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Exploring the water-energy nexus in the Omo river basin

A first step toward the development of an integrated hydrological-OSeMOSYS energy model

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Preface

This report is written as the thesis of master studies in Environmental Engineering and Sustainable Infrastructure at The School of Architecture and the Built Environment, at the Royal Institute of Technology, Stockholm (KTH). The thesis was conducted at the Department of Hydrology and Water Resources Management, Institute of Environmental Engineering, at the Swiss Federal Institute of Technology, Zurich (ETH Zurich). The supervisor of this thesis was Professor Paolo Burlando at ETH Zurich, and examiner Dr. Ulla Mörtberg at KTH, Stockholm.

The thesis is published in the name of KTH but the project was performed at ETH. Hence, for questions or issues regarding the content and project, please refer to the Department of Hydrology and Water Resources Management at ETH Zürich. It was written to support the project a Decision-Analytic Framework to explore the water-energy-food NExus in complex and transboundary water resources system of fast-growing developing countries (DAFNE).

Disclaimer: This document presents the views of the author and may therefore not reflect views from or be supported by the parties who are related to the project that this report is supporting.

Abstract

The issues of conflicts between water, energy and food (often referred to as WEF-nexus) has become a problem in countries where the energy system is rapidly expanding; one of those countries is Ethiopia. Ethiopia has a large potential of hydropower, which is what most of the electricity production currently comes from. However, this has proven to cause problems on other practices around or close to the power plants. An example is the Omo River basin where the development of the Gibe hydropower cascading scheme, with currently the three power plants Gibe I, I and III operating, have brought up the discussion of the downstream impact. For instance, indigenous people living in the lower parts of Omo river, practice flood recession agriculture, meaning they are depending on the seasonal floods. Further, Omo river has its outflow into Lake Turkana, Kenya, and the lake is highly dependent on the flow regime of the Omo river. Studies on the Omo river have been many, an example is the ones using Topkapi-ETH, a physically based rain-fall runoff model, that models the hydrological aspects of the river and considers, among others, water abstraction for irrigation and diversions to reservoirs for hydropower. However, the hydropower modelled worked on the basis of an averaged power demand; not necessarily reflect the actual demand. Hence, OSeMOSYS, the long-term energy optimization tool, was proposed to complement this study by modelling the energy system in Ethiopia. This current thesis had the aim to do so with the attempt to *explore* the possibility of a coupling between the models Topkapi-ETH and OSeMOSYS. The aim was to feed OSeMOSYS with varying water availability from Topkapi-ETH; in return, OSeMOSYS would feed Topkapi-ETH with a more realistic required energy production demand. An OSeMOSYS model was set up for Ethiopia, with national data extracted from the study The Electricity Model Base for Africa (TEMBA), disaggregating the hydropower to be able to model each of the hydropower plants in the Gibe cascading scheme individually. To couple the two models, two approaches were developed: Storage module and Reservoir module. The Storage module used the storage feature within OSeMOSYS and used the varying volume in the reservoir from Topkapi-ETH and converted it into an energy potential, as input to OSeMOSYS. The Reservoir module, on the other hand, used the external inflow (sum of all flows except upstream release), obtained from Topkapi-ETH, to the reservoir. An experimental set-up was performed to test how the OSeMOSYS model, with the two modules, would react to the input and which inputs were the driving forces affecting the electricity production. The results showed that OSeMOSYS can respond to the varying water availability received from Topkapi-ETH with the electricity production from the Gibe cascading scheme showed results reflecting this. However, there was a mismatch in the hydrological response in which OSeMOSYS did not seem to fully reflect the volume in the reservoir. For certain cases, the volume would be zero, indicating it would not store any water but instead use all incoming water directly for energy production. Hence, with respect to the results presented in this study, one can conclude that OSeMOSYS is prone to respond to changes in water availability. However, due to the incompatibility in the hydrological perspective in regard to the volume, the coupling is not complete. Before such a complete coupling can be achieved one needs to understand why OSeMOSYS does not reflect the hydrological characteristics. If this can be solved, then a feedback of the required energy production in the Gibe hydropower plants ought to be sent back to Topkapi-ETH.

Keywords: Water-Energy nexus, Topkapi-ETH, OSeMOSYS, Coupling of models, Omo river basin

Sammanfattning

Konflikten mellan vatten, energi och mat (ofta benämnt WEF-nexus) har blivit ett problem i länder där energisystemet snabbt utvecklas; ett av dessa länder är Etiopien. Etiopien har stor potential i vattenkraft, från vilket den största delen av elektriciteten kommer ifrån idag. Däremot har detta visat skapa problem kring andra verksamheter runtomkring eller i närheten av kraftverken. Ett exempel är Omo RIVER BASIN, beläget i sydvästra Etiopien. Exploateringen av Gibe vattenkraftverk i en kaskad schema, idag med de tre kraftverket Gibe I, IO och III i bruk, har skapat diskussion kring påverkan nedströms. Till exempel så bot Urbefolkningen i den nedre delen av Omo floden, där de utövar så kallad *flood recession* jordbruk, vilket innebär att de är beroende av säsonger av översvämningar för att bevattna marken. Vidare, Omo floden har sitt utflöde in i Lake Turkana, Kenya, och skön är starkt beroende av flödesregimen i Omo floden. Studier kring Omo floden har varit manga, ett exempel är de som har använt sig av Topkapi-ETH, en fysikaliskt baserad nederbörd yt-avrinnings modell, som modellerat de hydrologiska aspekterna I floden och tar hänsyn till, bland annat, extrahering av vatten i bevattningssyfte och diversion till vattenkraftsdam. Dock modellerade vattenkraftverken med utgångspunkt från ett uppskattat energibehov; nödvändigtvis inte det faktiska behovet. Således föreslogs att OSeMOSYS, en LONG-TERM energi optimerings modell, skulle komplimentera denna studie genom att modellera energisystemet i Etiopien. Den här uppsatsen hade som avsikt att testa de föregående med en ansats att *undersöka* möjligheten att sammankoppla de två modellerna Topkapi-ETH and OSeMOSYS. Målet var att förse OSeMOSYS med en varierad vatten tillgänglighet från Topkapi-ETH; i retur skulle OSeMOSYS förse Topkapi-ETH med ett mer realistiskt energiproduktions behov. En modell i OSeMOSYS skapades för Etiopien, med nationella data extraherad från studien The Electricity Model Base for Africa (TEMBA), där vattenkraftverk disaggregerades för att kunna modellera varje kraftverk I Gibe kaskad schema enskilt. För att sammankoppla de två modeller skapades två tillvägagångssätt: Lagrings modul och Reservoar modul. Magasin modulen använde en lagrings funktion i OSeMOSYS med en funktion av den varierande volym i en reservoar från Topkapi-ETH som omvandlades till en potentiell energi. Reservoar modulen däremot använde externt inflöde (summan av alla flöden förutom upströms utflöde), taget från Topkapi-ETH till reservoaren. Ett försök sattes upp för att testa hur OSeMOSYS modellen, med de två modulerna, skulle reagera till indata och vilken indata som är drivande och påverkar produktionen av elektricitet. Resultaten visade att OSeMOSYS kan besvara ett varierade vatten tillgänglighet kommen från Topkapi-ETH där produktionen av elektricitet från Gibe kaskad schema återspeglade detta. Däremot fanns en missanpassning i den hydrologiska responsen där OSeMOSYS inte fullt ut avspeglade volymen i reservoaren. I vissa fall var volymen noll, vilket tyder på att inget vatten kan lagras utan allt inkommande vatten går direkt till turbiner för produktion av energi. Således, med avseende på resultaten presenterade i den här studien, kan en dra slutsatsen att OSeMOSYS kan svara på variationer i vatten tillgängligheten. Däremot, på grund av missanpassning i the hydrologiska perspektivet med avseende på volmen, så är inte sammankopplingen mellan modellerna fullständig. Före en sådan fullständig sammankoppling kan uppnås måste en förstår varför OSeMOSYS inte återspeglar denna hydrologiska karaktär. Om detta kan förstås, så kan en feedback av den fordrade energiproduktionen i Gibe vattenkraftverken återsändas tillbaka till Topkapi-ETH.

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I would like to take this opportunity to thank each and all of you who have been a part of this journey. First, I would especially like to thank Professor Paolo Burlando at the Department of Hydrology and Water Resources Management, ETH Zürich, for giving me the great opportunity to work with his team and for supervising me during the thesis. Further, I also point gratitude towards Dr. Andrea Castelletti, Dr. Daniela Anghileri and all other people at the department at ETH for the support given while conducting this thesis. And to all others I come to have contact with during this time, both in Switzerland and Ethiopia.

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Stockholm, 22th of June 2017
Caroline Sundin

List of Abbreviations

a.s.l	Above sea level
CO_2	Carbon dioxide
CRGE	Climate-Resilient Green Economy
CPLEX	Optimization software package
CSP	Concentrated Solar Power
DAFNE	Decision-Analytic Framework to explore the water-energy-food Nexus
EAPP	Eastern Africa Power Pool
EEA	Ethiopian Energy Authority
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
EIA	Environmental Impact Assessment
EIA	U.S. Energy Information Administration
ESC	Ethiopian Sugar Cooperation
ETH	Swiss Federal Institute of Technology, Zurich
GHG	Greenhouse gas
GLPK	GNU Linear Programming Kit
GNU MathProg	Modelling language
GTP	Growth and Transformation Plan
Ha	Hectare
km^2	Square kilometre
KSDP	Kuraz Sugar Development Project
KTH	Royal Institute of Technology in Stockholm
dESA	division of Energy System Analysis at KTH
IEA	International Energy Agency

IRWR	Total internal renewable water resources
J	Joule
m	meter
m^3	Cubic metre
m^3/s	Cubic metre per second
MoA	Ministry of Agriculture
MoEF	The Ministry of Environment and Forestry
MoWIE	The Ministry of Water, Irrigation and Energy
MoWR	Ministry of Water Resources
OSeMOSYS	Open Source energy Modeling System
USD	United States Dollar
NPV	Net present value
PV	Photovoltaic
RES	Reference Energy System
SNNPR	Southern Nations, Nationalities and People's Region
TEMBA	The Electricity Model Base for Africa
tcd	Tons crushed per day
Topkapi	TOPopographic Kinematic wave APproximation and Integration
W	Watt
Wh	Watt hour
WEAP	Water Evaluation And Planning system
WEF	Water, energy and food nexus
WEO	World Energy Outlook
WRDF	Water Resources Development Fund

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1 Introduction

This chapter present an introduction to the subject and area of study along with previous work and motivation of research questions. Furthermore, the research question and objectives of this study is presented as well as the outline of the remaining of the report.

1.1 Context

With more than 1.6 billion people lacking access to electricity and almost half of that not having access to contemporary water supply system in the world, the urge for meeting these demands become crucial for the socio-economic development. Energy demand is expected to increase by a third by the year 2035 and water withdrawal is excepted to increase by as much as 55% by the year 2050. Hence, seeing water as a resource for many purposes, has been emphasized as a necessity in solving this problem (WWAP, 2014). The discipline of using an intersectoral approach for the analysis is often referred to as nexus and when regarding how water, energy and food are interconnected, one often refer to it as water, energy and food nexus (WEF). This topic and related issues has been stressed and acknowledged by many different stakeholders, among others the World Energy Outlook (WEO) (IEA, 2016a). The three sectors are all sensitive in terms of their security to provide access and availability of resources. In other words, they succinctly refer to (Bizokova et al, 2013):

- *Water security:* have access to water which is safe and affordable, meanwhile protecting maintaining the environment.

- *Energy security:* have the supply being available and continuously meeting demand and its peak at a given supply-price.

- *Food security:* have access to food which is adequate, nutritional and stable from a harvest perspective.

These three security issues have been identified by the United Nations (2017) as three out of seventeen Sustainable Development Goals: Zero Hunger (Goal 1), Clean Water and Sanitation (Goal 6) and Affordable and Clean Energy (Goal 7). Since water is a resource shared amongst different sectors for different purposes, IEA (2016a) has further acknowledged the challenge that this shared use brings specifically to future scenarios with climate and population change. However, by adopting a nexus approach and exploring different scenarios, an agreement and a best management practise may be reached. For instance, one may call upon the issue of water resources management in rivers with hydropower production as well as connected irrigation schemes. The trade-off one may face is more energy production from hydropower but less water available for abstraction to irrigation schemes, leading to less efficient cropping (WWAP, 2014). Attempts to integrate these three sectors and apply an integrated modelling approach have been made over the past years with modelling frameworks having been developed to integrate them in a common, holostic analysis (Bazilian, 2011). Providing a foundation to work with these questions is essential in solving them; and development and establishment of policies are a key factor (Khan et al, 2016).

Understanding the synergies between water and energy, and further food, will need a management based on the methodology of complex inter-sectorial, stakeholder and resource analysis. The barriers to this are, among others, data availability, accuracy and sensitivity of models and isolated sector management.

The nexus problem concerning primarily water and energy, is one which has been acknowledged as an issue in countries were the energy system is expanding rapidly and were rivers with high capacity for hydropower are emerging, for instance in Ethiopia. However, the development of large hydropower plants has raised the questions on what impact on both the environment and society it may have. An example is the discussion about the Gibe cascading scheme[1] with the hydropower plants Gibe I, Gibe II and Gibe III on the Omo River, which was intensified when the Gibe III was proposed and launched. The increase of hydropower capacity and water abstraction for irrigation schemes was believed to potentially harm the streamflow regime and environment of its basin. The indigenous population living in the lower parts live of flood retreat agriculture, making them dependent on seasonal floods. Also, change in the streamflow regime may have downstream effect[2] on the Lake Turkana, where Omo river has its outflow (Agriconsulting and Mid-Day, 2009). Being able to understand this impact and understand the sensitivity of the system is essential for the future development of the cascading scheme and regulating policies, not only for this case but for other similar projects.

1.2 Previous work and motivation of research question

This thesis was evolved to support the project a Decision-Analytic Framework to explore the water-energy-food NExus in complex and transboundary water resources system of fast growing developing countries (DAFNE), for which Omo River Basin is a case study (DAFNE, 2016).

The Omo river has been modelled from a hydrological point of view using the rainfall-runoff model named TOPopographic Kinematic wave APproximation and Integration (TOPKAPI-ETH) model for the Omo river basin was based on previous developments and enhancements over the years made by Ubierna (2014), Dilnessa (2015) and Boulos (2017). In ascending orders, the different projects had more detailed configuration of the hydrological system of the basin as well as more hydropower plants included. In these three pieces of works, the energy productions from the hydropower plants in the river was calculated exogenously. Further, these studies also looked at one reservoir as one single component, without regards to the overall system, and the energy production was given the policy to meet an averaged production target as well as having environmental release policies (i.e. minimum release to preserve conditions in the river). Hence, there was a need for a supplemental model computing the energy production in a power plant given an actual demand, and at the same time regarding the dynamics in the whole system. The hydrological and energy system have different scales, making it difficult for one single model to compute the outcome. Hence, by complementing one another, the two models could tackle two different problems of water allocation and energy production, ideally with a feedback mechanism in-

[1] Cascading scheme means that two or more hydropower plants are placed after one another in a river, meaning the upstream release from a power plant will feed the downstream power plant.
[2] Less flow or less continuous flow may decrease lake levels further down the river.

between.

For the energy model, Open Source energy Modeling System (OSeMOSYS) was assumed appropriate as it has been used for energy planning and forecasting. Furthermore, storage facilities in OSeMOSYS has been developed to support technologies such as hydropower withdrawing water from storing dams (Welsch et al, 2012). However, cascading scheme in OSeMOSYS, or any storage facility such as a dam hydro power technology, has been limited to a few cases. Flood (2014) modelled cascading using the storage facilities, which, created the necessary step of converting available water to a potential energy in the reservoir and interpreting the effects on capacity and production that the flow in the rivers may have. A development of and extension to the OSeMOSYS code was done by English et al (2017) where a new technology reservoir was added with corresponding characteristics such as dam height and the change of inflow of water, determining the water availability. This study uses historical and forecasted inflows to the reservoir but no feedback to the inflow model is sent back from OSeMOSYS.

Understanding the dynamics of the attempts to model both the hydrological condition as well energy production, makes it possible to argue that a coupling of these two approaches is necessary to get a more accurate understanding of a dynamic system. Despite food being a necessary sector in the nexus approach, this first attempt will merely focus on the water-energy nexus. This thesis will have focus primarily on the energy sector and its development in the country of Ethiopia and the Omo river basin using the results and methodology found by Ubierna (2014), Dilnessa (2015) and Boulos (2017). To better understand the water and agriculture/food sector and its background for the modelling, it is encouraged to read the aforementioned studies.

1.3 Research question and objectives

The aim of this project is to explore the possibility to develop a coupled hydrological-electricity model, in other words a water-energy nexus analysis, taking the Omo River in Ethiopia as a case study. The models to be coupled are the long-term energy planning and open source model generator OSeMOSYS and the rainfall-runoff model Topkapi-ETH. The coupling of these two models would be of soft linking character and first of its kind, in other words these two models have never been coupled before. The specific aim here is to evaluate how the upstream water availability affects the electricity generation and how the electricity generation affects the downstream release. Currently, Topkapi-ETH works based on optimizing the production at all time, based on a hypothetical energy demand. OSeMOSYS on the other hand, in theory, works on a hypothetical water availability. Hence, the question to answer is whether it is possible to feed OSeMOSYS with realistic water availability, and give back to Topkapi a realistic required energy production.

The specific objectives of the thesis can be written as:

- Explore the possibility of a coupled hydrological-electricity model for the Omo river basin by setting up a OSeMOSYS model feed by hydrological inputs
- Analyse and compare the electricity production between non-coupled model and different approaches to coupling as well actual observed values

- Determine plausibility of coupling the models, e.g. by analysing the coherency between the models in terms of volume and discharge

1.4 Outline of report

The structure of the remaining of thesis is presented here. Chapter 2 describes the methodology and split up into the following overall order: literature review done to understand the system and governing equations of hydropower plants, introduction of the two models used, the set-up of the OSeMOSYS model, description of Topkapi-ETH model, framework and methodology of coupling the models and lastly the experimental set-up perform to test the developed models and approaches. Chapter 3 present the results and Chapter 4 presents the discussion and analysis of the results. The conclusion is presented in Chapter 5 and followed by proposed future work of improvements and developments in Chapter 6.

2 Methodology

This chapter presents the methodology of coupling the models OSeMOSYS and Topkapi-ETH. First, the results of the literature review are presented, which was performed to understand the system and theory behind the coupling. The following sections introduce the two models and how they work. Further sections present a shorter description of how the OSeMOSYS model was set-up and followed by two approaches of modelling reservoirs tried in this study to explore the possibility of coupling. Additional sections describe how the Topkapi-ETH output had to be adjusted to fit the coupling approach as well as how the coupling was performed. Lastly, an experimental set-up is described that was used in order to test the plausibility of the approaches.

2.1 Results of literature review

This section presents the literature review made to understand the area of study: Omo River Basin in south-west Ethiopia. It gives the overall state of the country in terms of the energy, water and agricultural sector and a detailed view of the specific Gigel-Gibe cascading scheme found in the Omo River Basin. It lastly presents important features of energy conversion and governing equations for a dam hydropower and how the water balance is set in the dam.

2.1.1 Ethiopia – country overview

The Federal Democratic Republic of Ethiopia is a land-locked country located in the eastern part of Africa with Addis Ababa as its capital city. The country is surrounded by Eritrea in north and northeast, Djibouti in the east, Somalia in the east and southeast, Kenya in the south and South Sudan and Sudan in the west. With one of the largest populations in the world, it inhabited nearly 100 million people in 2015, out of which 80 million lived in rural areas and 19 million people in urban areas. The country's total area has been estimated to roughly 110 million hectares, meaning a population density of 90 people per km^2 (FAO, 2016). The country's GDP has exponentially increased since 2000, with a value of 61.54 billion USD in 2015 that corresponds to an annual GDP growth of 9.6% (World Bank, 2017a).

Undernourishment has decreased as a result of increased food availability. This has led to enhanced dietary energy supply has increased as well, in recent days standing at a deficit of about 236 kcal/capita/day. The access rate to safe, contemporary water sources has also increased from 1990 during which 13.2% had access to safe water, compared to 2014 when the value was 55.4% (FAO, 2017). In the 2016 World Energy Outlook (WEO) (IEA, 2016b), the national electrification rate of Ethiopia was estimated to 25%; hence, 75% of the population lacks access to electricity. In urban areas, the electrification rate was 85%, whereas in rural areas it merely amounted to 10%. Out of the total population, 95% still relies on traditional biomass for primary energy use, the rest is split between electricity and heat.

Ethiopia has set as a target to reach a middle-income status with a climate-resilient, low-carbon economy through the initiative Climate-Resilient Green Economy (CRGE). The aim is to build a green economy with decrease in GHG-emissions, but still robust growth. This is aimed to be done by improving agricultural practices, protect forestry and ecosystem services, expand electricity generation from renewable resources and move steadily to modern and energy-efficient technologies (Environmental Protection Authority, 2011).

2.1.2 Water and agriculture in Ethiopia

The total arable land in Ethiopia was in estimated to about 15 million ha with a permanent crops area of 1.14 million ha, resulting in a total cultivated area of 16.26 ha (14.7% of the country's total area). There are three major agroclimatic zones: areas with low or no rainfall and without significant growing period, areas with one rainy season and a single growing period and lastly areas with two rainy seasons and double growing periods. The first zone is found in the in east, north and south; the second zone in the west; and the third zone in the east and lowlands of south and southeast. The main commodities which are exported are among others coffee, oil seeds, cereals, cotton and sugarcane (FAO, 2016). A more detailed study on the water and agricultural sectors can be found in Appendix A.

With 12 major river basins, the country has four major drainage systems: Nile Basin, Rift Valley, Shebelli-Juda and North-East coast. Most of the rivers are seasonal, but do not necessarily dry out, and in regions below 1,500 m there are few perennial rivers (FAO, 2016). The drainage systems and their respective river basins can be viewed in Table 1, presenting the economical irrigation potential (FAO, 2016) and the river basin's area and annual flow (ITAB-CONSULT PLC, 2001).

Table 1. Drainage system and their river basins with respective characteristics in Ethiopia (FAO 2016; ITAB-CONSULT PLC, 2001).

Drainage System	River Basin	Irrigation potential (ha)	Area of River Basin (km²)	Annual flow (billion m³)
Nile Basin	Abbay	523,000	199,812	52.62
	Baro-Akobo	600,000	76,000	23.24
	Setit-Tekeze/Atbara	189,000	86,510	8.20
	Mereb	500	5,893	0.65
Rift Valley	Awash	205,400	110,000	4.90
	Afar-Denakil	3,000	64,380	0.86
	Omo-Gibe	383,000	79,000	16.60
	Central Lake	139,000	52,000	5.64
Shebelli-Juda	Wabi-Shebelle	204,000	200,214	3.16
	Genale-Dawa	423,300	168,100	6.10
North-East coast	Ogaden	0	77,100	0
	Golf of Aden/Aysha	0	2,223	0

For most of the river basin, a Basin Master Plan has been conducted. These were to serve as a guide for the water allocation; however, many of these plans are outdated and may not reflect the actual need of water (FAO, 2016). Furthermore, performing isolated studies for basins, which either share regions or resources, may cause conflicts between two basins. Hence, the Ministry of Water Resources (MoWR), today Ministry of Water, Irrigation and Energy (MoWIE), developed a strategy which harmonizes the different interests of the basin as well as making them consistent with the existing national laws and policies. This also called upon investigating in an institutional set-up, either on basin, regional or national scale (e.g. through MoWR) and which would be most suitable. Having River Basin Authorities were identified as most suitable here, and would work for large- and small-scale implementation where they would coordinate and play an advisory role (ITAB-CONSULT PLC, 2001).

