6 depending on scenario. Investment costs incurring for additional water infrastructure alone, i.e. excluding upgrading of current infrastructure to supply the current population with access to piped water, will increase over time. By 2050, we estimate annual costs of 1.5 to 1.8 million US$ for investment and a similar order (1.7 to 2.5 million US$) for operations and maintenance.

6 Concluding remarks

Water systems depend on inter-connected variables across spatial scales ranging from global (e.g. climate change, trade) to regional (e.g. country-level demographic and economic growth) to local (e.g. irrigation patterns, water reservoirs, soil fertility) conditions. This study on East Africa's Water Futures has integrated available scenarios from global studies with aspirations of East Africa's regional visions. We quantitatively assess pathways of the balance of water resources and water demand until the 2050s.

6.1 A scenario approach linking across spatial scales

The reference scenario REF is based on a widely used scenarios developed by a key constituency at the global scale, the IPCC. Specifically, we use the 'Middle of the Road' scenario from the Shared Socioeconomic Pathways (SSP2) combined with a model ensemble representing medium climate change. The East Africa regional vision scenario EA-RVS utilizes available regional vision documents and the results of a stakeholder workshop to develop a scenario for East Africa. As expected, the EA-RVS narrative represents a sustainable path into the future. It can therefore be interpreted as a regional application of the IPCC 'Sustainability' scenario SSP1. In our effort to interpret the EA-RVS narrative into quantified variables necessary for water system modelling, we have therefore relied on SSP1 data when no regional data were available.

Similar to the global SSP scenarios, in comparison to REF, the EA-RVS is characterised by lower population growth, higher economic growth, and faster expansion of modern technologies for energy and water supply. Although it is challenging to compare different data sources, there is a tendency that the regional aspirations in the vision documents show a more rapid development trend towards economic prosperity compared to the global scenarios. This is a result of future somewhat lower population numbers and higher economic output. To achieve this, the EA-RVS scenario envisages a strong improvement in educational attainment and investments in research and development. From the point of view of the water system, lower population numbers combined with higher economic growth contribute to reducing water challenges. This concerns in particular the challenge of access to and cost of water supply for increasing demand.

With respect to increasing water use for irrigation, the regional scenario for East Africa assumes major expansion of cultivated land equipped with irrigation. Even if the quantification and spatial distribution of future irrigated areas is uncertain, the EA-RVS apparently attaches great importance to the expansion of irrigated areas. In contrast, in the global sustainability narrative, emphasis is put on irrigation technology rather than on the expansion of irrigated land. Obviously, the motivations for scenario narrative differ between the regional context of East Africa and the global context. In East Africa today only a fraction of agricultural production relies on irrigation technology. In contrast, at the global level, a significant fraction of production increase over the past decades was due to expansion of irrigated production, with some detrimental effects on water scarcity.

6.2 Project scope and limitations

Quantitative assessment is crucially dependent on the quality of the data that force the modelling system applied for a key transboundary basin in East Africa, the extended Lake Victoria basin (eLVB). In this study, we have compiled available data on climate, demography, economic growth, land use, agricultural practices including irrigated areas, technologies and costs. This includes both data on base-year conditions (2010) and future trajectories until the 2050s. In the following, we summarize important limitations related to the data used in this study.

First, reliable spatial land use data are essential for accurate modelling of water systems and hydrological processes. The eLVB includes densely populated areas that have undergone rapid changes in land use in recent decades. Land use changes are characterised by deforestation, expansion of agricultural lands, and an increase in residential areas.

Development trends of runoff and discharge depend besides climate change on land use patterns. In particular, the distinction between areas regarding their runoff coefficient is of importance. The runoff coefficient is lowest for forests and shrub land and highest for built-up areas. Available global datasets may overestimate current extents of forests and underestimate sealed areas. For example, in CWatM we estimate for 2010 that 58% of the eLVB is covered by forests and shrub land. Other databases, for comparison, the GLC-SHARE database (Latham et al., 2014) reports lower amounts for the eLVB, 14% 'tree covered areas' and 18% 'shrub covered areas'. However, differentiation between forests, shrub land, agro-forestry systems or tree-based cropland (e.g. oil palm, orchards) is challenging because of definitions as well as limitations in remote sensing interpretations.

Further, irrigation water use accounts for most human water withdrawals. Depending on scenario and time we estimate between 56% and 82% (Table 5-7). Estimates for irrigation water demand require information on the extent of actually irrigated areas together with the applied irrigation technology. In this study we estimate extents of current irrigated areas based on best available global datasets on 'areas equipped with irrigation'. Up-to-date spatial information, in particular on the current extent of areas actually irrigated, could significantly improve the analysis.

Second, lacking data from regional climate change data, the study results presented here use climate change data derived from global modelling results. The eLVB is a comparatively small area from a climate change perspective. To the best of our knowledge, there are no data or studies that apply regional climate change models, e.g. for East Africa.