2.1.3 Energy in Ethiopia

Ethiopia belongs to the Eastern Africa Power Pool (EAPP) which is a regional organisation that was established in 2005, with aim to serve as a strong interconnector of electricity transmission between the member countries (Ea Energy Analyses and Energinet.dk, 2014a). The ministry of Water, Irrigation and Energy (MoWIE) is the federal institution that is responsible for policies and strategies as well as programs for energy resources. Moreover, they are also responsible for development, planning and management within the sector in relation to the resources. Under MoWIE, the Ethiopian Electric Utility (EEU), Ethiopian Electric Power (EEP) and Ethiopian Energy Authority (EEA) works. EEU are engaged in the national distribution and sale of electricity and EEP is engaged in the generation and transmission in the country. EEA is the authority that regulates activities relating to energy production, including among others safety and quality standards. The EEA further promotes and implements the Energy Efficiency and Conservation program, under which they created the Energy Efficiency & Conservation Directorate to be in charge (Atkins, 2015).

The National Planning Commission (2016) have completed the development and visions of the country has been presented the Growth and Transformation Plan II (GTP II) which present vision of how the country shall grow and transform, for the period of years 2015/16 to 2019/20, following the first version (GTP) 1 from 2009/10 to 2014/15. When GTP II was published in May 2016, the status of the country showed that per capita energy consumption was 86 kWh, which is low compared to neighbouring countries, and the electricity coverage was 60%. The final year of the plan (2019/20) aims for the consumption to increase to 1269 kWh per capita and the coverage to 90%.

In 2014, the mix of primary production of energy was consisted mainly of biofuels and waste and a smaller amount of electricity and heat. The imports of energy sources were mostly oil but also some coal and peat. No electricity was imported, but some was exported, to an amount of 3787 TJ (2052 GWh). The biofuels and waste were mainly used in for residential purposes whereas the electricity use was divided amongst the industries, commercial activities and residential purposes. The electricity use by sector can be viewed in Figure 1 (UN DESA, 2016b).

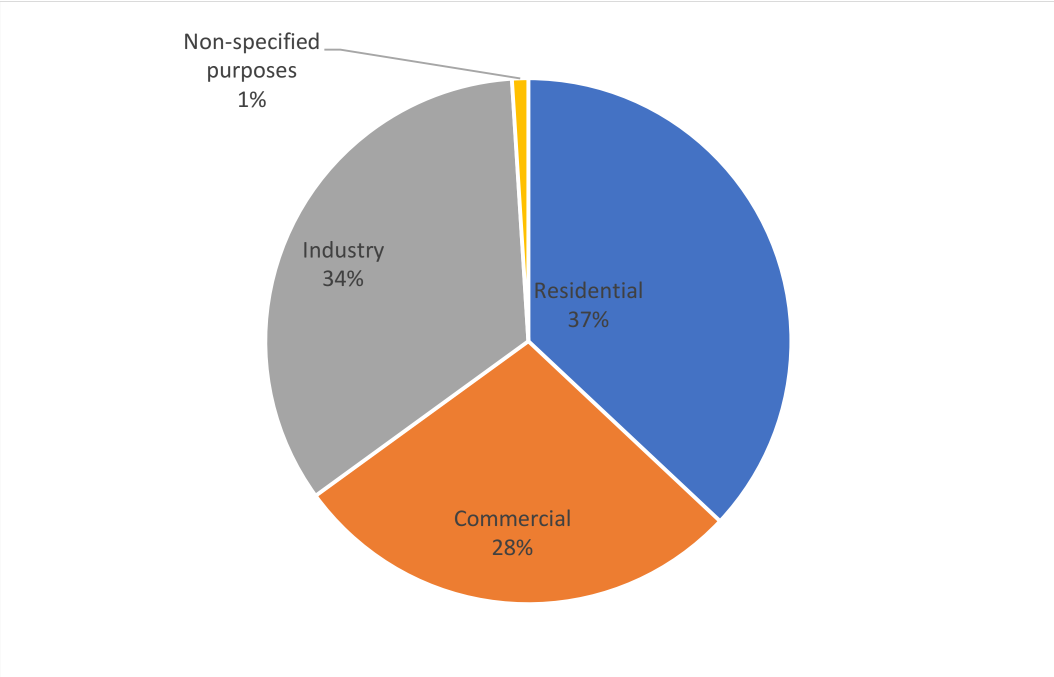


Figure 1. Share of electricity use by sector in 2014.

Regarding the electricity generation, hydropower dominates the production, with a potential of 45,000 MW (MoWIE, 2013). For instance, in 2015 Africa installed 692 MW of hydropower, out of which 374 MW where in Ethiopia, placing the country on 11th place of newly installed capacity in the world. Out of the total installed capacity, Ethiopia has the second largest amount in Africa, after Egypt (IHA, 2016). In 2014 hydropower showed dominance in the power production, with only a small part coming from combustibles and other sources, see Figure 2 (UN DESA, 2016a). MoWIE (2013) said that the two other main sources after hydropower is wind and geothermal power, which both have increasing potential. Some solar power also exists and is said to have potential for future development.

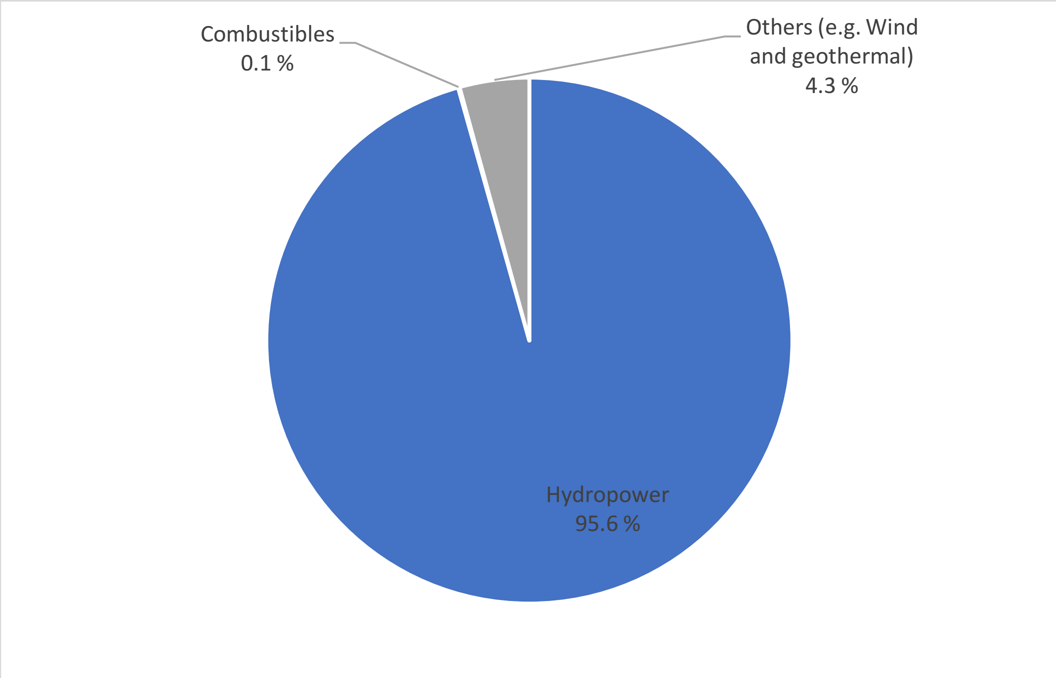


Figure 2. Share of total production by different technologies in 2014 (UN DESA, 2016a; MoWIE 2013)

The establishment of transmission lines in-between countries in Africa have made it possible for trading on the international electricity market. Having great potential of energy production. Ethiopia has put itself on a good position and is currently interconnected with Djibouti and Sudan and plans include Kenya (Ea Energy Analyses and Energinet.dk, 2014a). The Sudan connection is partly existing and is, together with connection to Kenya, part of the North-South Power Transmission corridor (IRENA, 2015). Furthermore, Eritrea and Somalia have been suggested to be potential countries of trading, however, estimates predict this to occur around the year 2025 (TEMBA). Table 2 present the interconnectors, how much capacity it has and when was commissioned or is planned for (Taliotis et al, 2015).

Table 2. Transmission connections between Ethiopia and trading countries.

Connection	Capacity [MW]	Status	Year of introduction
Ethiopia – Djibouti	180	Existing	-
Ethiopia – Sudan	6600 (200)[1]	Existing	-
Ethiopia – Kenya	2000	Planned	2018
Ethiopia – Eritrea	200	Assumed	2025
Ethiopia – Somalia	400	Assumed	2025

[1] 200 MW is currently existing of 6600 MW in total

To meet the trading demand, expansion of hydropower has been identified to be a solution due to its high potential. The Blue Nile, with Grand Ethiopian Renaissance

Dam, and the Omo River, with the Gibe hydropower cascading scheme, have proven to have the biggest potential for hydropower in the country (IHA, 2016).

2.1.4 The Omo river basin

The Omo river basin, located in the south-western part of Ethiopia, lies within the Rift Valley drainage system, see Figure 3. The river has its outflow in Lake Turkana, Kenya, in the south. The figure also shows the regions of the country, which themselves are further split into sub-regional levels called w*eredas*. The Omo river flows from north to south, with the tributaries Gibe and Gojeb rivers. The basin has a total area of 79,000 km^2 and an annual flow of 16.6 billion m^3, reaching Lake Turkana in the outlet of the Omo River. The basin is shared between the regions Oromiya and the Southern Nations, Nationalities and People's Region (SNNPR), approximately 25% and 75% respectively (ITAB-CONSULT PLC, 2001).

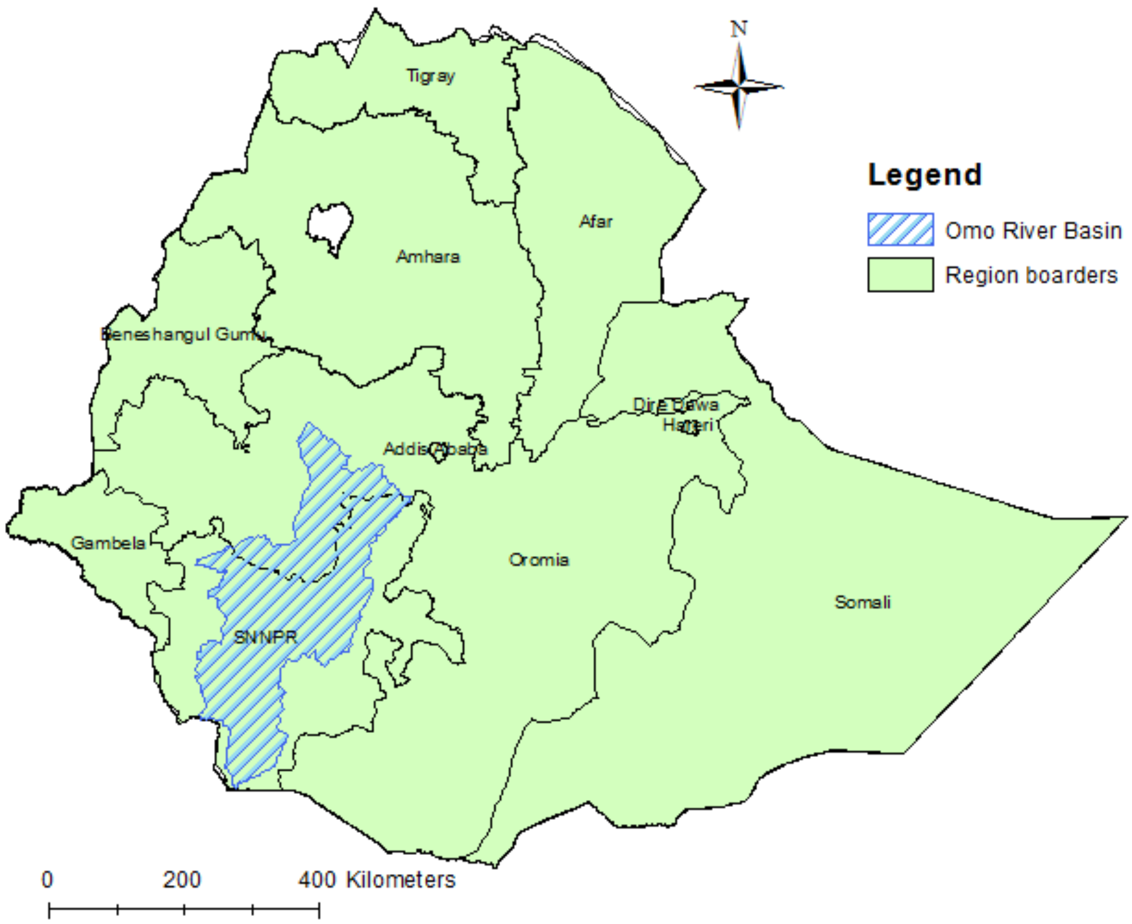


Figure 3. The Omo river basin location in Ethiopia modified in ArcGIS with data from Boulos (2017) and Map East Africa (2017).

As for the rest of the country, most of the agricultural activity is rain-fed and dominated by smallholder farms. About 90 % of the annual run-off in the basin is concentrated to

July to September, meaning irrigation and hydropower production is dependent on storage reservoirs (ITAB-CONSULT PLC, 2001). The hydropower potential in the basin have been estimated to a total of 2,583 MW (mostly large scale). The irrigation potential differs between studies, FAO (2016) estimated 383,000 ha and the Omo-Gibe Master Plan (2001) estimated 348,000 ha. The major power plants operating in the basin are three Gibe hydropower plants, currently operating in a cascading scheme: Gibe I, Gibe II and Gibe III. Plans have been made to establish two additional hydropower plants in the Gibe cascading scheme: Gibe IV and Gibe V. However, recently a new power plant Koysha has just started to be constructed at close location to the proposed location of Gibe IV and V, raising questions on whether the two latter will be built at all (Salini Impreglio, 2013). The hydropower plant setup is described more in detail in next section.

Additional information regarding agriculture and establishment of sugarcane cultivation as well as physical properties of the basin can be found in Appendix B.

2.1.5 Gibe-hydropower cascading scheme

The Gigel-Gibe hydropower cascading scheme currently consists of the three operating power plants Gibe I, Gibe II and Gibe III. As mentioned earlier, the plan before was to expand this scheme with two new plants: Gibe IV and Gibe V. However, the new project of Koysha hydropower plant was started in 2016 (Salini Impreglio, 2004), with a capacity equal almost to that of Gibe IV and Gibe V together. The current set-up of the power plants is presented in Figure 4. Gibe I is connected via a 26-km long tunnel to Gibe II, meaning the outflow of Gibe I feeds Gibe II. Downstream of Gibe II, the newly built Gibe III is located. Included in the figure is also the locations where it has been proposed that Gibe IV and Gibe V would be build but also where the location of the new project Koysha hydropower is.

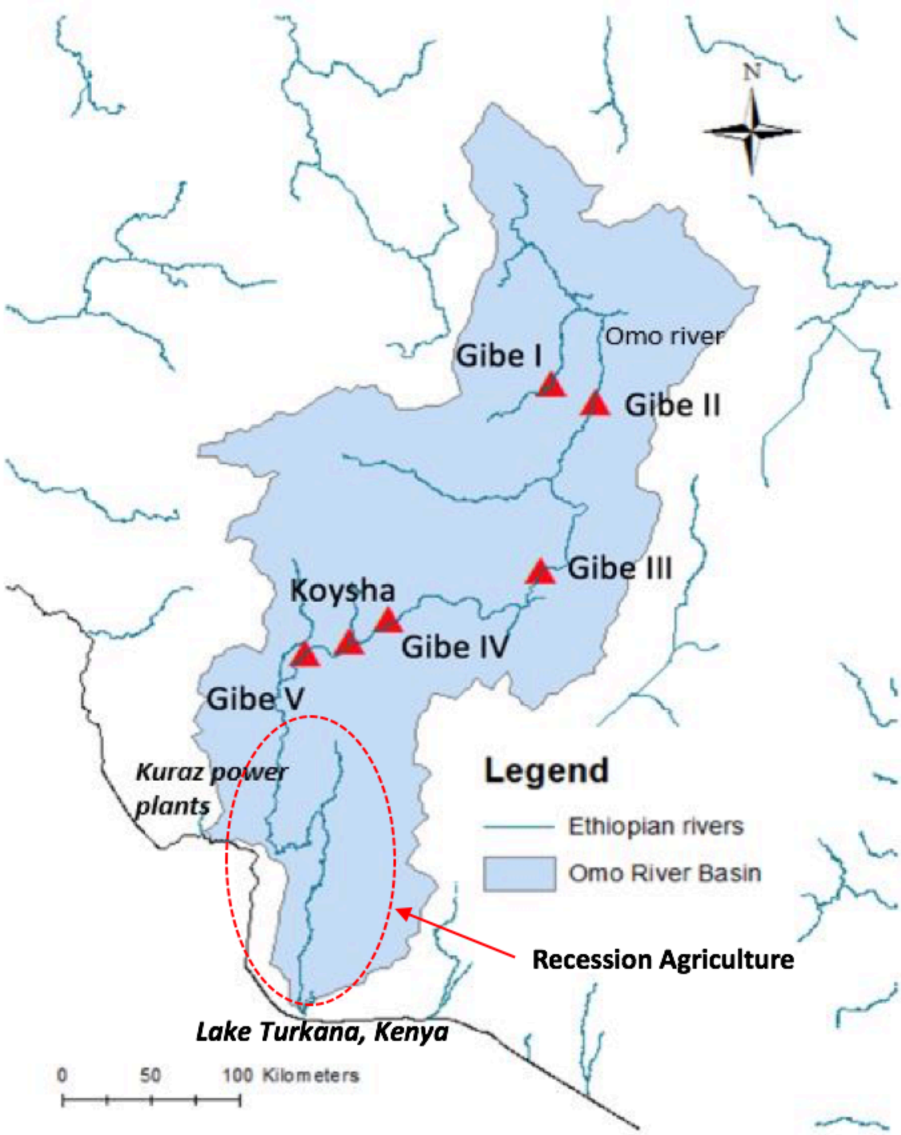


Figure 4. Location of existing and planned hydropower plants as well as location of recession agriculture in the Omo river basin modified in ArcGIS with data from Boulos (2017). The outflow in the south is into Lake Turkana, Kenya.

Table 3 contains features of the six different dams, commissioned or planned, on the Omo River. Those denoted with "-" means either not applicable or no available information. RC = reinforced concrete and RCC = Roller Compacted Concrete.

Table 3. Features of hydropower project commissioned or planned on the Omo River

Features	Gibe I	Gibe II	Gibe III	Gibe IV	Gibe V	Koysha
Status (year)[1]	In operation (2004)	In operation (2010)	Filling phase (2015)	Planned (2020)	Planned (2020)	Commissioned (2017)
Installed capacity [MW] [1]	184	420	1,870	1,472	436	2,160
Power production [GWh] [2]	722	1,635	6,500	5,917	1,937	6,450
Dam type[3]	Rock	RC	RCC	RCC	RCC	-
Dam height [m] [3]	40	55	243	164	60	178.5
Dam volume [Mm^3] [4]	839	-	14,700	10,000	-	6,000
Turbine[5]	Francis	Pelton	Francis	-	-	Francis
Plant factor[6]	0.46	0.44	0.46	-	-	-

[1] EAPP Masterplan (2014b) except: Koysha from Salini Impreglio (2014)
[2] UNEP (2013) except: Gibe III from CESI and Mid-day (2009) and Koysha which is from Salini Impreglio (2014)
[3] UNEP (2013) except: Koysha from Salini Impreglio (2013)
[4] Gibe I from Salini Costruttori S.p.A ad CESI (2004), Gibe III from CESI and Mid-day (2009), Gibe IV from UNEP (2013) and Koysha which is from Salini Impreglio (2013)
[5] Gibe I & II from Pietrangeli and Pallavicini (2007), Gibe III from CESI and Mid-day (2009) Koysha from Salini Impreglio (2014)
[6] CESI and Mid-day (2009)

Several environmental impact assessments (EIA) have been conducted for the Gibe power plants on their impacts in the lower Omo River region; mostly for hydrological and environmental purposes but also socio-economic ones. Depending on the year of publishing, they study different Gibe power plants, e.g. studies before 2009 are for Gibe I or II and studies after are mainly for Gibe III. The result of how the power plants would affect the level of Lake Turkana differs; where the majority state that the level would decrease but a couple of studies claim it could instead have positive impact. Additionally, how much the lake level would decrease varies, from levels of 1.5 m to as high as 12 m (UNEP, 2013). Avery (2010) acknowledged the case of the Gibe hydropower to create issues of transboundary challenges since the Omo river lies within Ethiopia and Lake Turkana almost fully in Kenya.

The downstream population, in the lower Omo, practise farming which often is retreat flood cultivation; meaning it is dependent on seasonal flood that floods the land on the plains leaving the crops to use the residual soil moisture (CESI and Mid-day, 2009). Further, Omo River also serves 90% of the total inflow to Lake Turkana (Avery, 2010). The benefits of the cascading scheme would be to increase the: electricity generation contributing to the national grid, labour opportunities and economical revenues (Salini Costruttori S.p.A and CESI, 2004; CESI and Mid-day, 2009). The EIA for Gibe II (ibid.) concluded that the project may have impact on the flood occurrence, reducing its frequency. During the dry seasons, it was also proposed that the power plants would have a compensatory release of water, in order to maintain the ecosystem downstream.

When Gibe III was proposed and under planning, the EIA identified potential impact of the lower Omo region due to change in river conditions. These were mainly connected to the recession agriculture, dry seasons grazing and fishery resources induced the need of controlled environmental floods. The reason behind it was the fact that the reservoir of Gibe III would regulate the flows downstream in the river, causing more flow during dry season and less flood during wet seasons as water is then retained. It was then proposed that the controlled flood should occur for 10 days during August and September, as the original time of the natural occurring flood (CESI and Mid-day, 2009). Another study made on the impacts of Gibe III showed that the monthly average flows at Gibe III site and at the inflow to Lake Turkana changed and would change accordingly in the dry and wet season respectively. During the peak in August and September, the flow could be as much as half of the natural in the Omo river and nearly as much in Lake Turkana. With the controlled flood, one could raise the flow to the natural occurring one, however not enough to cover the entire duration of the peak (Agriconsulting and Mid-Day, 2009). However, the controlled flood was questioned by Avery (2010) who discussed weather a 10-days flood pulse would be enough but instead several pulses with another duration may be better.

2.1.6 Hydropower

There are three different categories of hydropower: run-of-river, reservoir and pumped storage. The run-of-river uses natural inflow from the river and is therefore dependent on the instant flow, hence, having no or little storage. A reservoir, on the other hand, may store water in a dam making the production relying on the available volume and the hydraulic head. One major advantage is that a reservoir can store larger volumes of water from for instance snow melt in the spring, making it possible to meet higher demand of production during low seasonal flow. Lastly, a pumped storage pumps water from a river or a lower reservoir up to a higher reservoir where it is released (IRENA, 2012). The configuration of placing two or more hydropower downstream of one another is called cascading. This means that that the upstream power plant regulates the flow downstream by changing its release. However, if the downstream power plant is a run-off-river, this regulation is often more significant than it is a reservoir; reservoirs are storing water in much larger volumes than the incoming water (IEA, 2012). Hydropower from an environmental and socio-economic perspective is presented in Appendix C.

The energy in a reservoir can be computed using Bernoulli's equation (University of Leeds, 2017) for potential energy in Equation 1:

$$E = \rho * g * h * V \qquad \textbf{Equation 1}$$

Where E is the potential energy in J, ρ is the density in kg/m^3, g is the gravitational constant 9.81 m/s^2, h the hydraulic head in m and V the volume of the reservoir in m^3.

The potential energy is turned to kinetic energy when the water is released and the power output of the hydropower plant is dependent on the volume flowing through the turbine. By modifying the equation used in the study by, for instance, Cervigni et al (2015) and applying Bernoulli's equation, one gets the following relationship in Equation 2:

$$P = \rho * g * h * Q * \eta \qquad \textbf{Equation 2}$$

Where P is the power output in W, ρ is the density in kg/m^3, g the gravitational constant 9.81 m/s^2, h the hydraulic head in m, Q the flow through the turbine in m3/s and η the efficiency of the turbine.

The water balance of a reservoir can be written in different ways but commonly include the terms in Equation 3 proposed by Miyamoto (2009).

$$S_j = S_{j-1} + (Q_{in,j} - Q_{out,j}) - (E_j - P_j) - PE_j \qquad \textbf{Equation 3}$$

Where S is the storage of the reservoir, Q_{in} the inflow and Q_{out} the outflow of the reservoir, E the evaporation, P the precipitation and PE the percolation. All variables in the unit of m^3. The j stands for the time, e.g. day or year, the parameters are measured for.

2.2 OSeMOSYS and Topkapi-ETH

OSeMOSYS is a long-term energy planning tool that uses linear optimization. The code of the OSeMOSYS model is written in modelling language GNU MathProg and the open source GNU Linear Programming Kit (GLPK) (GLPK, 2010) may be used for the solving of code. If the code is too big or complex, the optimization software package CPLEX (IBM) is advised. The objective function of the model is to minimize the net present value (NPV) costs of the energy system, for a given energy demand. The energy demand is exogenously defined for various forms such as electricity, heat, transportation etc. The model is divided into "blocks", all including specifications of the objective. The blocks are: costs, storage, capacity adequacy, energy balance, constraints and emissions (Howells et al, 2011).

Topkapi-ETH is a physically based rainfall-runoff model. It was first developed by Prof. E. Todini at the University of Bologna and was modified in 2012; also, given the new name Topkapi-ETH. The modifications were made at the Department of Hydrology and Water Resources Management at the Institute of Environmental Engineering, at ETH Zurich. The new version adds to the old one the possibility to add, among others, anthropogenic structures such as reservoirs, geomorphological processes as erosion as well as the possibility to integrate it with other models to increase the modelling capacity of the model. The main inputs are temperature, precipitation and cloud cover transmissivity. The outputs are many and depending on the scope; one can get volume of and inflow to a reservoir, evaporation, percolation etc. The components that build of the models are meteorological (e.g. irradiance), hydrological (infiltration), anthropogenic (e.g. reservoir) and geomorphological (e.g. channel bed-load transport). The model works on a basis of grid cells where flow directions are defined by the 2x2 neighbourhood with one outflow direction (Rimkus, 2013).

2.3 System boundaries in Omo River Basin

The main focus area of this study was the Omo river basin and the Gibe cascading scheme. However, due to the limitations that a local model of the Omo River Basin may yield in terms of, for instance, no consideration of transboundary trading of electricity and meeting demands by production of other technologies, a national model with expansion of the Omo river basin was created. The national model for Ethiopia was extracted from The Electricity Model Base for Africa (TEMBA) (Taliotis et al, 2015) and its data was obtained from division of Energy System Analysis (dESA) at KTH, Stockholm[1]. For certain assumptions made in TEMBA, which are not mentioned in this report, and further information about how TEMBA was developed one can refer to the work made by Taloitos et al (ibid.). Whenever mentioned again in this report, TEMBA refers to the data, assumption and methodology of that study.

It was necessary to set the boundaries for the Omo river basin in regards to which energy sources to model. As discussed in Section 2.2.5 Gibe I, II and III are operating and/or in filling phase. The next expansion of the hydropower has earlier been to first build Gibe IV and later on Gibe V. However, as likewise discussed in Section 2.2.5, Koysha hydropower plant was last year commissioned and the construction has started. Since the information is contrarious, this study took on three different set-ups, based on the scheme viewed in Figure 5. The first set-up used the current operating one with Gibe I, II and III. The second set-up added Koysha to the current one whereas the third set-up added Gibe IV and V.

In addition to the hydropower plants mentioned above, a try of including the planned Kuraz power plants (see background in Appendix B) was also done. These include a total of 220 MW installed power divided on six power plants. These proved not to produce anything, or very little in the end of the simulation period, and was hence omitted in the final results (Ea Energy Analyses and Energinet.dk, 2014b)

The modelling period was chosen for 2010-2050, as in TEMBA, in order to be able to model long-term energy transitions in the country.

[1] KTH - School of Industrial Engineering and Management, Unit of Energy Systems Analysis, Brinellvägen 68, SE-100 44 STOCKHOLM, Sweden

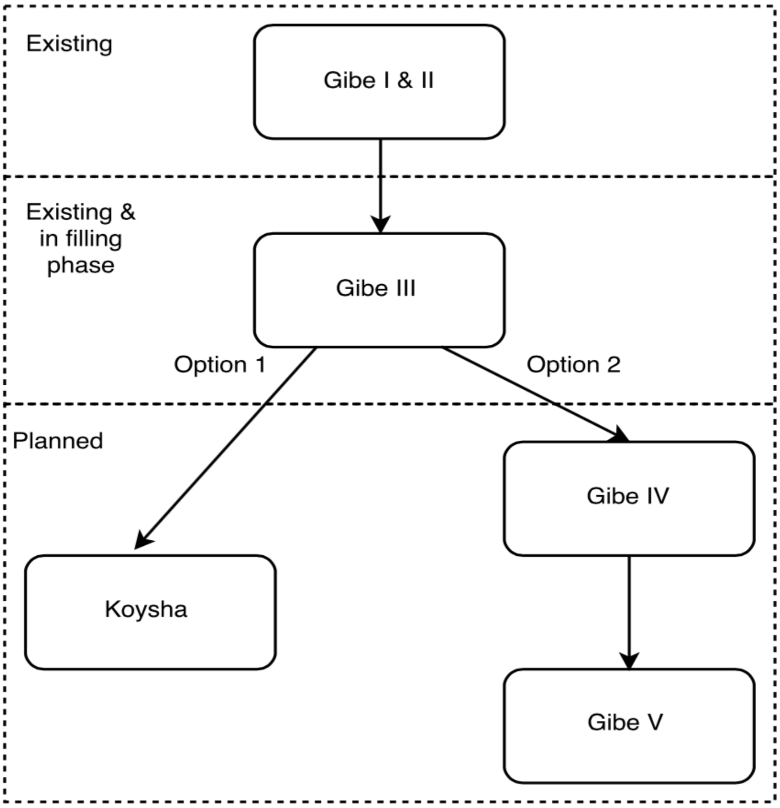


Figure 5. Possible set-ups of hydropower in the Omo River Basin.

2.4 Assumptions & limitations

The major assumptions and limitations of the methodology are presented below.

- The hydropower plants Halale Werabesa and Gojeb dam are planned on the tributaries to Omo river. However, due to limitations in finding data and the decision of only considering the Gibe cascading scheme and the alternative Koysha, these two projects were omitted from this study.
- Transmission lines for trading were set up in the model; however, since only Ethiopia was modelled, simply one-way direction is accounted for (i.e. exports from Ethiopia).
- All hydropower plants are assumed to have a dam. However, in reality, Gibe II is considered a run-off-river fed by the release of Gibe I. But for the first try in this study, it was assumed that Gibe II is having a dam but which is considered to have inflow corresponding to the outflow from Gibe I and a volume and inflow dependent on the one of Gibe I. This assumption is one made in order to make the model run smoothly and to be able to capture the cascading characteristics. However, there was also tests done removing the reservoirs of Gibe II, more in the sense of theoretically treating it as a run-off-river.
- Topkapi-ETH had, in the most updated version, a time resolution of days. OSeMOSYS is a long-term energy model, meaning that it does not necessarily specify as much details. This puts limitation to the coupling and these assumptions are discussed in detail in Section 2.7.

- Topkapi-ETH is currently just available in a period of 10 years. Hence, in order for the model to run until 2050, values had to be repeated for year following this period. This is discussed in detail in Section 2.8.
- In order to match the objectives of this thesis, TEMBA and its values were adjusted to fit the new time resolution. Further, the specific technologies in the Omo River Basin were first abstracted from the corresponding parameter (e.g. dam hydropower) and later added as single technologies for each power plant.

2.5 The OSeMOSYS model

The OSeMOSYS model is defined by *Sets* and *Parameters*. *Sets* are elements in the model which are constant throughout the whole modelling period. The sets can be for instance technologies producing energy (e.g. biomass power plant) and fuels which are energy carriers (e.g. biomass or transmission lines). A full list of the sets can be found in Appendix D. *Parameters* on the other hand, are functions of the sets which may change over the modelling period. For instance, it can be the variation of *CapitalCost* for the fuels, technologies and storage or the demand from different sectors. A full list of the parameters and their default or one-time values used in this study can be found in Appendix F.

The next sub-sections will describe the most important features of the sets and parameters for the OSeMOSYS model but is supplemented with additional information of the methodology in Appendix E and data in Appendix F. Two approaches to coupling were performed, using two different methodologies and codes in OSeMOSYS. The approaches are explained briefly in Section 2.6 and in detail in Appendix E and data in Appendix F.

2.5.1 Reference Energy System

A Reference Energy System (RES), which defined the available energy conversion and production technologies, of Ethiopia can be viewed in Figure 6. It separates the national system with continuous line to the Omo River Basin in dashed lines. Technologies (such as fuel extraction, power plants, transmission lines etc.) are represented in blocks whereas energy carries are represented as lines.

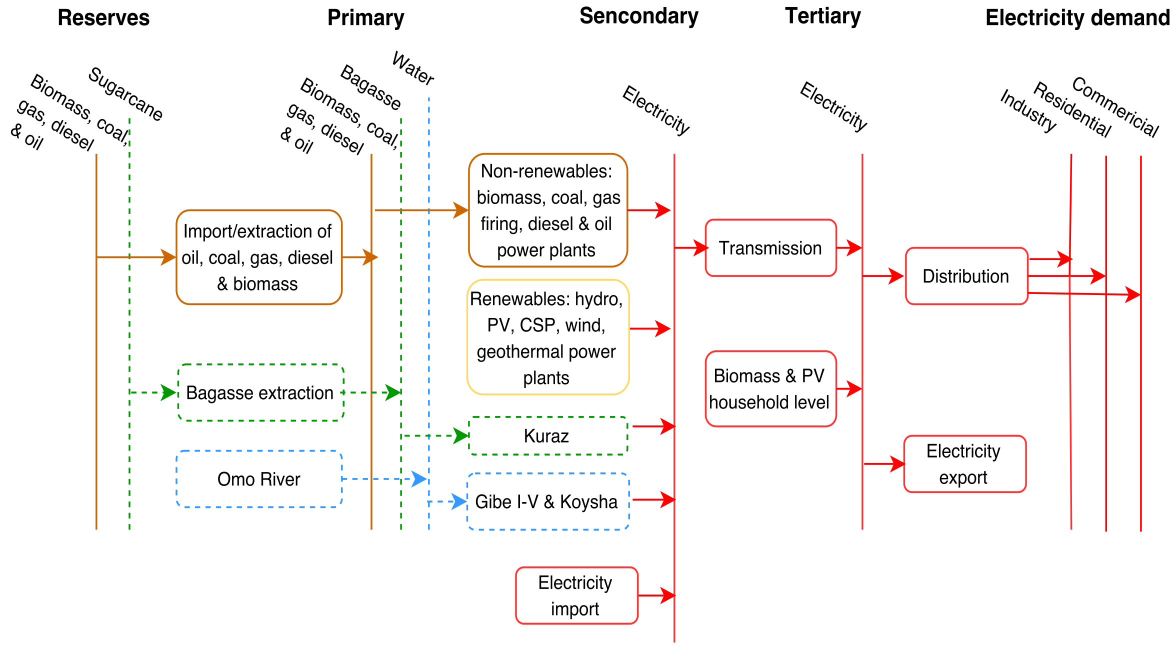


Figure 6. Reference Energy System for Ethiopia (continuous) and Omo River Basin (dashed).

Sets and parameters written in italic refers to the actual name it has in the model, e.g. *CapitalCost* is the parameter capital cost assigned for a technology.

2.5.2 OSeMOSYS model set-up

Below is a brief description of the main parameters used in the OSeMOSYS set-up. As mentioned earlier, they are further described in Appendix E and with its data in Appendix F.

The **Units** chosen for the model were PJ for energy, GW for power, MUSD (USD 2010) for monetary values and Mton for emissions. As there is no unit conversion in OSeMOSYS, the units should be consistent for all inputs. For instance, since power is in GW and monetary value in MUSD, the *CapitalCost* for a technology will be entered as MUSD/GW.

The **Time split** was done using 12 seasons each one corresponding to one month of the year. Further these were split into day and night, hence, creating 24 *TimeSlices*.

The **Demand** was assumed to be represented by three demand sites:

- **Industry.** Heavy industry
- **Urban.** Urban residential and commercial and services
- **Rural.** Rural residential

The final demand can be viewed in Figure 7 and is based on final electricity consumption for 2010-2014 from the IEA (2017) and with future assumption of a decreasing industrial demand and an increasing rural and urban demand. The industrial demand was projected to have an annual decrease whereas the urban and rural demand was projected to have an increase to meet a final electricity consumption target in 2050.

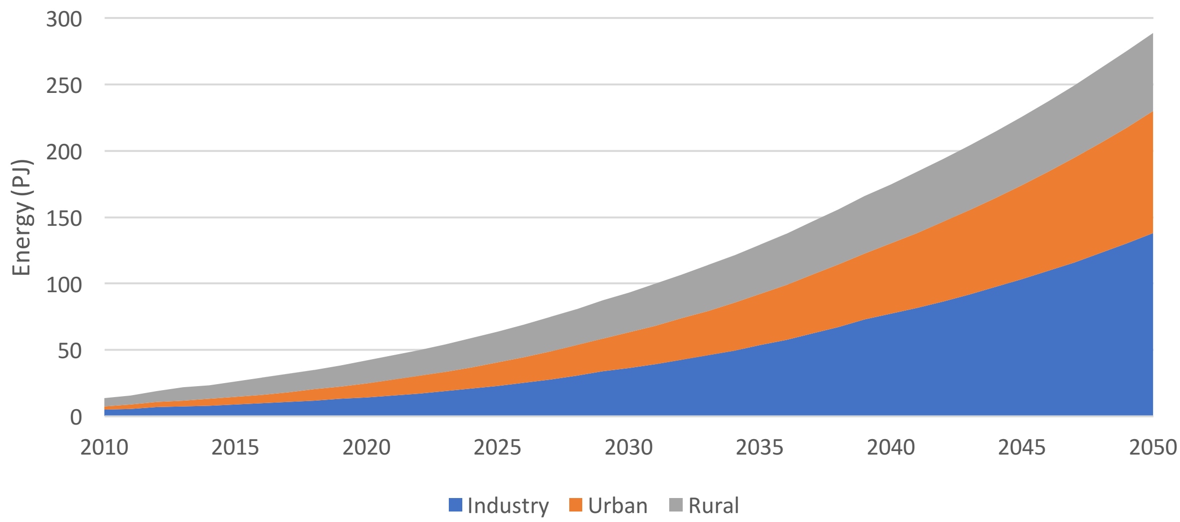


Figure 7. Projected industrial, urban and rural demand of Ethiopia used in this study.

The **Costs** assigned to the sets (fuels and technologies) in OSeMOSYS are represented by the parameters *CapitalCost*, *FixedCost* and *VariableCost*. Capital cost is a one-time cost needed to install the capacity and bring the power plant into operation. Fixed costs and variable costs correspond to operation and maintenance costs. Fixed cost is not dependent on the amount of production and is hence fixed; variable on the other hand varies with the amount of production. The costs for fuels and technologies in TEMBA were kept the same. For the technologies in the Omo river basin, the capital costs for Gibe I-III, Koysha and Kuraz were obtained from U.S. Energy Information Administration (EIA) (2013) and for Gibe IV & V the EAPP Masterplan (Ea Energy Analyses and Energinet.dk, 2014b) was used. Furthermore, fixed and variable costs were also obtained from EAPP masterplan (ibid.) except for Koysha hydropower plant since this one is not included there, instead it was assumed to have the same value as the other hydropower plants. Lastly, the costs of different technologies usually depend on the learning curve of the specific technology; for renewable technologies, the costs usually drop faster than those for e.g. fossil fuel. The trend line used for the costs in this model is based on the same trend as the one in TEMBA.

The **Capacities** of the technologies are constrained by different parameters, among others:

- *TotalAnnualMaxCapacity*. Assumed to be the installed capacities for existing or planned technologies.
- *ResidualCapcity*. Capacity remained before the modelling period, i.e. technologies present before the modelling starts. For this study, this was assigned to the technologies in the Omo river basin to “force” the model to use them.

- *TotalAnnualMaxCapacityInvestment & TotalAnnualMinCapacityInvestment*. Maximum and minimum investment respectively done in a technology each year. Only used for technologies from TEMBA.

Additional parameters constraining the capacities of certain technologies are upper and lower boundary of the activity, either on annual basis or as a single value for the entire modelling period. Again, these were only used for technologies from TEMBA.

The **Availability** determines the maximum time a technology may run for the whole year. On the other hand, the **Capacity** of technologies determines how much a power plant can produce in a year over what it would produce if it ran at full capacity during this year. The **Operational life** of technologies determines how long they may be in practise for. All these three parameters were adopted from TEMBA for the new technologies in Omo River Basin, except for the capacity factors for Gibe I-IV and Koysha, these calculations can instead be found in Appendix E.

The **Input** and **Output** to and from a technology with respect to a fuel tells how many units of input fuels are required to produce 1 unit of output fuel and how much energy is produced when we enter I unit of energy as input respectively.

2.6 Modelling reservoirs

This section will present the first step of making it possible to couple the model by creating reservoir features in the OSeMOSYS model for the hydropower plants that can receive hydrological inputs from Topkapi-ETH. Two approaches were used for this, which are both explained in the sub-sections.

The two approaches made in OSeMOSYS to model hydropower reservoirs was distinguished by: the first one being a function of the volume (m^3) whereas the other one being a function of the flow (m^3/s). The first approach, using volume as the main governing variable, will be referred to as *Storage module*, as it uses the built-in feature of storage in the original OSeMOSYS code[1], which can have different kinds of storages (i.e. hydropower dam, battery etc.). The other approach, using the inflow as governing variable, will be referred to as *Reservoir module*, as it uses an extension in the work by English et al (2017)[2] that represents a reservoir in hydrological terms. Figure 8 shows the general approach of the system which applies for both approaches.

The primary reason why choosing these two approaches was firstly to assess the differences, since they use different input and modelling approach, in its modelling performance and how they can represent reality. Further, it was also of interest to try them both in order to assess the difficulties of coupling; in other words, how they differ in terms of input, output and how much external calculations needed.

[1] *The code can be found at:* https://github.com/tniet/OSeMOSYS/blob/279552b34300350d43e5c77247f8175d7d8ac0c7/OSeMOSYS_GNU_MathProg/osemosys.txt

[2] *The code can be found at:* https://github.com/tniet/OSeMOSYS/blob/master/OSeMOSYS_GNU_MathProg/osemosys_short.txt

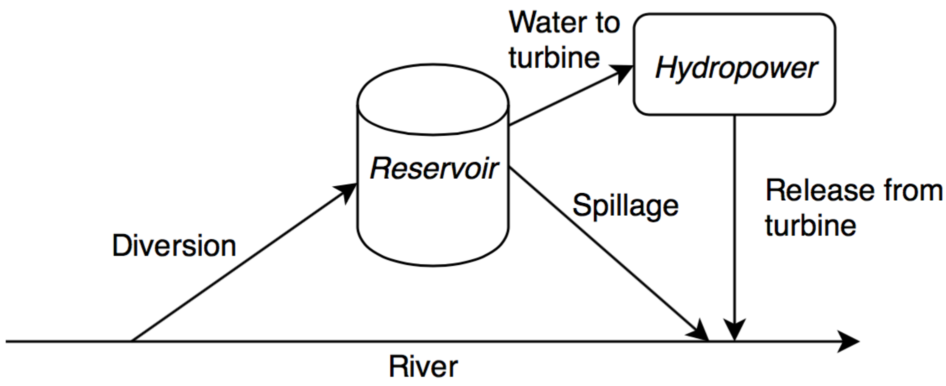


Figure 8. Overview of the system of a reservoir and hydropower with possible spillage.

2.6.1 Storage module

Storage is a feature within the original OSeMOSYS code; a visualization of how the storage set-up works can be viewed in Figure 9. However, the specific approach of using storage presented in this study was developed by the author of this thesis by adopting parts of the methodology by Flood (2014), where storage was also modelled in OSeMOSYS using similar requisitions, and concepts of coupling between the hydrological model WEAP (Water Evaluation And Planning system) and OSeMOSYS by Cervigni (2015). The methodology and assumptions of the Storage module is described in detailed in Appendix E with input data in Appendix F.