Third, cost estimations presented in this study for required water sector investments are based on cost parameters from literature sources. Further specification to local conditions would improve results. In conclusion, data availability and accessibility to available regional data remains a limiting factor.

Apart from data constraints, further improvements to the water modelling system are required. Current model runs operate on a comparatively high resolution (i.e. 61 sub-basins in the eLVB). For each sub-basin, we identify the least-cost combination of water supply and demand management option to satisfy human water demand with monthly available water resources and environmental flow constraints. Calculations show whether surface water, renewable groundwater or treated wastewater is required to meet human water needs.

Concerning access to surface water resources, we currently do not account for the distance of water demand needs to surface water within a sub-basin. A spatial layer showing a region's propensity to access surface water, in particular for irrigation, would help to distinguish the sub-basins in terms of their likelihood of accessing river and lake water resources. Variables for an indicator may include distance to rivers and lakes, elevation difference and slope. Similarly, maps showing the depth of the groundwater table are also needed to accurately assess the costs of using renewable groundwater resources. However, digital maps of groundwater tables are rare, even in industrialized countries.

6.3 Conclusions and stakeholder response to modelling results

The water modelling scenario results for the extended Lake Victoria Basin (eLVB) have been presented and discussed in a stakeholder workshop held in Entebbe / Uganda in December 2018[25]. It brought together more than 50 practitioners, researchers and policy makers from all concerned member countries of the Lake Victoria Basin Commission (Burundi, Kenya, Rwanda, Tanzania, and Uganda). This workshop provided the framework for joint learning based on presenting and discussing of the modelling results but also hands on exercises to explore the database resulting from the model runs. All these elements lead to the following conclusions:

Connection between climate change, rainfall, runoff, and river discharge: Global circulation models show only small changes in annual in the eLVB for the coming decades (up to 2050). However, monthly time scale analysis highlights that variability over the year increases with a tendency of the rainy seasons to become wetter and the dry seasons dryer. There is a tendency of a shift of the rainy seasons marked by a later onset and a shift of a few days towards later discharge peaks in general. Due to higher evapotranspiration resulting from rising temperature, projected increases of a more concentrated rainfall can nevertheless lead to lower runoff. The drainage system of the eLVB basin is characterised by a series of large lakes, which create a storage effect and lead to a considerable delay in the response time of the river discharge. Hence, despite a period of less runoff from the various land use systems of the basin in the 2030s the river discharge might still increase for the following decade, the 2040s. In general, the flow regime shows a high inter- and intra-annual variability, which can superimpose climate change effects. However, compared to 2010, the GCMs indicate that the western and south-western regions of the eLVB tend to become drier until the 2050s and the eastern regions wetter.

Changes in land use and water use and their effect on river discharge: The at least doubling of population until the 2050s combined with strong economic growth will likely cause significant changes in land use. Expansion of areas with higher runoff characteristics, such as built-up areas and cultivated land, to forest areas will lead to more runoff and discharge. At the same time, increasing water use (4 – 5-fold increase in water withdrawals across all economic sectors from 2010 to 2050) leads to less discharge. The combined effects of land use and human water use will lead to more or less unchanged discharge in the coming decades.

Two water scarcity indicators show different signals of water scarcity: The water crowding index - WCI (Falkenmark) defined as per capita withdrawal of water per year (m^3/person/year) shows a signal of water scarcity in the basin. Another water scarcity indicator, the water exploitation index (WEI), is calculated as the ratio of water availability and water demand. It shows a more moderate signal of water scarcity. The WCI applies globally unified “water demand entitlements” across all economic sectors of water use. It does not relate water demand to the socio-economic context. In contrast, the WEI is based on the simulated local water balance; hence calculations use data from the local socio-economic context. The fact that the indicators WCI and WEI provide a different interpretation of water scarcity in the eLVB (Figure 5-36, Figure 5-37), can be an expression of “economic water scarcity” because the estimated demand of the WEI is lower than the globally unified “entitlement”. This underpins current conditions highlighted in section 3.3 where only a fraction of the population has access to water services and those having access may do this with insufficient reliability.

[25] See web-page entry on the workshop: http://www.iiasa.ac.at/web/home/research/181204-east-africa-water.html

Main characteristic of the two modelled scenarios: Simulations show a "brighter" water future for the East Africa Regional Vision Scenario (EA-RVS) which is guided by the development ambitions of the EAC and its partner states compared to the Reference Scenario (REF) which assumes a business as usual trend. A more moderate population growth, higher per capita GDP and more ambitious irrigation area expansion in the EA-RVS compared to the REF lead to:

- An overall higher water demand for the EA-RVS due to higher irrigation water needs. However, the trend lines of water demand for the two scenarios converge over time (Figure 5-22) because of higher population growth in REF.
- Despite of higher water withdrawals in scenario EA-RVS, the discharge of the river Nile remains relatively unchanged in both scenarios, mainly because of the compensating effects of climate change and changes in land use.
- A shift in simulated overall water demand distribution across sectors with significantly higher irrigation water demand in the EA-RVS compared to higher domestic water demand in REF (Figure 5-23).
- Considerably lower annual operation & management costs (about one third lower) for supplying water in the case of EA-RVS while there are similar total investment costs for additional infrastructure in both scenarios (Table 5-12, Table 5-13).