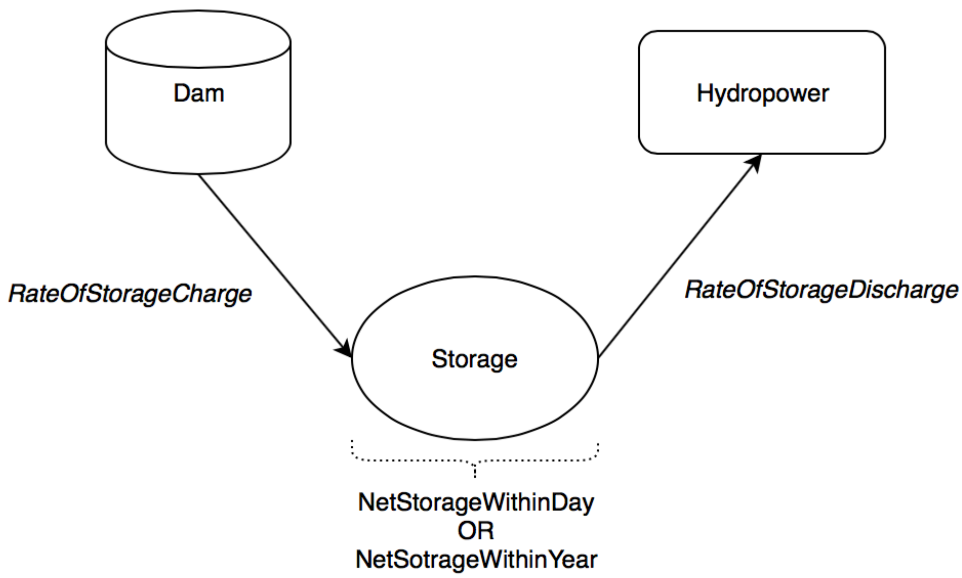


Figure 9. Storage module set-up in OSeMOSYS with the features dam, storage and hydropower.

What the major difference between having a storage compared to not having one, is that the storage can be used at a time where the demand is high but the capacity of other technologies is low. Looking at Figure 9 again, a technology first charges the storage, when it is economically convenient, in one mode of operation[1] through the *RateOfStorageCharge*. This is lowered constrained by the activity of the dam (*RateOfAcitivty*); hence, the dam constrains the storage. When the storage is discharged through the *RateOfStorageDischarge*, the opposite occurs which constrain the activity of the hydropower, i.e. "forcing" it to take energy. Moreover, the activity of the technology is constrained by the capacity factor (see definition in Appendix E), meaning that if the capacity factor of the dam is low, the system will be forced to spend a lot of money to meet the demand with other, more expensive, power plants[2]. However, if there is storage available, this can be used in times when demand is high and capacity factors are low, resulting in less cost for the system. Since the objective function is to minimize the cost and meet demand, then OSeMOSYS will chose to use storage at those times.

2.6.2 Reservoir module

The new extension of the OSeMOSYS code with having a reservoir, makes it possible to use hydrological inputs without externally converting them to energy. Each hydropower plant was assigned a reservoir and the main hydrological variable was the external inflow, which refers to all inflow which do not come from upstream release, i.e. the collection of precipitation, runoff, baseflow etc. Figure 10 shows a visualization of the system when using reservoirs and their main parameters; again, the bold terms refers to a general water balance whereas the terms in italic refers to the OSeMOSYS parameters. The methodology and assumptions of the Reservoir module is described in detailed in Appendix E with input data in Appendix F.

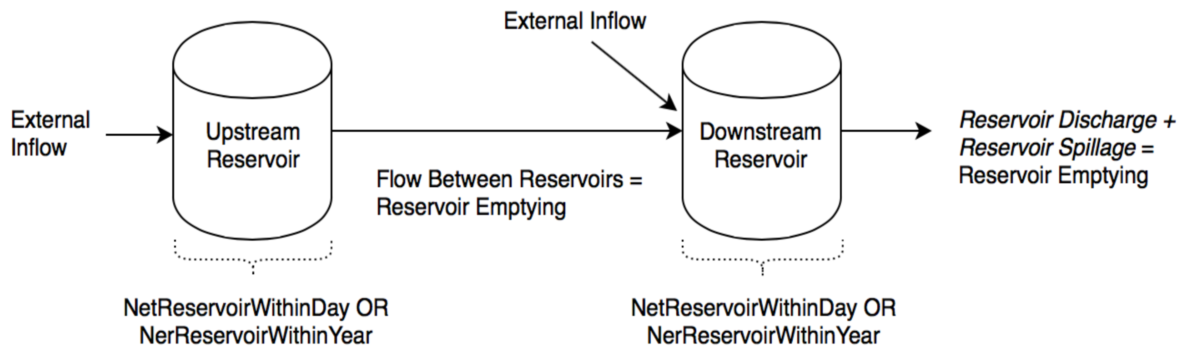


Figure 10. Schematic view of the system and its flows with main parameters in the Reservoir module code.

---

[1] A technology can have a different modes of operation in which is can do different things, for instance a biomass plant can produce heat in one mode and electricity in another. Same thing applies for the storage, it is being charged in one mode and discharged in another one.

[2] If a power plant A has lower capacity factor than power plant B, then A will produce less per time unit and hence the cost will increase

Again, reservoirs were in this approach first incorporated in the model to have storage or water which can be used to balance the demand and generation. The reservoir approach follows the same reasoning as the storage module when it comes to capacity factors; the activity is constrained by the available water, maximum flow rates and the storage capacities of the reservoirs. The reservoirs modelled in this study did not have storage in order to avoid having to convert water into potential energy again (leading to possible errors) and since no actual data for the storages was available.

2.7 Hydrological input from Topkapi-ETH

Topkapi-ETH was used in this study as the hydrological model for the Omo river basin. The model computes various outputs; where the ones of most interest were, the ones obtained from the lake/reservoirs monitoring. The outputs for the reservoir and all time steps were: volume (m^3), water level (m), inflow (m^3/s), outflow (m^3/s), evaporation (m^3/s), infiltration/exfiltration (m^3/s) and indication of overflow (1 for overflow and 0 for no overflow). In order to couple the models, the time resolution had to be matched. OSeMOSYS can have very small time steps, however this brings computational problems and since it was only the hydropower plants in the Omo river basin which would be modelled in more detail, a middle way was sought. This middle way was to make monthly averaged values, which makes it possible to capture hydrological differences over the year, such as the flooding and high precipitation in August and September. Hence, values from Topkapi-ETH of volume and flow in and out of the reservoirs were calculated into monthly averages. The water level was also monthly averaged, as it was needed when calculating the head of the reservoir. The outflow of the reservoirs was made into yearly averages, in order to compare these values with the new modelled ones in OSeMOSYS. The values of the averaged outflow can be found in Appendix G.

The reader should note that in Boulos (2017), different policy releases for Gibe III were modelled: 1) no release, 2) 10-day release á 1000m^3/s and 3) 10-day release á 1200 m3/s. However, for this study only policy one (1) was considered.

2.8 Coupling of models

This section will describe how the coupling of the models was performed and how the methodology was systematically developed. The basic idea for the coupling is to soft-link them and feed the OSeMOSYS model with either the volume available in the reservoirs (storage module) and the external inflow to the reservoirs (reservoir module), see Figure 11 and 12. The output in terms of release of water and how the volume of the reservoir changes, could potentially be a feedback back to Topkapi-ETH in future work. The two next sub-sections each present how this linking was done for the two approaches respectively. Blue colour indicates variables from Topkapi-ETH and orange indicates variable calculated within OSeMOSYS.

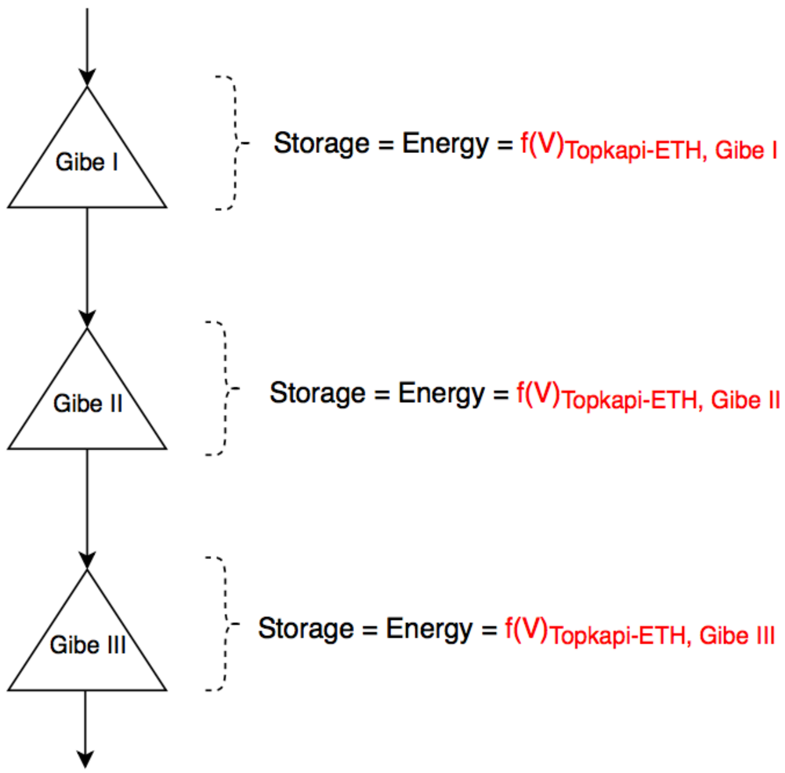


Figure 11. Framework of how to couple and integrate Topkapi-ETH with OSeMOSYS in Storage module.

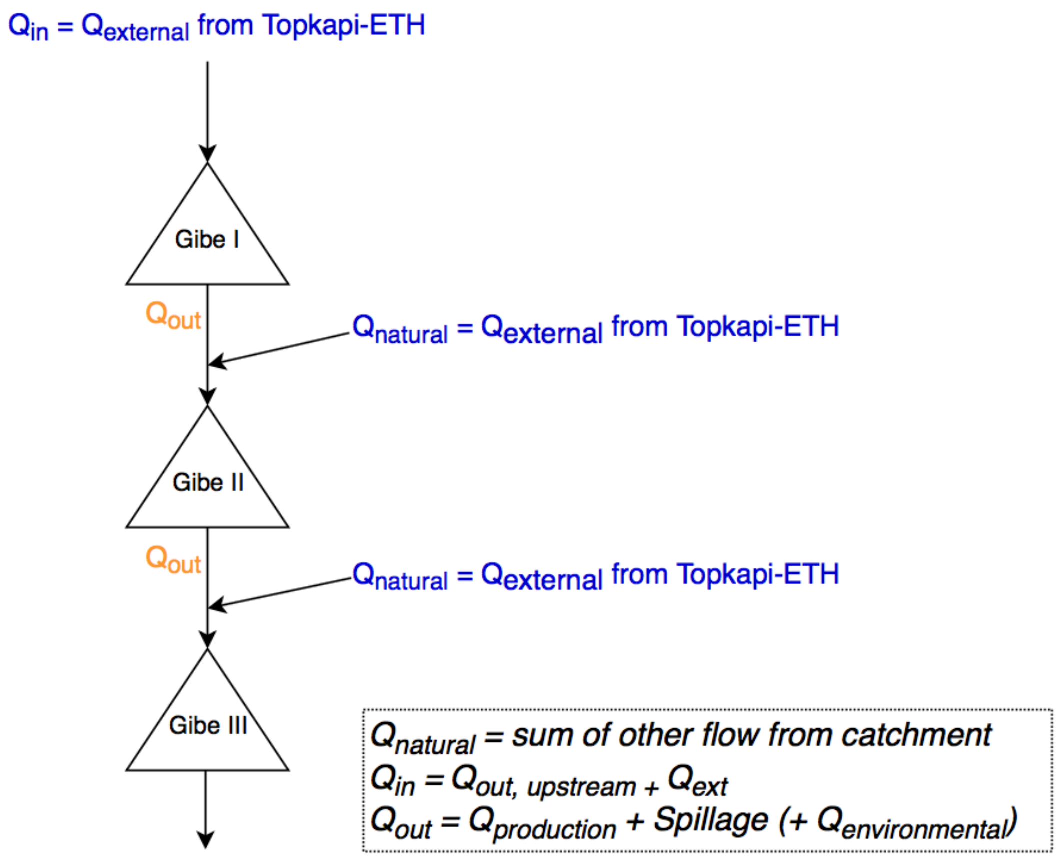


Figure 12. Framework of how to couple and integrate Topkapi-ETH with OSeMOSYS in Reservoir module.

The most recent simulation in Topkapi-ETH by Boulos (2017) has data given for each day of the month, for 10 years. The simulated period is based on historical data and was set up to run between 1998-2008. First thing to establish, was a method of how to integrate this limited timeframe with the OSeMOSYS long-term modelling. The idea adopted was to re-use the values for certain years to match year of introduction, and for the remaining years repeated from the already modelled values, but randomized. This will unquestionably yield an error, however creating new values without anything to base those assumption on, possible having the wrong characteristics of the basin, this limitation was made. Keeping the characteristic of the streamflow regime was prioritized and since the study is merely explorative and under time limit, it was after consideration assumed useable. For instance, Gibe III is introduced in year 2016, therefore the previous years used values from only the Gibe I & II model and for the 10 next year values from the model of Gibe I, II & III. The remaining years, i.e. from 2027, have random values from the Gibe I-III simulation. Important to note is that the random selections were not done individually for the power plants, but yearly, else the hydrological conditions would not match. For instance, for year 2030 all power plants were given the values they had 2015. Table 4 shows the different outputs which were used for different years. The outputs this applies for are: volume of reservoir, water level and the in- and outflow of the reservoir.

However, that for the storage approach the dams which were not existing before the modelling period (i.e. for Gibe III-V & Koysha) had to be included from the beginning of the model period, else the model would not run. However, their respective hydropower plant was introduced in the planned year.

Table 4. Use of the output data from Topkapi-ETH in regards to its time allocation.

Gibe I-III		**Gibe I-V**		**Gibe I-III & Koysha**	
Year	*Output values*	*Year*	*Output values*	*Year*	*Output values*
2010-2015	Gibe I & II*	2010-2015	Gibe I & II*	2010-2015	Gibe I & II*
2016-2026	Gibe I-III	2016-2020	Gibe I-III	2016-2020	Gibe I-III
2027-2050	Random	2020-2030	Gibe I-V	2020-2030	Gibe I-III & Koysha
-	-	2031-2050	Random	2031-2050	Random

** For Gibe III-V & Koysha, their dams were introduced from 2010.*

2.8.1 Coupling with Storage module

For coupling with the Storage module, the volume for each dam and time step (i.e. monthly or yearly averaged values) were the main input variables. The dam was given input as function of the volume for *TotalAnnaulMaxCapacity* and *ResidualCapacity,* which constrained the capacity of the dam and therefore the *RateOfStorageCharge*. Further, the water availability was also assumed to put constrain on the *CapacityFactor* of the dam, if less water is available, the dams will have less annual production, and vice versa. The storage was also given input which was a function of the volume for *ResidualStorageCapacity* and *StorageLevelAtStart*, in its turn constraining the possibility of discharging the storage. How these parameters were linked was by using the conversion from the volume of water to energy potential in the reservoir, according to Equation 1. The methodology is again described in detail in Appendix E and its input data in Appendix F.

A key concern in the coupling was to keep the water balance of the reservoir and ensure it is represented in the model. Figure 13 presents how the water balance can be visualized and written using the storage approach; the bold terms refers to a general water balance whereas the terms in italic refers to the OSeMOSYS parameters. The inflow comes from the dam technology and the output is the discharge of the hydropower. Hence, the *RateOfStorageDischarge* presents how much energy is being discharged and could be calculated into an amount of water, again using conversion between energy and water.

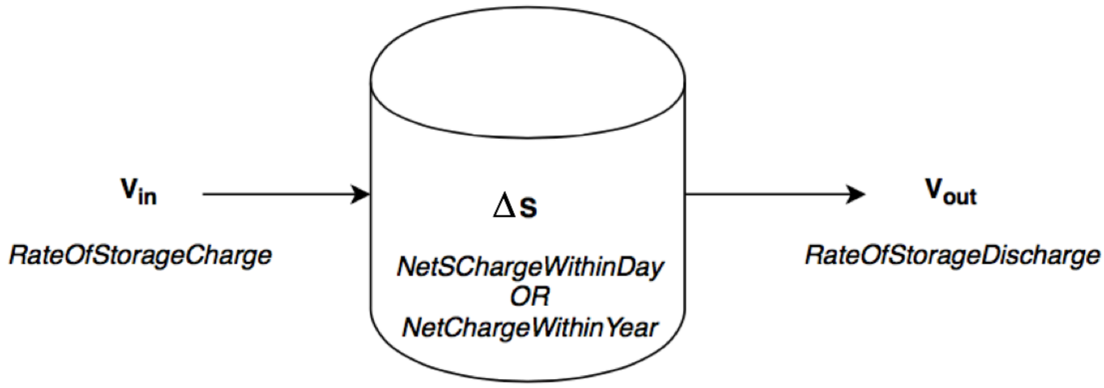


Figure 13. Water balance over a reservoir using Storage module.

The water balance may be written as in Equation 4:

$$V_{in} = V_{out} \pm \Delta S \qquad \textbf{Equation 4}$$

The drawback with this approach was that there was no term for spillage, instead this one was calculated externally after each simulation using Equation 5. If the spillage term is negative, it means that there is no spillage, whereas if it is positive then this surplus would go to spillage.

$$Spillage = V_{out} - V_{max} \qquad \textbf{Equation 5}$$

The final volume of the dam for the end of each time slice is given as the *StorageLevelDayTypeFinish* or yearly as *StorageLevelYearFinish*. These can hence be written in the general form as in Equation 6.

$$V_t = V_{t-1} \pm S_t$$ **Equation 6**

Where V_t is the volume at t and V_{t-1} the volume at the previous time step. S_t is the change in storage during this time slice, i.e. the *NetStorageWithinDay* or *NetStorageWithinYear*.

2.8.2 Coupling with Reservoir module

For coupling with the approach of using Reservoir module, the main input variable was the external inflow for each reservoir and time step (i.e. monthly averaged values). Furthermore, the head of the reservoir was also time-dependent and was calculated using Topkapi-ETH values of water level in relation to the maximum head.

Figure 14 presents how the water balance for the Reservoir module can be visualized and written using the reservoir approach. This approach has separate output terms for spillage and discharge.

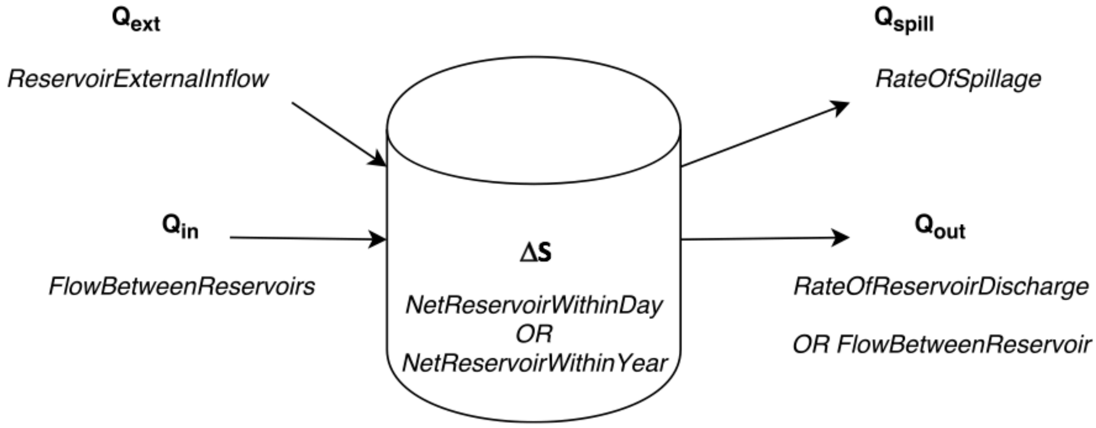


Figure 14. Water balance over a reservoir using Storage module.

The water balance can be written as in Equation 7:

$$Q_{in} + Q_{ext} = Q_{out} + Q_{spill} \pm \Delta S$$ **Equation 7**

The final volume for the end of each time slice is given as the *ReservoirLevelDayTypeFinish* or yearly as *ReservoirLevelYearFinish*. These can hence be written in the same general form as Equation 6, however, now with S_t as the parameters *NetReservoirWithinDay* or *NetReservoirWithinYear*.

2.9 Experimental set-up

After the models were set-up the phase of executing the models began. This was done though an experimental set-up using only Gibe I-III in order to analyse and compare the results obtained and understand the dynamics and constraints of the models. Figure 15 shows how the experimental set-up was performed.

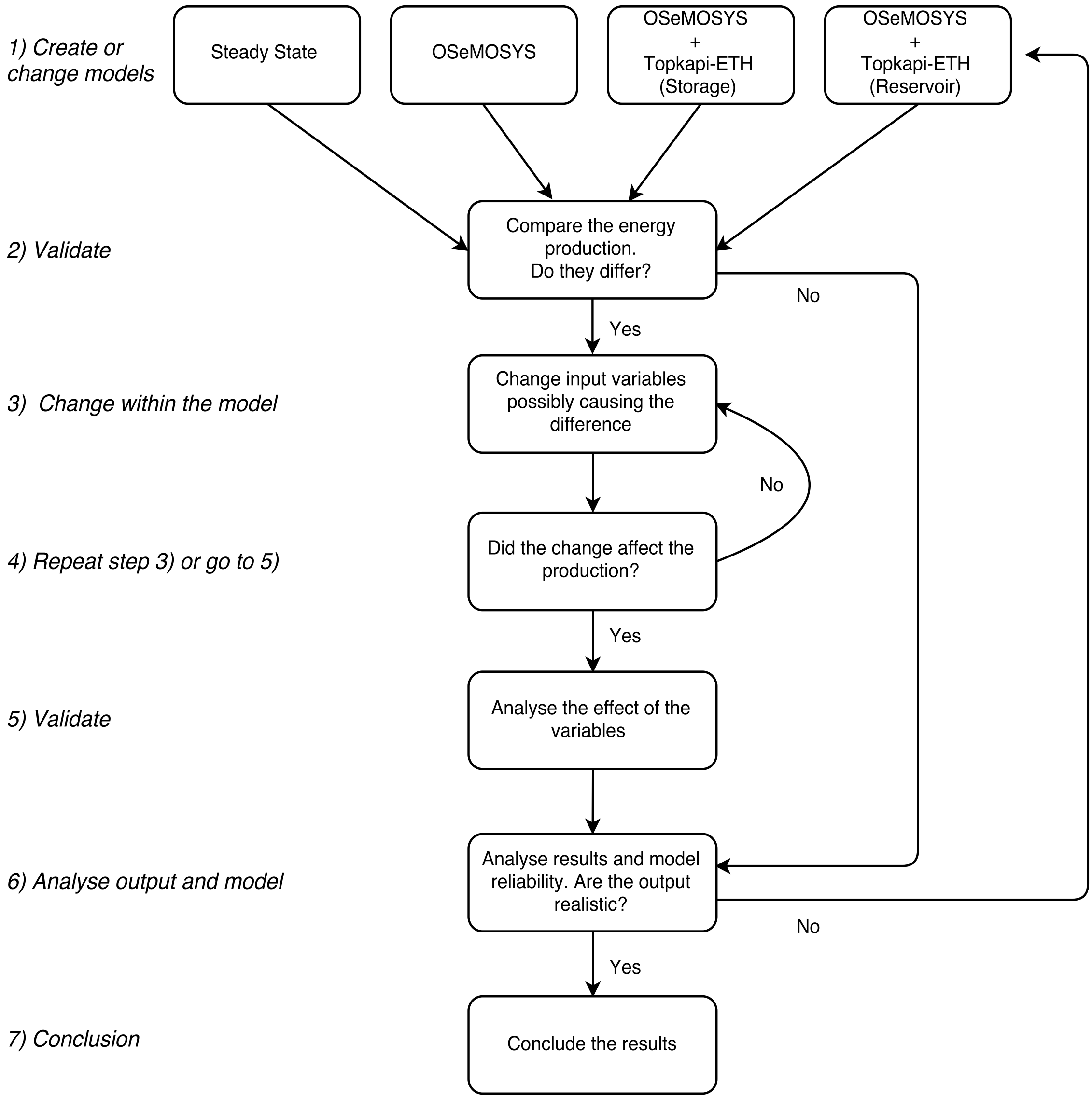


Figure 15. Experimental set-up to try the models and approach used in this study.

1) Create

A **steady state** simulation was performed were the values from 2010 were put constant throughout the whole modelling period. In case the value was zero in 2010 but later non-zero, the first non-zero was used from the year it appeared. Furthermore, the demand was also set higher[1] than the original 2010 value in order for the model not to stop or produce too little (i.e. in the case of having very low demand). This was done in order to see when the system reaches steady state in the production in order to be able to analyse the dynamics and effects within the model of the transient models.

Modelling **without Topkapi-ETH** meant to exclude all technologies, storages and reservoir that had an input of this hydrological data. This was done to be able to see how well OSeMOSYS can capture the hydrological changes the input yields compared to when there is no hydrological input as well as to understand the dynamics of the other two approaches (e.g. differences in production etc.).

The **Storage** and **Reservoir modules** were as described in Section 2.6.1 and 2.6.2.

2) Compare and analyse

The production of the different models was compared and validated to one another in order to see if they matched or not. If they did match, the models behave similar. If they did not match, then there were behaviours within the models which needed to be understood.

3) Change within the model

Variables changed within the Storage and Reservoir modules to understand what affects the outcome. For the storage module, the *CapacityFactor* was decreased in a first try and in a second try the *ResidualCapacity* of the dam as well as the *ResidualStorageCapacity* were put to almost full capacity. For the reservoir module, the external inflow (Q_{ext}) was increased.

4) Repeat step 3) or move on

If the aforementioned changes in variables within the models did not affect the production, then other variables ought to be changed. In this study, the changes mentioned in step 3) did prove to have an effect, and one could hence move on to the next step.

5) Validate

Validate if the effect on the production is in lines with the hypothesis of why the change was made.

6) Discuss and analyse

This part of the experimental set-up was performed in order to analyse other output variables than the production. The main outputs which were of interest were the volume in the dams (storage module) and reservoirs (reservoir module) as well as the discharge of water in the two models. It was proven that both the volume and discharged showed deviating patterns in both the storage module and reservoir module; however, the reservoir proved to have (presented in the results) more

[1] Industry: 45 PJ. Rural: 34 PJ. Urban: 33 PJ.

deviations of the volume and was therefore prioritised. Hence, a few changes regarding the most apparent inaccuracies were made.

Storage model:

- Exclude the storage for Gibe II and model it as a hydropower without hydrological input dependency in order to see if that affects the volume and discharge of Gibe I & III.

Reservoir model:

- Exclude the reservoir for Gibe II and model it as a hydropower without hydrological input dependency in order to see if that affects the volume and discharge of Gibe I & III.
- Set the volume of Gibe III's reservoir to maximum volume from start in order to see if that makes the volume not go to zero.
- Add a dummy reservoir with low capacity after Gibe III's reservoir in order to see if that makes the volume not go to zero.

These changes were made but not included in the final model or results. However, their results are presented in Appendix H and discussed in the discussion.

Lastly, Gibe I and II as very small in comparison to Gibe III and they behave in that comparison more as a run-off-river. Hence, for the analyses of hydrological coherence, the focus was on Gibe III.

7) Conclusion

A final conclusion was drawn on the performance of the models and what variables that still proved to not show a well coherence or patterns as excepted; meaning, if the discharge did not correspond in magnitude to what had been modelled in Topkapi-ETH before, then values or assumptions in either Topkapi-ETH or OSeMOSYS may not be correct.

2.9.1 Adding Gibe IV & V and Koysha

The future hydropower plants Gibe IV & V and Koysha were added to the existing cascading scheme as in Figure 5 in Section 2.3 in order to further study how the system would react to more power plants. For instance, how this may affect the production in the basin and the country overall, as well as how adding more power plants may affect either volume or discharge.

3 Results

This chapter presents the results obtained from the modelling of this study. It includes the production for the different approaches of coupling and the non-coupled OSeMOSYS model, as well as their steady state. Furthermore, the effect on production of changing the available storage in the storage module and the external inflow in the reservoir module, is illustrated. Moreover, the discharge and volume of Gibe III is presented for the two modules; as mentioned in the methodology, Gibe I & II are so small in comparison to Gibe III that they can in theory be treated as run-of-rivers. Lastly, the production of the models Gibe I-V and Gibe I-III & Koysha is presented, as well as the volume for Gibe III, IV & V and Koysha. The results are discussed in the next chapter, where a motivation why these results were presented here is also argued.

Appendix H contains more results which are complementary to the experimental set-up in the methodology and the results presented here.

3.1 Steady State

Figures 16 and 17 shows the steady state model for the Storage module; first plot shows when all parameters are held constant and the second plot when one has changing demand.

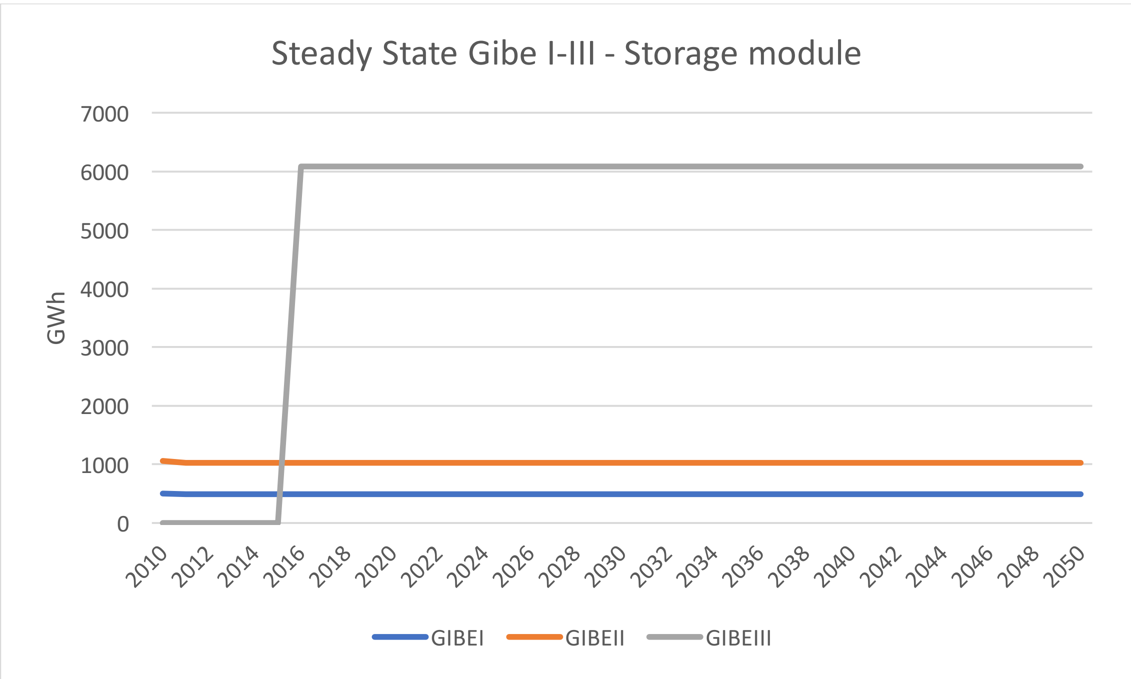


Figure 16. Steady State for Gibe I-III in the storage module.

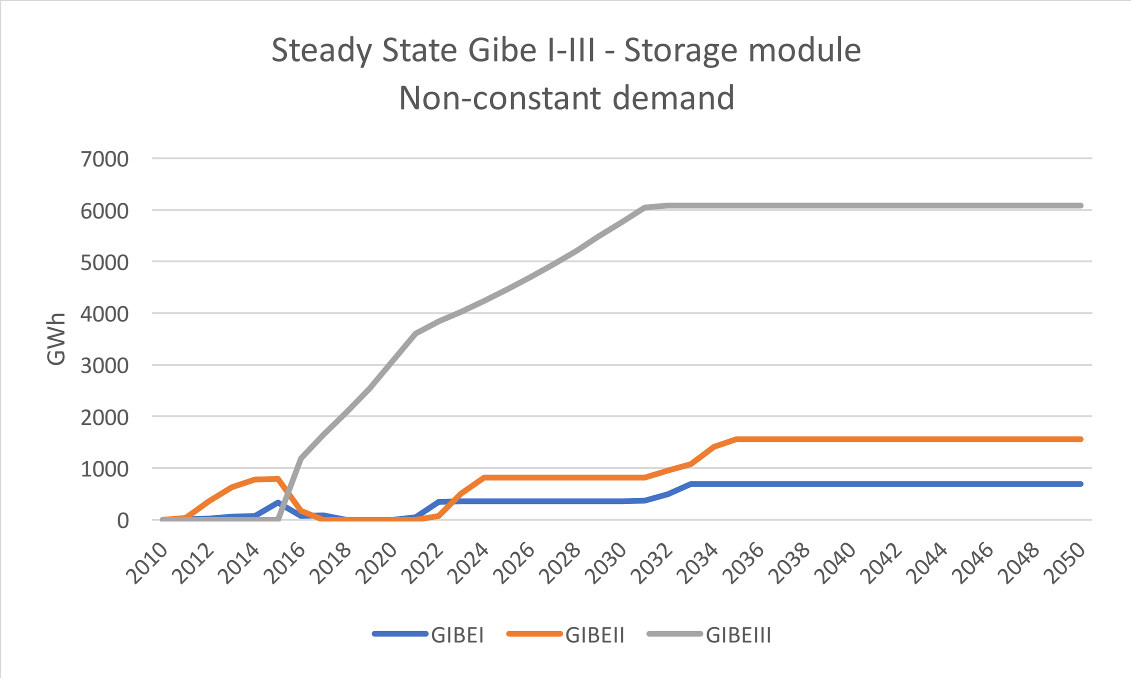


Figure 17. Steady State for Gibe I-III in the storage module with non-constant demand.

Figures 18 and 19 shows the steady state model for the Reservoir module; first plot shows when all parameters are held constant and the second plot when one has changing demand. However, in the steady state for the reservoir, the geothermal power plamt was set to have varying *ResidualCapacity*, else the model would not have a feasible solution, this is shortly commented in the duscussion.

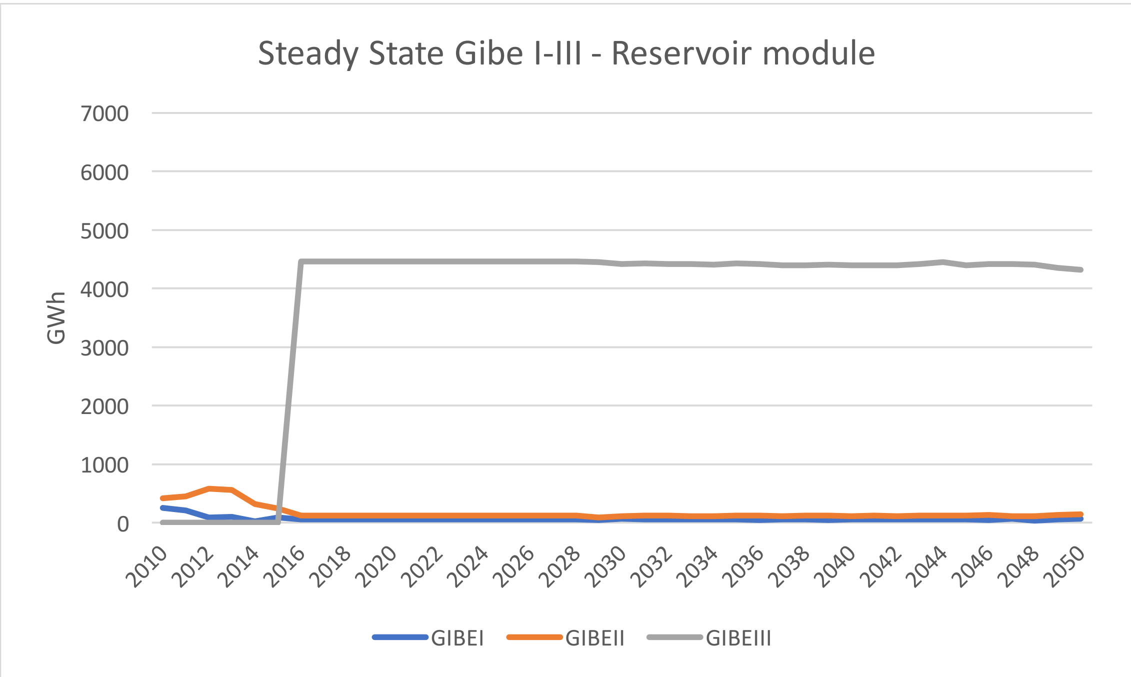


Figure 18. Steady State for Gibe I-III in the reservoir module with. Note that geothermal technology is not constant.

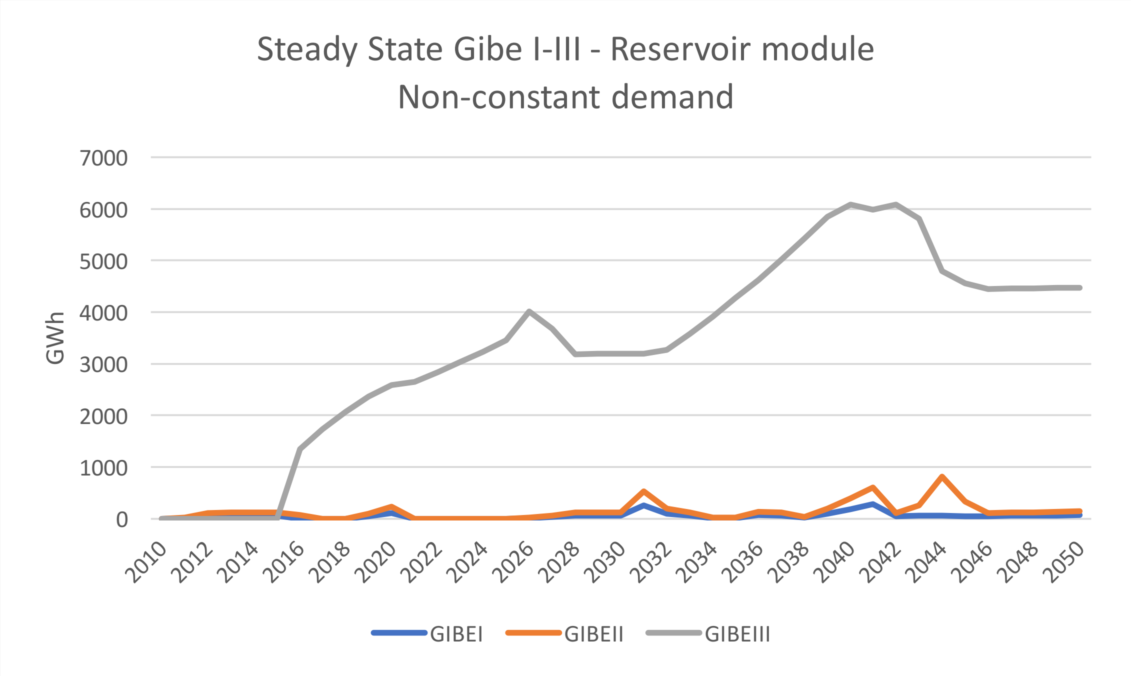


Figure 19. Steady State for Gibe I-III in the reservoir module with non-constant demand.

3.2 Production

The results of production from the non-steady state models are presented below. In other words, here the input varies over time. Figures 20, 21 and 22 shows the production of the power plants Gibe I-III in first the model using no Topkapi-ETH input (hence no reservoir feature), second the storage module and last, the reservoir module and last.

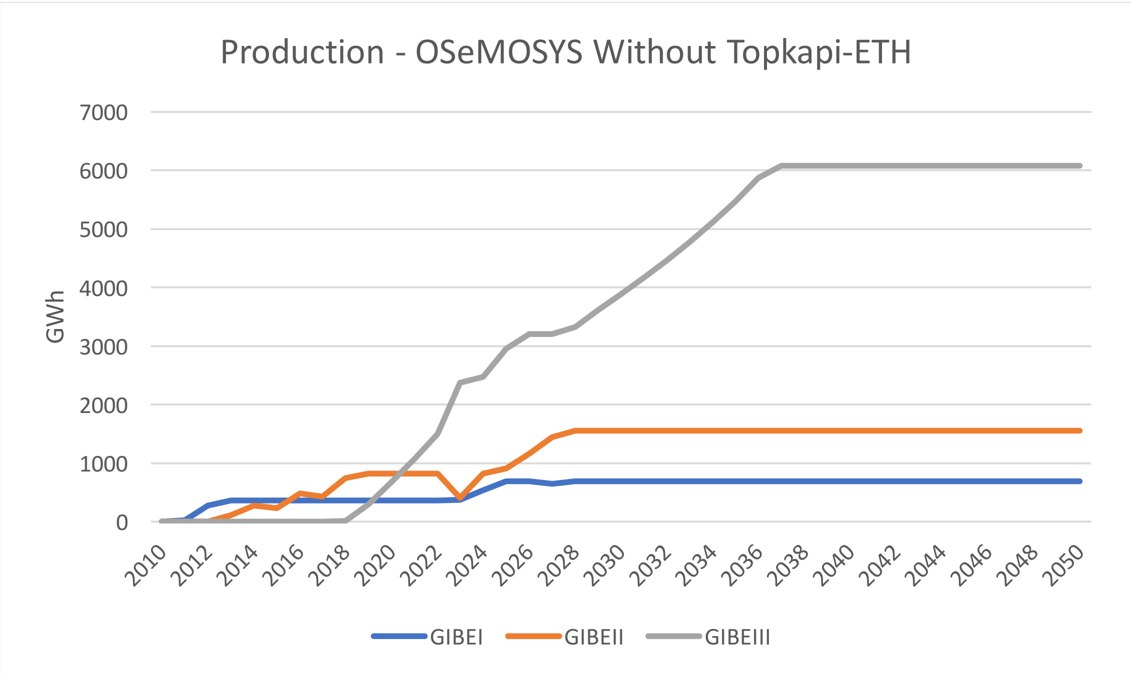


Figure 20. Production in Gibe I-III hydropower plants when no Topkapi-ETH input were used.

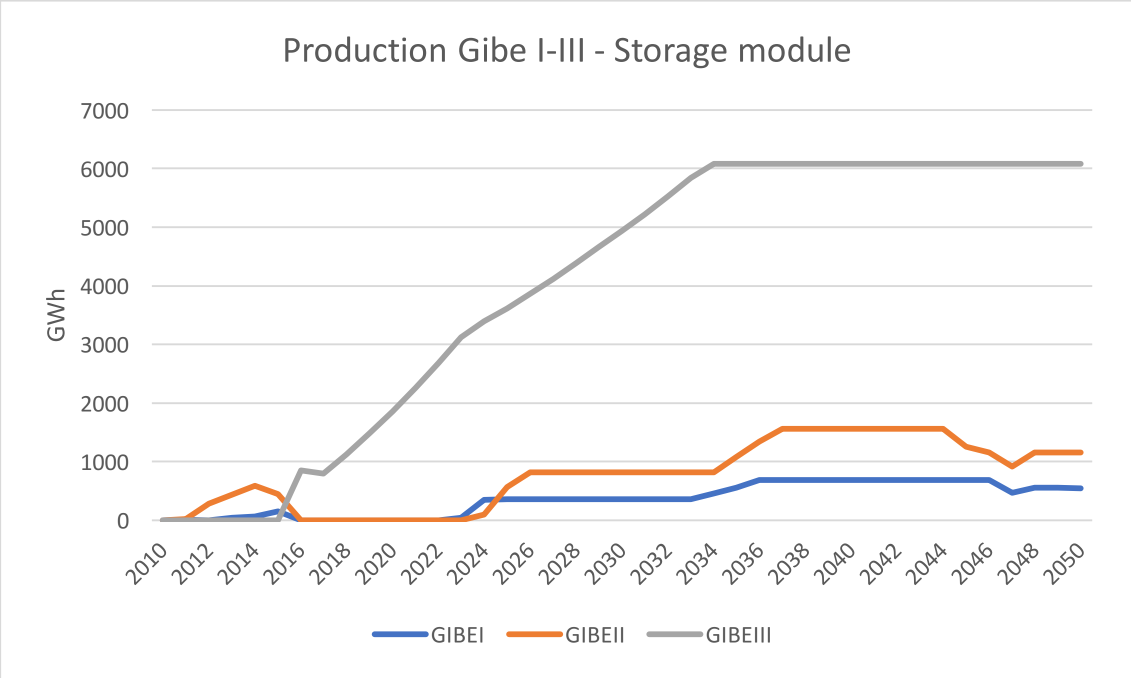


Figure 21. Production in Gibe I-III hydropower plants in the Storage module.

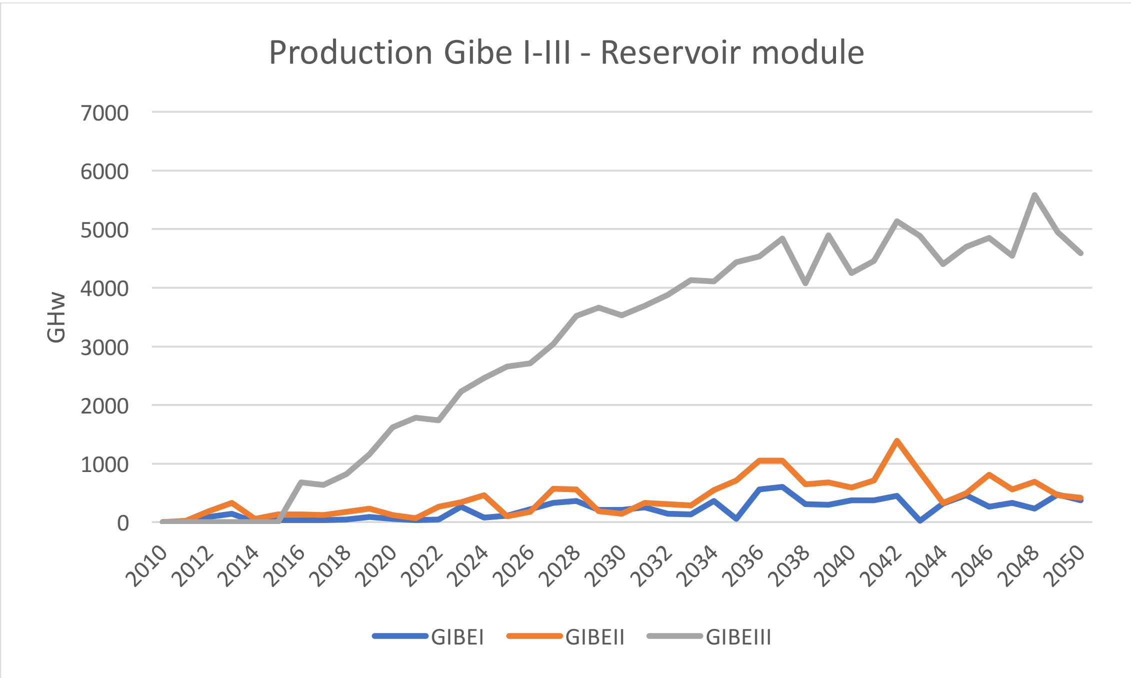


Figure 22. Production in Gibe I-III hydropower plants in the Reservoir module.