6.4 Implications for policy making

The workshop described above has also discussed policy recommendations, which are documented in an annex of the workshop report[26]. The policy recommendations proposed by the workshop participants relate to the knowledge base stemming from their respective professional background and duties rather than to the information and data resulting from the model runs. In order to change this, researchers involved in producing the modelling results would need to guide such discussions more proactively. On the other hand, more prescribed discussion themes may compromise the participatory nature of the process, which the organisers did not want to risk.

Considering the policy areas raised by the participants of the workshop and linking them to the results of the model runs some implications for further policy work and policy setting can be derived. The strategic direction proposed in the EAC Vision 2050 (EAC, 2016a), which was one of the key documents to set modelling parameters for the East Africa Regional Vision Scenario EA-RVS seems generally appropriate as it points overall towards a "brighter water future" compared to the Reference Scenario REF. However, in order to avoid future water scarcity conditions, it is recommend to address the following themes and possibly consider them for future investment options and policy developments.

Ensure moderate population growth: Possible future water scarcity conditions are mainly driven by a sharp increase of future human water demand. A key factor here is population growth and increasing per capita GDP. The socio-economic conditions of the study area would not justify compromising on economic growth indicators. Therefore, it seems imperative to implement measures which support a slowdown of population growth. Increasing the level of educational attainments, for both woman and men, will play a key role here and has the co-benefit of supporting economic development.

Focus on water scarcity hotspots: When identifying policy measures for mitigating water scarcity hotspots, it seems more appropriate to use the Water Exploitation Index as a reference, as this index

[26] Available on http://www.iiasa.ac.at/web/home/research/181204-east-africa-water.html

is based on the local water balance. The analysis shows that particular attention must be paid to the Kagera and the Simiyu Sub-Basins, as water withdrawals are expected to reach a level that drives these sub-basins in situations of severe water scarcity, especially during dry months. The Kagera sub-basin is today already characterised by a high population density, which is expected to increase sharply in the coming decades.

Increase rain and flood water harvesting: The eLVB has a low artificial storage capacity to compensate for seasonal fluctuations. In response to local variability patterns, smaller scale storage facilities appear to be an appropriate option as they offer lower investment costs, easier maintenance and operations, and better risk management.

Appropriate measures to intensify agricultural production: Population growth, economic development and other factors will require the intensification of agricultural production in order to produce more on the already existing agricultural land and limit expansion of agricultural land use systems. Such intensification should focus on sustainable solution options which at the same time strengthen resilience and wellbeing of the population.

Water use efficiency: Apparently there is a huge need for investment to build water infrastructure in all sectors of the economy. This offers an opportunity to immediately implement efficient solutions for water use. Such novel investments must be accompanied by capacity development measures in order to ensure optimal implementation and use of the water-efficient infrastructure.

New approaches for treatment of wastewater: The investment needs and operation and maintenance costs for wastewater treatment are substantial and often exceed the economic capacities of developing countries. Discharging untreated wastewater into the environment is not an option. This calls for new approaches in wastewater management that minimise wastewater loads in the first place. Unavoidable wastewater requires both onsite and centralised treatment solutions. Especially in regions with future water scarcity, the treated wastewater could be used for reuse in agriculture.

Water proofing of future investments and land use planning: Especially larger investments should be subjected to water audits, water footprints or any suitable approach which water proof such investments. Such analysis should not only be applied to infrastructure investments but also to all measures with an impact on water cycles in terms of water quantities and quality such as land use planning etc.

Conjunctive use of surface water and groundwater: Surface water and groundwater will continue to be the most important sources to meet the growing demand for water. Reuse of wastewater is likely to only have a small share even towards the 2050s. The local hydrological situation must be carefully assessed, both for investments in groundwater and surface water abstraction measures.

Transboundary water governance: The water management issues within the investigated eLVB catchment area are highly interconnected at various levels. From a hydrological perspective, the interconnected 61 sub-basins, which form 8 major sub-basins, provide a helpful analytical framework. However, water governance takes place primarily at the country-level and also at the level of the Lake Victoria Basin Commission (LVBC). The LVBC is very important institution for harmonizing data and the formulation and implementation of policies. The policy framework appears to be largely fit for purpose. However, LVBC and its member countries may need to put more emphasis on the enforcement of policies and regulations.

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International Institute for Applied Systems Analysis
Schlossplatz 1, A-2361 Laxenburg, Austria

+43 (0) 2236 807 0

info@iiasa.ac.at

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