3.3 Changing variables within the storage and reservoir module

Figure 23 shows the effect of the production in the Storage module if one decreases the *CapacityFactor, ResidualCapacity* and *ResidualStorageCapacity* of the dams, in other words, decreases the available storage of water.

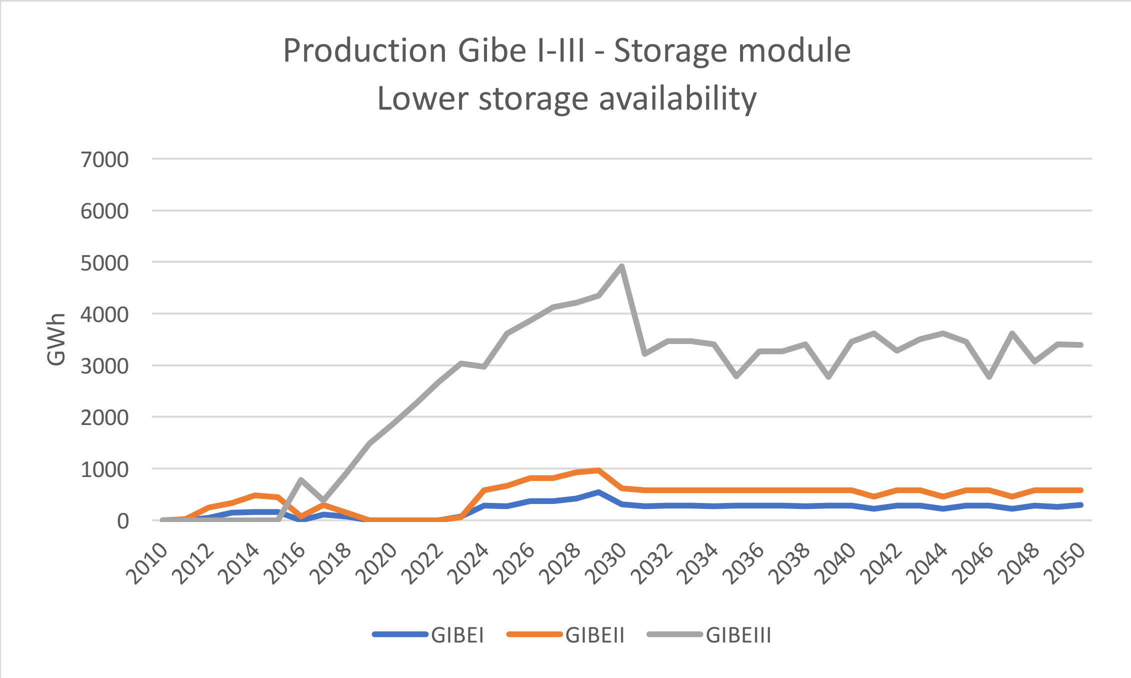


Figure 23. Production in Gibe I-III hydropower plants in the Storage module when changing the storage availability.

Figure 24 shows the effect on the production in the Reservoir module when one increases the external inflow to the reservoirs.

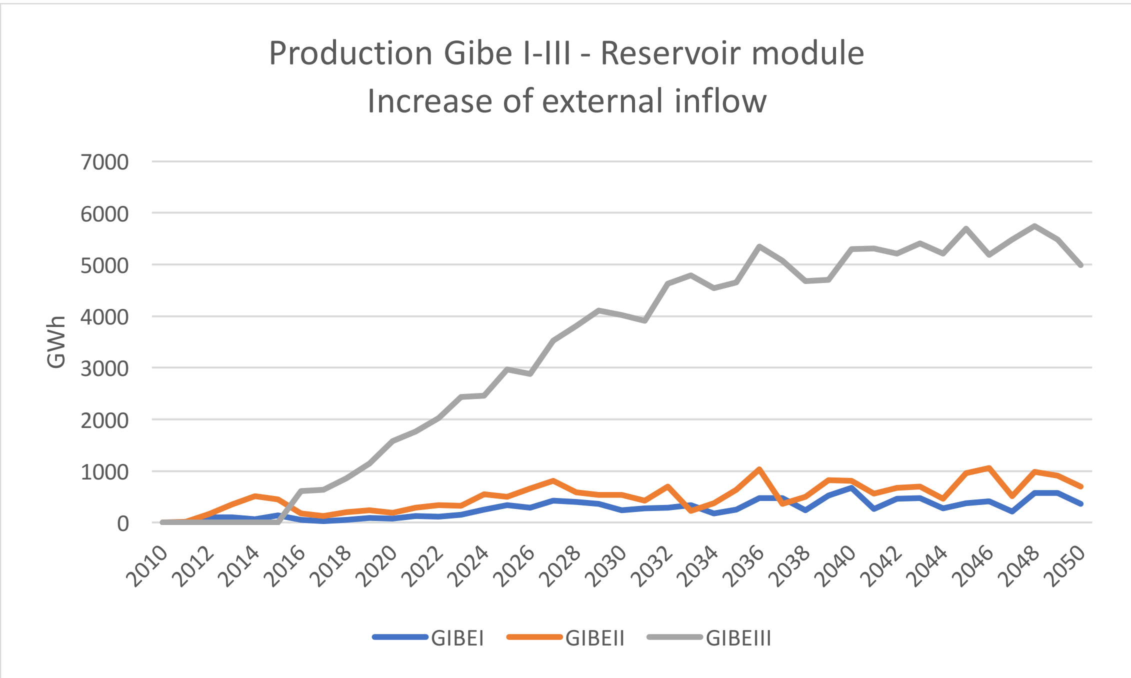


Figure 24. Production in Gibe I-III hydropower plants in the Storage module when changing the external inflow.

3.4 Volume in dam/reservoir for Gibe III

Figures 25 and 26 shows for Gibe III the volume of the dam/reservoir in the Storage and reservoir in Reservoir module respectively. Figure 27 shows the volume of Gibe III when one adds a dummy reservoir.

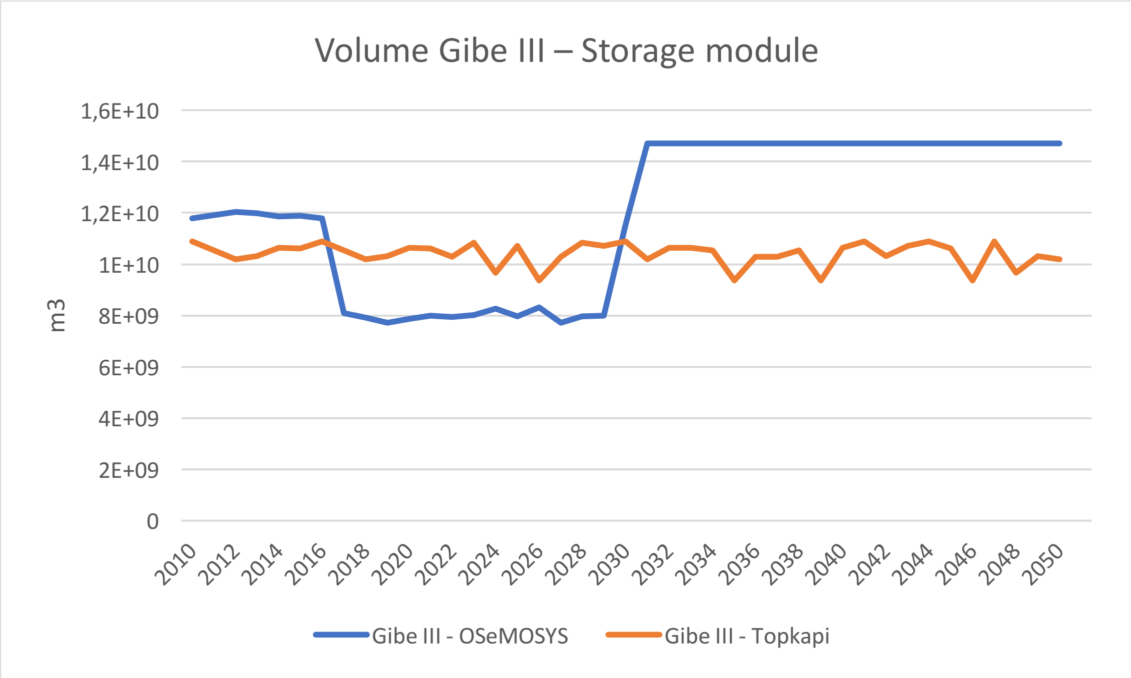
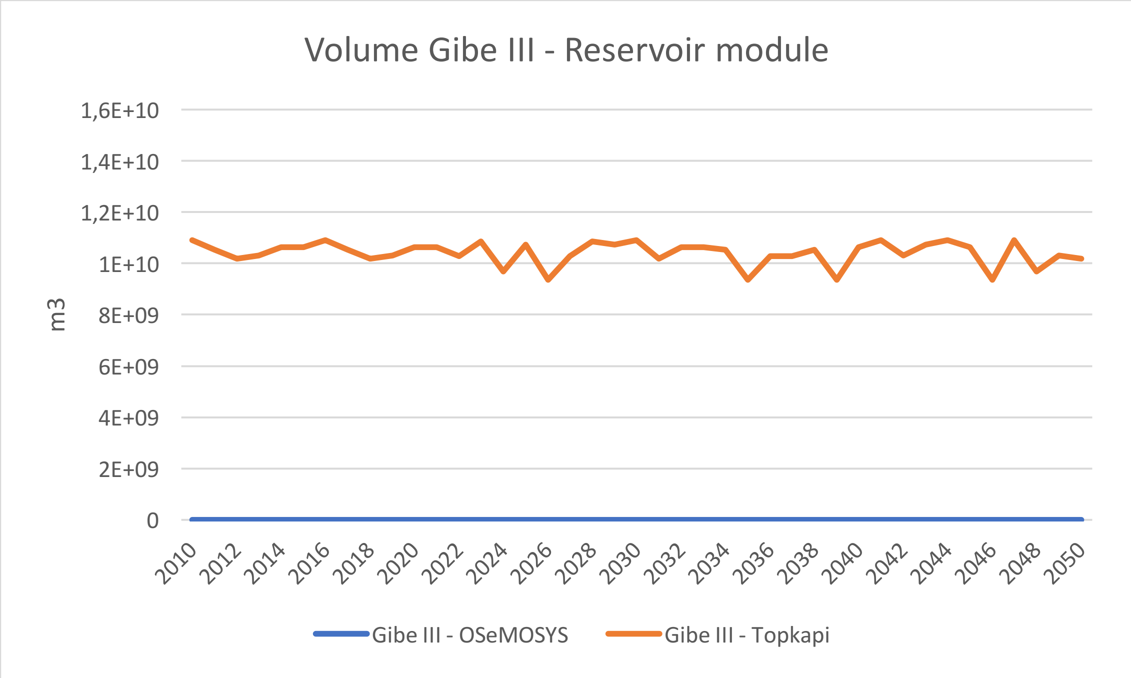


Figure 25. Volume in the Gibe III dam in the Storage module compared to modelled Topkapi-ETH values.



Figur 26. Volume in the Gibe III dam in the Reservoir module compared to modelled Topkapi-ETH values.

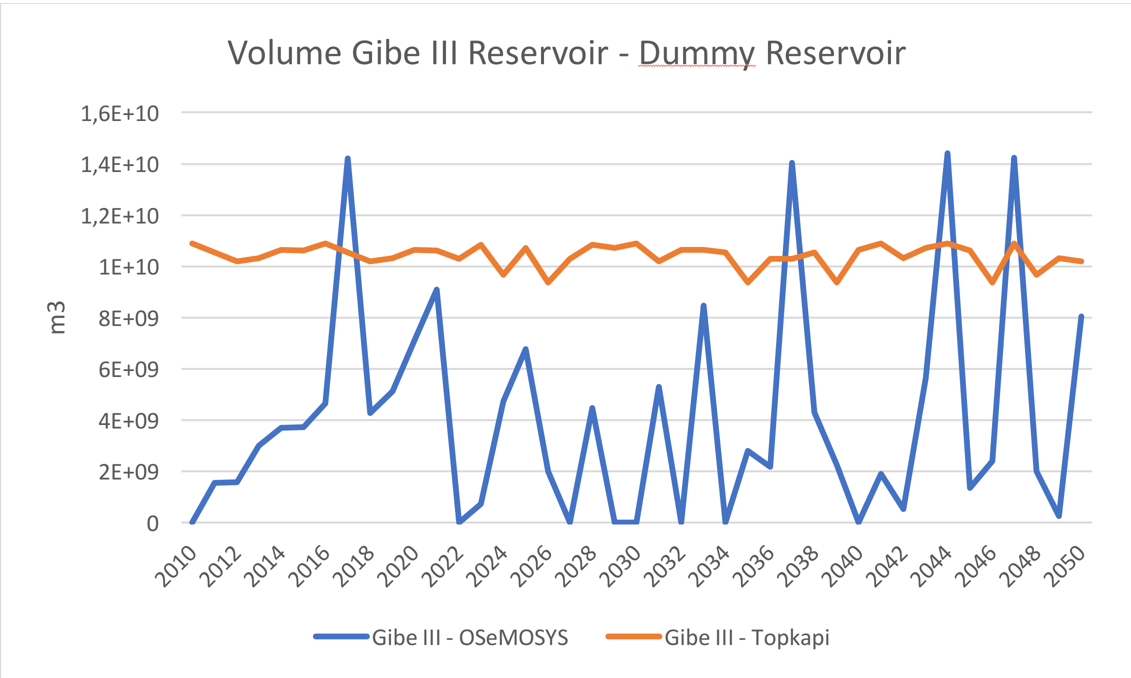


Figure 4-27. Volume in the reservoir of Gibe III in the Reservoir module when one adds a dummy reservoir after Gibe III.

3.5 Adding Gibe IV & V and Koysha – Storage and reservoir module

Figures 28 and 29 shows for Gibe I-V the production in the Storage and Reservoir module respectively.

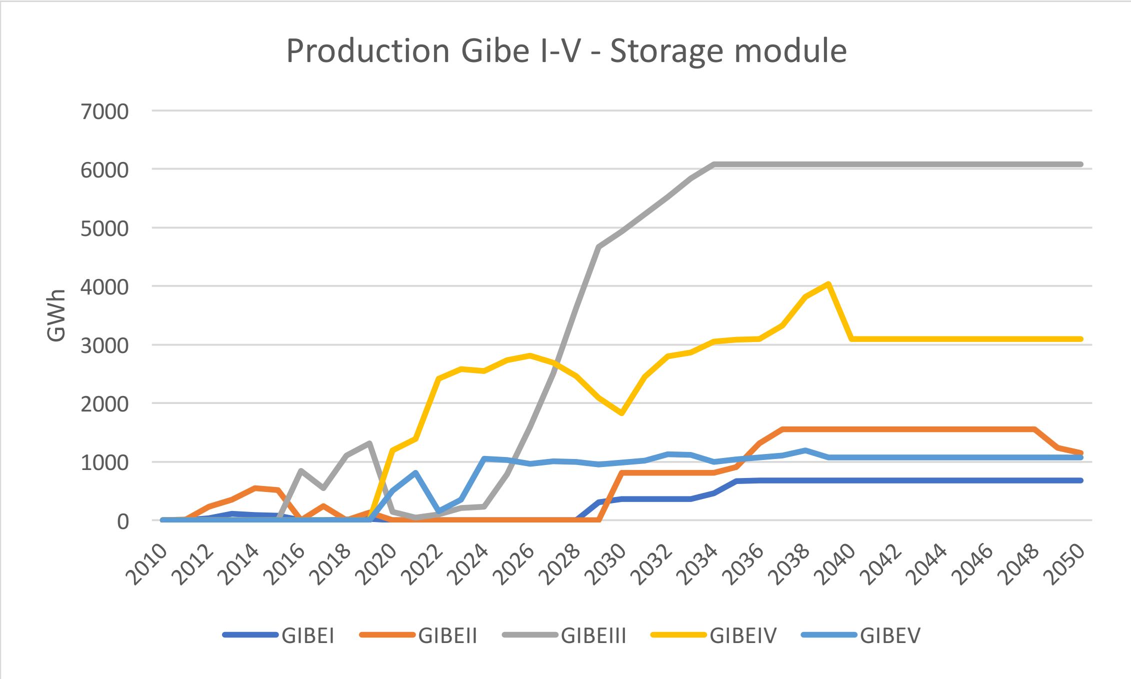


Figure 28. Production in Gibe I-V hydropower plants in the Storage module.

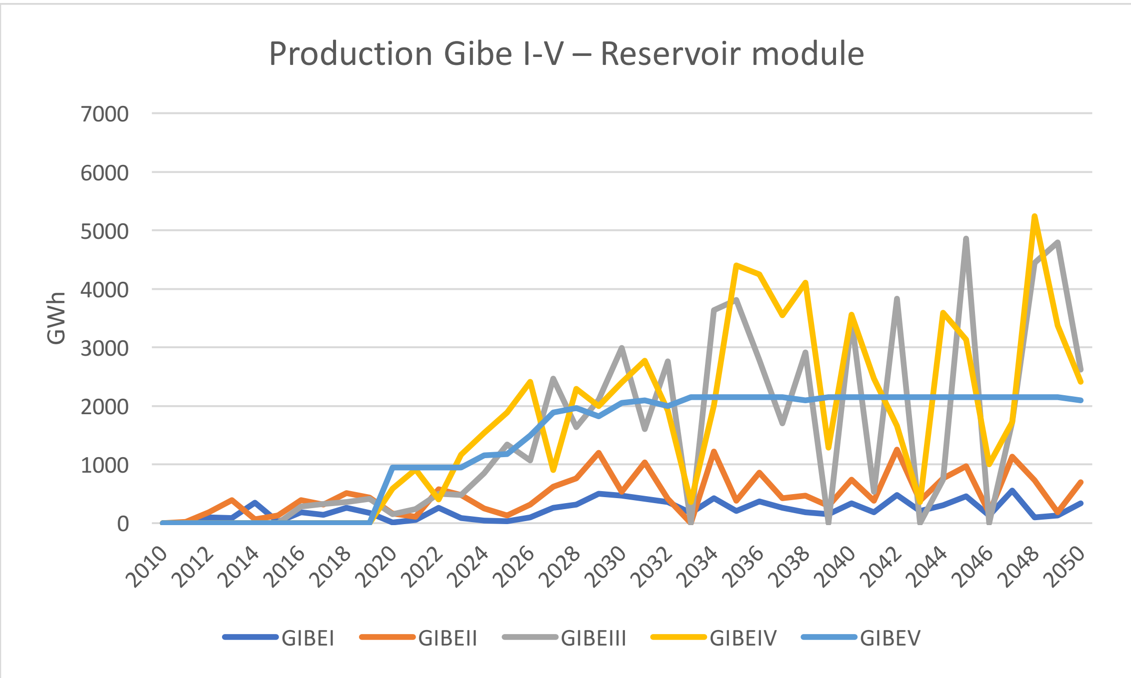


Figure 29. Production in Gibe I-V hydropower plants in the Reservoir module.

Figure 30 shows the volume of the reservoir of Gibe III, IV and V in the reservoir module.

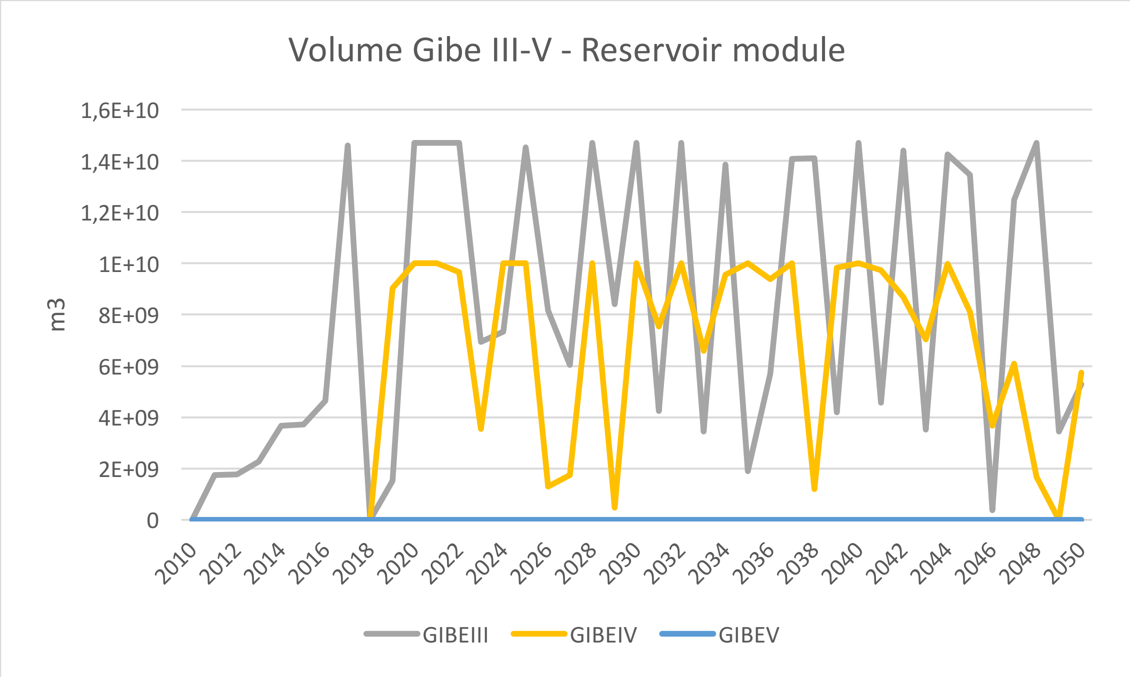


Figure 30. Volume in the Gibe III-V dams in the Storage module.

Figures 31 and 32 shows for Gibe I-III & Koysha the production in the Storage and Reservoir module respectively.

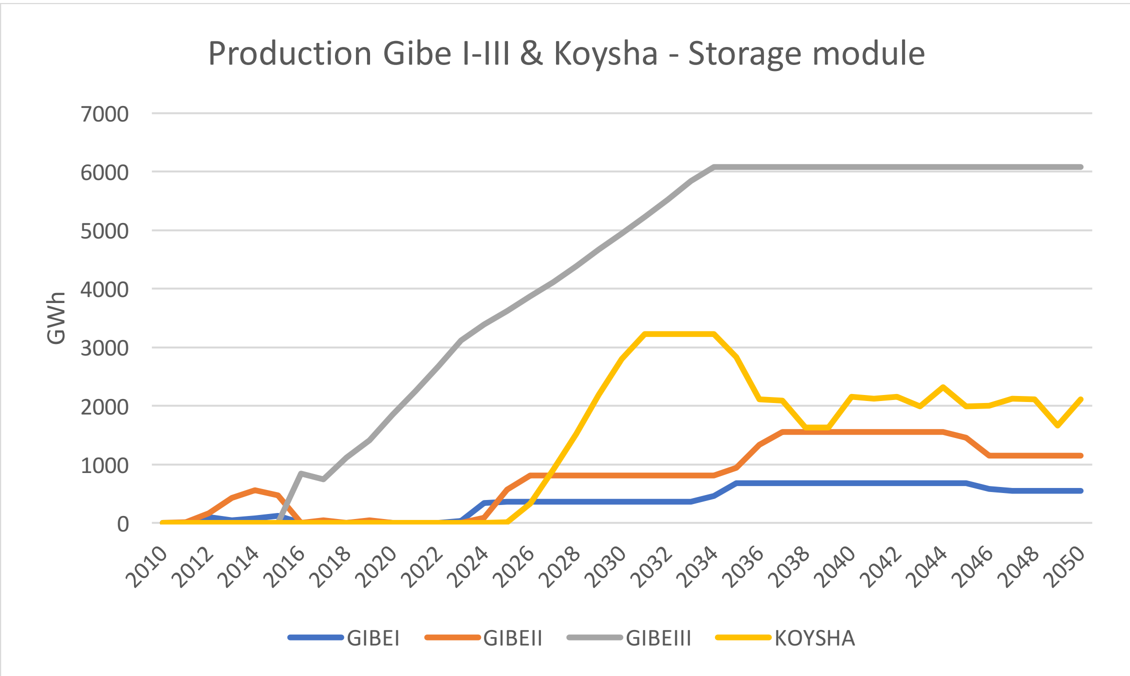


Figure 31. Production in Gibe I-III & Koysha hydropower plants in the Storage module.

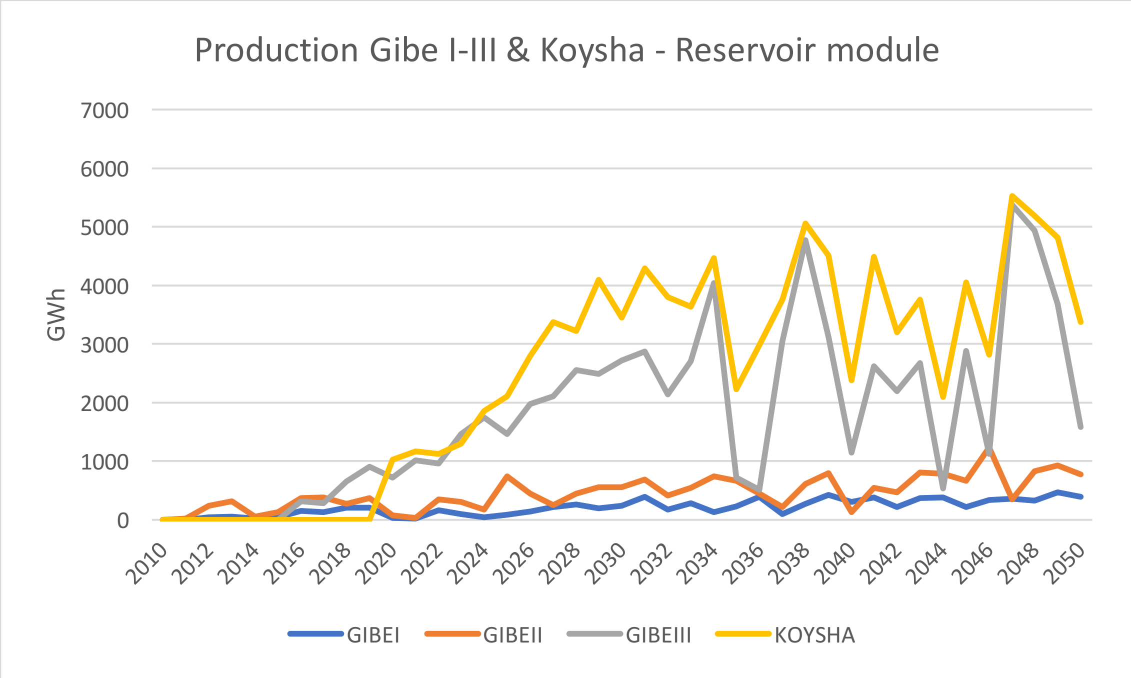


Figure 32. Production in Gibe I-III & Koysha hydropower plants in the Reservoir module.

Figure 33 shows the volume of the reservoir of Gibe III and Koysha in the reservoir module.

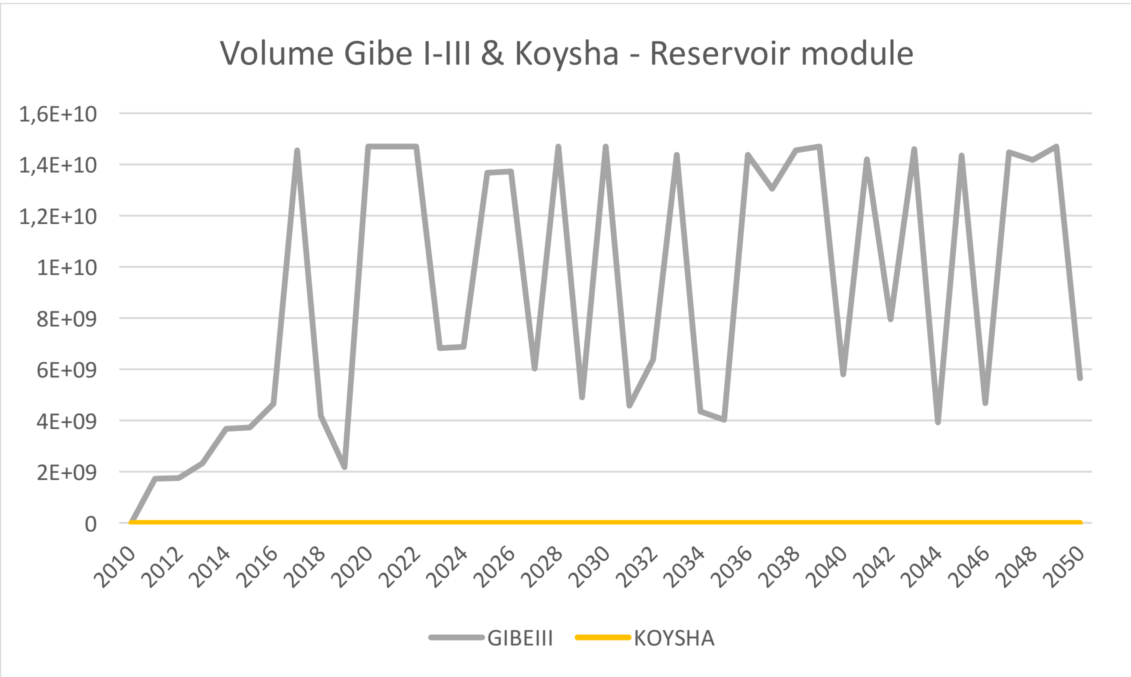


Figure 33. Volume in the Gibe III & Koysha dams in the Reservoir module.

4 Discussion

This chapter will discuss the results of this study as well as a discussion about the limitations of the model as well as the approaches of coupling used. Two approaches have been made to test if the coupling is possible, but it should be noted that these were not solely the only ones available; there may be many more ways of performing this. But as a start, and with the time given, these two were considered feasible. This Chapter is divided into three subsections; the first one discuss the general set-up of the model and approaches, the second the production from the power plants, both the Gibe cascading scheme as well as Ethiopia, and the third the volume of the reservoirs.

4.1 Assumption and limitations in model set-up

Beginning with the limitations and boundaries the model has, one can question the impact of them and how the effect the final results. The time resolution of the two models and how these were integrated may certainly cause some errors. Topkapi-ETH had a resolution of hours, which were averaged to a minimum of monthly values instead. Peak values, both large and small, may hence affect the final external inflow, the volume or the head which were used as input. One can probably argue that for this study, which was about merely exploring the coupling, one can argue that these can be negligible, however, they shall not be dismissed fully and certainly taken into consideration for future studies. On the topic of Topkapi-ETH values, the fact that the latest simulation only runs for 10 years, the rest of the modelling period having randomised values of the simulated ones, does mean that the results shall be sensibly analysed. In other words, having values re-used may mean one miss long-term changes which may occur in the flow regime. Specifically, since it can be argued to be valid to assume that climate change will occur, either natural or enhances by anthropogenic sources. A 10-year period does not show local trends and differences, and, particularly, does not capture long-term varieties in the climate. Therefore, the results of future production in the Gibe cascading scheme, which now is depending on this 10-year simulated values, may show values that will deviate in the future. Consequently, this urge for the need to have Topkapi-ETH extended to simulate for a longer period, in order to make an adequate analysis.

Furthermore, the model is based on the extraction of national data for Ethiopia from TEMBA. The advantage of the model is that it made it possible to considered the whole system and the Gibe cascading scheme in parallel, rather than isolating the Omo river basin. However, the transparency of how the latter model was done is not trivial and all assumptions made within it are not easily accessible. Moreover, many assumption and values from there was adopted on the Gibe cascading scheme as well, for instance transmission and distribution losses as well as some costs. Again, for a study of exploring the possibility of coupling, these assumptions not fully known can be accepted; however, for future studies or developments these should be thoroughly investigated and corrected to match updated and perhaps more accurate values and conditions.

Another assumption made in this study is having Gibe II treated as a dam hydropower plant rather than run-off-river power plant that it technically it is. This assumption was in first place made in order to be able to make it be dependent on the water availability in the river as well. However, since Topkapi-ETH does not have the reservoir of Gibe

II activated in its simulation, it is difficult to make comparisons. Therefore, tests done with excluding the reservoir of Gibe II were done to see the effects, these can be viewed in Appendix H. There will not be a detailed analysis in this, but as o comment on can see that the production of Gibe II becomes high and stable from start, also making Gibe I not produce, in contrary to when the reservoir is activated for Gibe II. For a future accurate analysis, it is advised to have Gibe II activated, but model it as a run-off-river in OSeMOSYS as well.

4.2 Production from the power plants

Moving on to the results presented in Chapter 4, one can begin to look at the Steady State results. Setting all variables and parameters constant, yields a behaviour one could expect: the production becomes the same (Figure 16 and 17). The demand, the costs and the capacities of all technologies are constant which means that there is nothing in the model that forces the production to change; both for the Storage and Reservoir module. However, having the objective function of OSeMOSYS[1] in mind, one could expect that changing the demand would change the production. This is evident in Figure 4-2 when changing the demand to be, the only, non-constant variable in the Storage module. The production shifts and have an increase through the modelling period. The comparison between Figure 16 and 17 implies that the demand that is exponentially increasing (See figure 7 in Section 2.5.2) drives the production to do the same. The production converges after roughly half of the modelling period, implying the demand is satisfied with this production and/or that the hydropower plants cannot produce more due to capacity constraints. In this case, the latter explanation is valid; the power plants reach their maximum production capacities. For the Reservoir module, the same applies, however, the production pattern differs; the steady state has lower total production per each power plant and when changing the demand to be non-constant the production never reach a converging state. Why it does not have as high production in the steady state, can be explained by the fact that with the given constraints, the inflow to the reservoirs and available water is not enough to produce at maximum. When applying a non-constant demand, there is still not a steady increase as in the Storage module, this again implies that the incoming water and its availability is not enough to meet this demand. Instead the demand needs to be meet by other technologies in the system.

In regards to the steady state, a short comment ought to be done on why the Steady State of the Reservoir module would not have a feasible solution when having the ResidualCapacity of the geothermal technology constant. The reason why, was unfortunately not discovered; at a first try this parameter was unchanged and the model ran, but when correcting this to be constant, the model would simply not have a feasible solution. However, this could be set constant in the other runs, when the demand, external inflow or both was varying. This implies that for some reason, OSeMOSYS can not find an optimal solution for this set-up when all parameters are kept constant. Investigating in the reason must be left for future work.

As can be seen from the results of the production in Figures 20, 21 and 22 there is a difference between the results depending on which approach one uses. This implies that OSeMOSYS is prone to respond to varying water availability, under the

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[1] Minimizing the NPV costs for the system while meeting the demand

circumstances the coupling was performed here. Furthermore, the production for all three cases are also comparable with the ones made in the study of Boulos (2017), see Appendix I. This implies that the optimization done in OSeMOSYS is compatible with the ones made in Topkapi-ETH, the latter including environmental constraints. In other words, one can make environmental, and additional for instance for irrigation, constrains that ought to be reflected in the production in OSeMOSYS. This makes the one-way from Topkapi-ETH to OSeMOSYS feasible.

Moreover, if one looks closely at the results in Figures 20, 21 and 22, the difference is not proportional at all years but varies from year to year. In theory, one could possibly expect the OSeMOSYS model without Topkapi-ETH input to produce the most for the Gibe hydropower plants, since this one can be argued to have an infinite or full amount of volume available. However, as was mentioned in Section 2.6.1 and 2.6.2, using storage or reservoir does not necessarily mean it will be less production due to less water. Instead it has, as mentioned, to do with the demand for a specific time and the capacity of all available power plants. In the Storage module, the capacity of the dam will charge the storage, which in its turn will "force" the hydropower to produce when there is a need of it. In the Reservoir module, we have a continuous inflow of water, which constraint the production and in similar way, "forces" the hydropower to produce with this available water. In both cases, OSeMOSYS choses to produce differently because there is a storage or reserve which is cheaper to use than other technologies.

In order to test the sensitivity of OSeMOSYS in regards to the input as well as to prove that the production in fact is dependent on the capacities of the dam and inflow in the Storage and Reservoir module respectively, two parameters each were changed. Figure 4-8 shows how the production decreases when the *CapacityFactor* of the dam in the Storage module is changed. Making this parameter decrease means that the dam will be able to charge the storage less, in the same amount of time than if it would have a higher factor. In actual terms, it means that we assume that there is less volume available in the dam, which may constrain how much it can release for hydropower production. Another approach for the Reservoir module was made, Figure 24 shows what happens if we assume that the Q_{ext} is higher. The results show us that with more water entering the reservoir, the more the hydropower plants produce. This follows the argument that the production in this approach is constrained by the water availability in terms of the incoming flow.

When adding the planned power plants in two different configurations, ending up with one of Gibe I-V and one with Gibe I-III & Koysha, one can also see from Figure 28, 29, 31 and 32 that the production for the current power plants Gibe I-III changes. This can again be explained by the objective function of OSeMOSYS which want to minimize the costs, indicating that it is more cost-effective to produce from the new power plants at times than the old ones. However, for Gibe I-V the production differs largely between the Storage and Reservoir module. In the Storage module (Figure 29) what is noticeable is that both Gibe IV produce much less than what it would, if it were to run at full capacity. This could be explained by the fact that its dam has much lower *CapacityFactor* than the other dams (see Appendix F) and under the same argument as before, this will affect the production negatively. What one can also observe is that Gibe II is almost zero from period 2018-2029, which happens as the same large peak in production from Gibe IV. In the Reservoir module, there is a large variation in the production, however here Gibe IV has higher production than Gibe III, although it never reaches its full potential (which it does not necessarily have to). Interesting to notice here is how the production of Gibe V shows a much more constant behaviour than the others, despite the variations of inflow it has. Similar trends can be seen in The Gibe I-III & Koysha set-up; Koysha produce much less in the Storage module than it could which again can be partly explained by the fact that its dam has lower *CapacityFactor* than the others. However, here Koysha starts producing much later than both Gibe IV and V, instead, Gibe III partly covers all production. This can be explained by the fact that the total cost of using Koysha is higher than using Gibe IV and V; Koysha has a bigger total cost per installed capacity than the other two (See Appendix F). In the reservoir module, Koysha produces higher values, more in the range of what one could expect, indicating that the Reservoir module approach can visualise the varying water availability in a more accurate way.

Lastly, another important aspect which should be considered for future studies to compare the results of the production with real-time observed values. The production here is driven by a variable demand, defined by the user, as well as costs and availability of other technologies. However, it may that neither of the power plants reach the level they do, or they actually produce more. Hence, for calibration purposes, this comparison and analysis would be meaningful.

No matter the different models (Storage module, Reservoir module or OSeMOSYS without Topkapi-ETH input) the demand remains the same and if the constrains change that affects the production on the Gibe cascading scheme negatively (i.e. producing less), this "lost" energy must come from somewhere else. Hence, it may be important to look at the large-scale and understand what happens in the whole of Ethiopia. Hydropower has been presented to have large capacity in Ethiopia (Figure 2.2) so does it in this model, and the costs (presented in Appendix F) assigned are also relatively cheap for the hydropower compared to other e.g. geothermal or biomass power plants. The costs changes over time and the total costs (capital, fixed and variable summarized) show that biomass power plant, small scale hydropower plant and geothermal are the most expensive ones.

For the Storage module, the difference in the production in the Gibe hydropower plants does not reflect a big change in the national model (Appendix H). When looking at the difference between the Storage module and the OSeMOSYS model without Topkapi-ETH input, in fact the difference is which of the Gibe hydropower plants that produce. For instance, in one year Gibe I produce less in the Storage module, but for the same year Gibe II produced more (Appendix H) One can spot small changes in the national model, but not as obvious ones as for the Reservoir model (discussed below). What one could say from this is these is that since Gibe I-III can always produce what it should, OSeMOSYS will use them. However, the difference in which one that is producing must lie in the character of the constraints; the possibility to store water makes it possible to produce at time when necessary.

For the Reservoir module, one can see that there is a slight change in the production compare to the OSeMOSYS model without Topkapi-ETH (Appendix H). The comparison show that the 2028, OSeMOSYS starts to invest in some Solar PV technique as well as oil fired gas turbines and if one also looks regard the total cost, one can see that both of these two technologies are cheaper than the Gibe power plants. Therefore, given the demand and the capacity that the Gibe power plants have, OSeMOSYS chose to invest in cheaper and more cost-effective technologies. There is also more investment done in run-off-river hydropower plants (HYDM2), which also have a lower cost than the Gibe hydropower plants.

4.3 Volume in the reservoirs

Regarding the hydrological comparison between Topkapi-ETH and OSeMOSYS one needs to be careful. The outflow from the reservoirs is not possible be compared since Topkapi-ETH works under different hypothesis than OSeMOSYS do. For instance, Topkapi-ETH is having a minimum environmental release, which is not considered in OSeMOSYS. However, the volume of the reservoir can be compared in the order of magnitude, since, again, the two models work under different hypothesis there will be a natural miss-match specific values cannot be compared. Since Gibe I and II are very small in comparison to Gibe III, the focus was merely on the analysis of Gibe III.

The volume was analysed for Gibe III, Figure 25 shows the volume from the Storage module and Figure 26 from the Reservoir module. What is evident here is that in the Storage module, there is low or no sensitivity to the varying volume. In the Reservoir model, the volume behaves very unexpected: the volume is zero at all times. The behaviour of the volume in the reservoir of Gibe III did not change when starting a maximum level from start. Further, even though a dummy reservoir did help the volume of the reservoir of Gibe III, Figure 27, it proved to cause unexpected drops in the power production which could be argues not to be very realistic, as the demand is constantly increasing. This could request trying to model the reservoir with a storage module within it; in other words, having a reservoir feed the storage when there is excess of water coming in, i.e. water which does not need to be discharged for the hydropower production.

A further interesting observation in the Reservoir module for Gibe I-V and Gibe I-III & Koysha set-up is that the volume for Gibe V and Koysha is zero, as in the case for Gibe III when it was the last reservoir in the cascading scheme (Figure 30 and 33). This implies that OSeMOSYS treats this last reservoir more as run-off-river, in a way which is not trivial to understand by either looking at the code nor the results. Adding a dummy reservoir after the Gibe III proved, as earlier mentioned, to make the volume of the last reservoir to develop but have a slight negative effect on the accuracy of the production. One attempt to fix this could be to try to modify the code so that it models a lower volume limit for the reservoir (which the Storage module has for its dams). Or one should merely accept that OSeMOSYS cannot fully in itself reflect hydrological responses which may seem natural or obvious in this current set-up. This is left for future studies; the explanation can simply lie within the set-up and approaches used in this study. Or the OSeMOSYS itself is not exhaustive enough to perform this kind of modelling.

Neither the Storage module nor the Reservoir module proved to fully represent the volume here. Despite that it is not in detailed comparable to the volume modelled in Topkapi-ETH, the Storage module did not seem to replicate the varying nature of the reservoir input and the Reservoir module seemed to not treat the reservoir as a storing feature. For these reason, we can validly question if the coupling works in complete. Even though we can say that the production shows an excepted behaviour and values, one can not know if the miss-match in volume representation between Topkapi-ETH and OSeMOSYS may impose errors or inaccuracies to the final production. For instance, if the volume in the reservoir of Gibe III is zero, then one can question if the hydropower plant produces adequately; if OSeMOSYS had been able to replicate the volume, would we have more production since there is water stored for times were there is no or less inflow. These are questions that remains unanswered currently due to the non-trivial nature of the OSeMOSYS code and model.

5 Conclusion

This thesis has presented the exploration of coupling the two models Topkapi-ETH and OSeMOSYS. Two different approaches of coupling were done using a Storage module and a Reservoir module. What one can conclude is that it is possible to couple the two models and OSeMOSYS showed response to variable water availability in its production. However, this production was different depending on whether one used the Storage model or the Reservoir module, both compared to a Steady State condition as well as a model with OSeMOSYS without any Topkapi-ETH input or dependency. The production for all the models are driven by the demand, defined by the user, as well as the assigned costs for all power plant and their fuels. However, experiments also proved that the Storage module was driven by the availability of water, in the OSeMOSYS defined by, among others, the *CapacityFactor* of the dam. For the Reservoir model, the external inflow to the reservoirs proved to have large impact on the production.

However, despite the production showing adequate and accurate results, comparing with previous Topkapi-ETH modelling as well as actual production, the volume in the reservoir did not respond in an attentive way. This implies that there is something within the OSEMOSYS model which cannot fulfil the water balance and hence there is a miss-match. Before trying to use OSeMOSYS have a feedback to Topkapi-ETH in the form of the required energy production, this miss-match need to be understood. If it is not understood and corrected, the coupling cannot be done in completion.

In conclusion, what this study has proven is that a coupling is possible with positive responds on the production. However, with the given conditions, chosen approaches to couple and the insights into the OSeMOSYS code and its dynamics, the coupling cannot be completed fully but needs more elaboration on the hydrological aspects and how these are modelled.

6 Future work

The study presented in this report as played a foundation for the possibility of coupling Topkapi-ETH and OSeMOSYS. However, for future studies, there are several improvements, extensions and developments that can be done. To mention a few, one can start with one of the major drawback which is the fact that Topkapi-ETH is only simulated for 10 years; it needs to be developed for more years. Further, a neater way to couple the models in regards to the different time resolutions they have is advised and proposed. Also, the coupling made here was tested for two approaches, but many other ways can be done and elaborated on. As these did not prove to show the expected results, having the volume not acting very realistic, it is necessary to either understand where the coupling or modelling is wrong, or to try new approaches.

One could also expand the analysis to include a hydrological model which expands the study to be about WEF-nexus as well, in comparison to the WE-nexus performed here. The latest Topkapi-ETH study does include some policies of water abstraction for irrigation purposes, however, there is a reason to believe these can be extended and more wide-ranging. This expansion would not only include water for irrigation but also that of livestock; merging crops and livestock would make it possible to define a food demand.

Since it was evident from the results that the demand is a driving factor, one could study this demand even more and make it more detailed by including more sectors to ensure the total demand is covered. Furthermore, since the cost and other available technologies also have an impact on the results, one could also try to make the model even more detailed, adding more technologies in the Omo river basin, or validate what is already included. For instance, if there are existing or planned hydropower plants (E.g. Halale Werabesa and Gojeb dam) located in connections to the Omo River, for instance upstream, then they could be included. If they are not included one may lose effects on the streamflow regime, given that the power plants are located at such a distance (within the basin or catchment) that they have a noteworthy impact. Additionally, there is reason to argue that there may be a necessity to update the other technologies in TEMBA, as they are based on targets and plans which can be changed or updated.

Lastly, when, and if, the coupling is possible, having scenarios would make the analysis more dynamic. These scenarios could be of climate characteristics in Topkapi-ETH, e.g. more/less precipitation, and in OSeMOSYS one could elaborate with the demand. The scenarios are many and having two models make it even more dynamic as one can cover more sectors in one scenario.

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Appendix A – Water and agricultural sector in Ethiopia

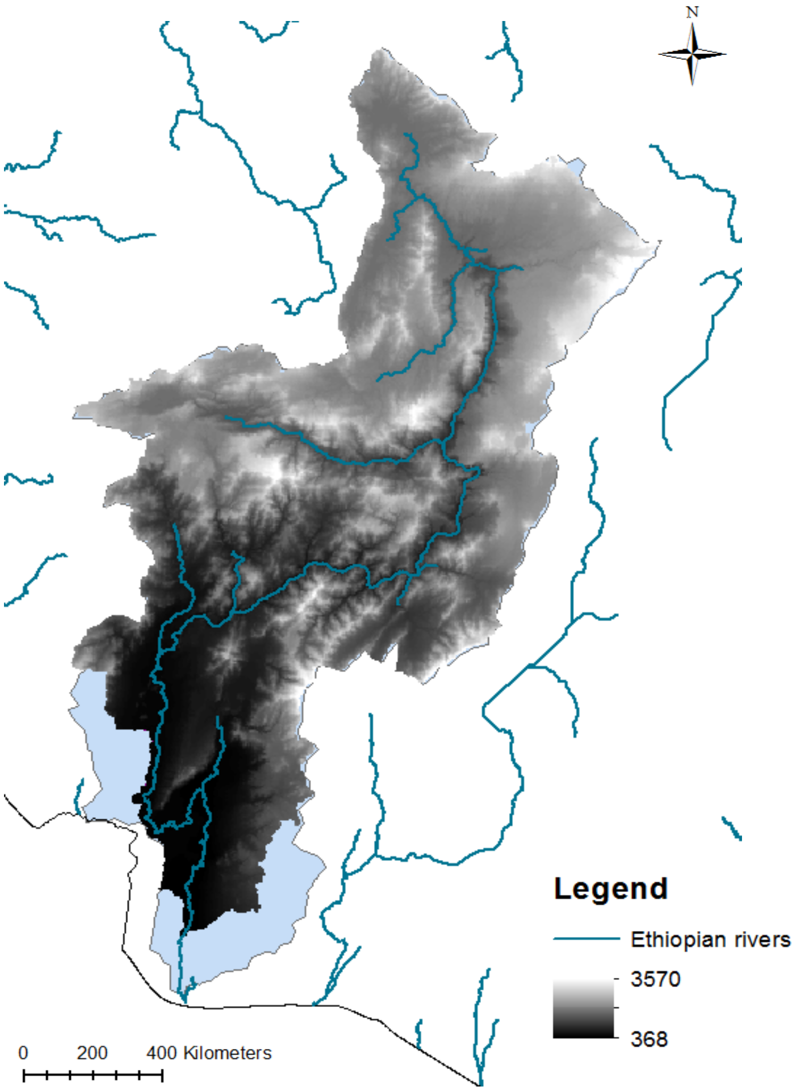
Ethiopia has 11 freshwater lakes, 9 saline lakes, 4 crater lakes and 12 major wetland areas. The majority of the lakes are found in the Rift Valley, where several lakes do not have any surface water outlets and are therefore very saline. The total internal renewable water resources (IRWR) are estimated to 122 million m^3 per year. No external resources are entering the country and hence Ethiopia is considered as the "Water Tower of East Africa"; a water tower, feeding neighbouring countries with 96,500 million m^3 of water each year. Groundwater potential has been less exploited but is often more easily available in the arid areas, where it provides a large share of the drinking water. The country has a large potential of reservoirs which can be used for hydropower generation, irrigation and drinking water supply purposes. The total dam capacity in the country has been estimated to 31.48 km^3 (FAO, 2016).

The total water withdrawal in 2016 was 10,550 million m^3, all of which coming from freshwater reserves. Agriculture is the sector that withdraws the most water, amounting to 9,687 million m^3 in 2016, including 687 million m^3 for livestock. More recent data is not available for the municipal and industrial sectors, however, 2005's value stated 810 million m^3 and 51 million m^3 respectively. The irrigation potential was 2,700,000 ha in 2013 and in 2015 a total of 8,583,00 ha was equipped for irrigation. However, the share of cultivated area which was equipped for irrigation was merely 5.3%. Traditional farming in Ethiopia relies on rain-fed irrigation and it was not until irrigated sugar estate established in 1950's that the large-scale irrigation started to be developed (FAO, 2016).

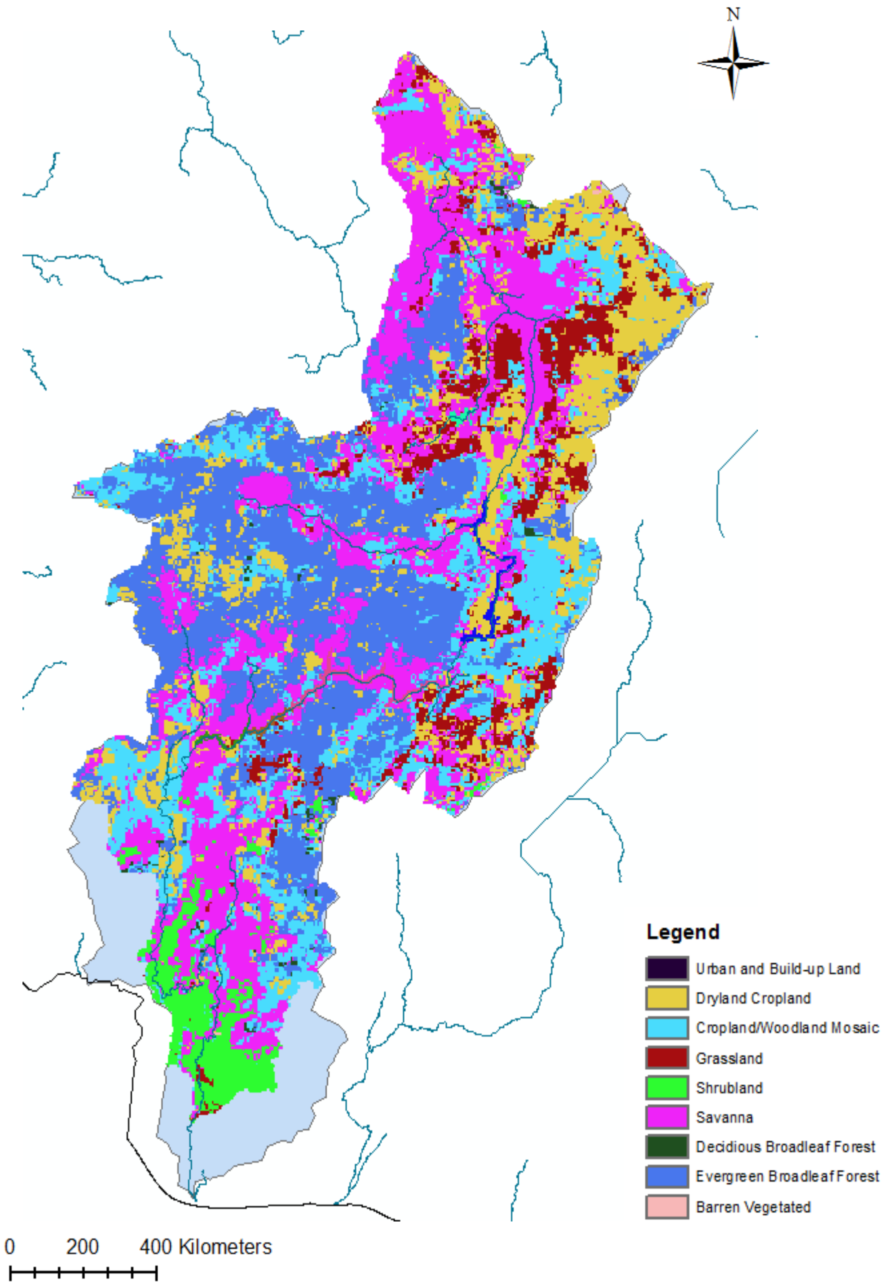
The water resources management and development are managed by different institutions at a federal level. The Ministry of Water, Irrigation and Energy (MoWIE) is responsible for the overall management of the water resources, including utilization and protection. The Ministry of Environment and Forestry (MoEF) is responsible for the protection and preparation of the environmental law, directives and policies. Lastly, the Ministry of Agriculture (MoA) handles the water management regarding irrigation, both through water harvesting and rain-fed. In addition to this, the Water Resources Development Fund (WRDF), child-institution of MoWIE, support the work with infrastructure development. Further local basin and regional authorities work at a sub-national level with more detailed and site-specific issues (FAO, 2016).

Appendix B – Omo River Basin

The rainfall varies throughout the basin, with an annual value of 400 mm in the south lowlands to 1900 mm in the highlands. The average for the country is 1400 mm per year. The temperature varies as well, with less than 17°C in the highlands and over 29°C in the lowlands. The altitude in the highlands can reach over 4,200 m a.s.l. and as low as less than 500 m a.s.l. in the lowlands, the first figure below showing the altitude in the basin. The altitude together with the temperature makes it possible to distinguish four agro-ecology zones in the basin. The land cover typically consists of cultivated land, forestland, woodland, grassland and bush and shrub lands (ITAB-CONSULT PLC, 2001). Figure below shows the land-use in the basin.



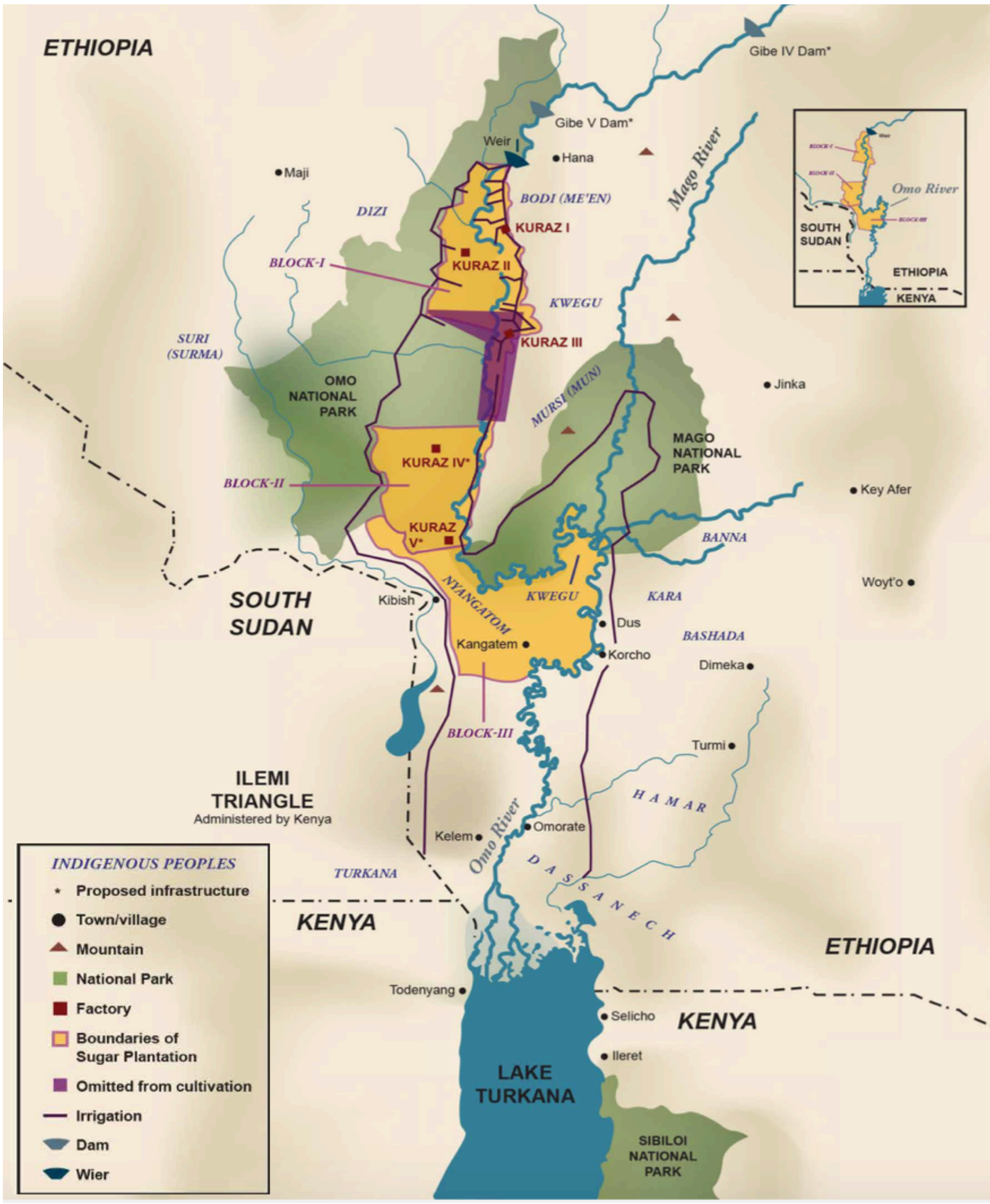
Altitude (m.a.s.l) of Omo River Basin modified in ArcGIS with data from Boulos (2017).



Landuse in Omo River Basin modified in ArcGIS with data from Boulos (2017).

The total amount of irrigation potential in the whole basin differs across different studies, from 100,000 ha to almost 450,000 ha (Avery, 2012). In the highlands, the farming system is mixed with cereal crop domination but also areas used for multiple crops or double cropping. The lowlands are dense with agro-pastoral groups that practice flood-retreat cropping. The latter is hence sensitive to the change of flows and water availability in the rivers. The agriculture mainly consists of smallholder farms, contributing to 98% of the total farming. The average area per farmer is 2 hectares and is mostly rain-fed (ITAB-CONSULT PLC, 2001).

Irrigation schemes have been identified to be more suitable in the lower parts of the Omo River since the higher elevation in the north contributes to less efficient pumping (CESI and Mid-day, 200). Hence, agricultural schemes have been suitable to establish here. The Kuraz Sugar Development Project (KSDP) have been said to be one of the biggest agricultural schemes ever launched by the government of Ethiopia, as a result of the goal of expansion of sugar cultivation in the GTP I. The Ethiopian Sugar Cooperation (ESC) would establish the factories in the lower parts of the Omo River, situated in the surroundings of Mago and Omo National Park, see Figure below. The KSDP would have an agricultural area of 175,000 hectares with five factories, out of which three has a processing capacity of 12,000 tcd (tons crushed per day) and the remaining two a capacity of 24,000 tcd. The first factory, Kuraz 1, was planned for the commission in the middle of 2016, whereas Kuraz 2 and 3 have been scheduled for 2017 (Kamski, 2016a). From the burning of the bi-product bagasse, it is possible to generate electricity in a biomass power plant. This has been suggested for the Kuraz factories by the EAPP Masterplan, all having corresponding power plant generating and transmitting electricity to the national grid (Ea Energy Analyses and Energinet.dk, 2014b).



Location of the Kuraz Sugar Development Project's factories. Obtained from Kamski (2016a).

Due to the early stage of the project, it has been difficult to assess and evaluate any environmental impact. However, it has been proposed that the schemes may influence the availability of water downstream as well as its water quality. For instance, the changes in soil may influence groundwater recharge and the use of fertilizer pollute the water (Kamski, 2016a). The change of the hydrological cycle has caused the continuous flood-recession agriculture to be at stake, making the livelihood in the area to be compromised (Kamski, 2016b). Avery (2012) supposed that KSDP would require a large amount of the inflow from Omo River to Lake Turkana for irrigation. If inefficient irrigation, the amount could be as high as 40% of the flow.

Appendix C – Hydropower from an environmental & socio-economic perspective

Hydropower has had different areas of use; in the beginnings being used by the Greeks for grinding wheat to flour, later for milling and pumping and today it is a widely-used source of energy. What all these purposes have in common is that they use mechanical energy. It is today one of the largest renewable energy source and has the advantage of being able to respond to a fluctuation in demand in minutes and when a reservoir is present, it can store energy. Hydropower can range in size from being small scale at a few watts to large scale at several gigawatts. What differentiates them in scale is among others the number of turbines; large scale power plants usually have several turbines whereas small-scale power plants may only have one. Further, small-scale ones are often connected to the off-grid or mini-grid and the large scale to the centralized grid (IRENA, 2012).

Hydropower is a renewable energy resource that does not have any CO_2-emissions related to its operations, however, the construction has assigned emissions and can therefore not be considered a full carbon neutral technology. During plant's lifetime, from construction to final operation, one must consider issues relating to its presence. Issues which have been identified with the technology is change or abnormal fluctuations in flow regime, water quality, biodiversity as well as the displacement of population and effects on fish migration in dams. Hence, environmental performance in hydropower is continuously improving with, for instance, silt erosion resistant material to avoid silt entering the turbines and turbines that are fish-friendly (IRENA, 2012). IEA (2012) discussed the impacts that climate change may have on hydropower and identified three specific changes: river flow due to changes in precipitation, extreme flood or drought events putting pressure on dam safety and sediment load due to changes in hydrology and use of catchment.

Socio-economic issues were further identified by the IEA and they stressed the importance of water and energy nexus as an increase of population and more water withdrawal will stress water availability even more. In the context of socio-economic questions, the issue of properly taking care of indigenous peoples and their practices in the area has been identified. Construction in areas where they live may cause losses in resources or changes in their activities, e.g. agricultural practices, and pose risk to their health (IEA, 2012).

Appendix D – Technologies, fuels, storages and reservoirs in OSeMOSYS model

Technologies used in OSeMOSYS model.

Technology	Description	Technology	Description
BIOMASSIM	Biomass import	GIBEII	Gibe II Hydropower plant
BIOMASSEX	Biomass extraction/production/refining	GIBEIII	Gibe III Hydropower plant
BMCHP	Biomass CHP plant	GIBEIV	Gibe IV Hydropower plant
CSP1	CSP (Without storage)	GIBEV	Gibe V Hydropower plant
CSP2	CSP (With storage)	HYDM1	Small hydro power plant (SHP)
CSP3	CSP (With gas firing)	HYDM2	Dam hydro power plant
COALIM	Coal import	HYDM3	Run-of-river hydro power plant
COALEX	Coal extraction/production/refining	KOYSHA	Koysha Hydropower plant
COALSCP	Coal power plant	KURAZ	Biomass plant (Bagasse)
DIESELIM	Diesel import	OILIM	Oil import
DIESELEX	Diesel extraction/production/refining	OILEX	Oil extraction technology
DIESELI	Diesel power plants (100kW, Industry)	OILGCP	Oil fired gas turbine OIL SCGT
DIESELR	Diesel power plants (1kW, Rural, Residential/Commercial)	SOPV	Solar potential
DIESELU	Diesel power plants (1kW, Urban, Residential/Commercial)	SOPVUT	Solar PV (Utility)
DIESELUT	Diesel power plants (Utility)	SOPVR	Solar PV (Roof top, Rural)
DISTU	Distribution technology (Tertiary to Urban)	SOPVR1	Solar PV with storage (1 hr, Rural)
DISTR	Distribution technology (Tertiary to Rural)	SOPVR2	Solar PV with storage (2 hr, Rural)
DISTI	Distribution technology (Tertiary to Industry)	SOPVU	Solar PV (Roof top, Urban)
ELDJH	Ethiopia - Djibouti Historic trade link	SOPVU1	Solar PV with storage (1 hr, Urban)
ELERP	Ethiopia - Eritrea Planned trade link	SOPVU2	Solar PV with storage (2 hr, Urban)
ELKEP	Ethiopia - Kenya Planned trade link	TDam1	Dam facility for storage 1
ELSDHP	Ethiopia - Sudan Historic and Planned trade links	TDam2	Dam facility for storage 2
ELSOP	Ethiopia - Somalia Planned trade link	TDam3	Dam facility for storage 3
GASIM	Imported Natural Gas fuel	TDam4	Dam facility for storage 4
GASEX	Natural gas extraction technology	TDam5	Dam facility for storage 5
GASCC	Natural gas (Combined Cycle)	TDam6	Dam facility for storage 6
GASSC	Natural gas (Single Cycle)	TRANS	Transmission technology (Secondary to Tertiary)
GEOT	Geothermal power plant	WI25	Wind (Onshore, 25% CF)
GIBEI	Gibe I Hydropower plant	WI30	Wind (Onshore, 30% CF)

Fuels used in OSeMOSYS model.

Fuel	Description
BIOMASS	Biomass fuel
COAL	Coal fuel
DIESEL	Diesel fuel
DJET	Ethiopia - Djibouti Historic trade link
EL1	Electricity from power plants
EL2	Electricity after transmission
ELURB	Urban demand
ELRUR	Rural demand
ELIND	Industrial demand
ERET	Ethiopia - Eritrea Planned trade link
GAS	Gas fuel
KEET	Ethiopia - Kenya Planned trade link
OIL	Oil fuel
SDET	Ethiopia - Sudan Historic and Planned trade links
SOET	Ethiopia - Somalia Planned trade link
SOLARPV	Solar PV Potential

Storages used in OSeMOSYS model.

Storage	Description
SDam1	Storage for Gibe 1 dam
SDam2	Storage for Gibe 2 dam
SDam3	Storage for Gibe 3 dam
SDam4	Storage for Gibe 4 dam
SDam5	Storage for Gibe 5 dam
SDam6	Storage for Koysha dam

Reservoirs used in OSeMOSYS model.

Reservoir	Description
RES1	Reservoir for Gibe 1 dam
RES2	Reservoir for Gibe 2 dam
RES3	Reservoir for Gibe 3 dam
RES4	Reservoir for Gibe 4 dam
RES5	Reservoir for Gibe 5 dam
RES6	Reservoir for Koysha dam

Appendix E – OSeMOSYS methodology

In this section parts of the methodology of the OSeMOSYS model set-up is described in detail.

Time split

The time split is dependent on different sets and parameters. The set is *TimeSlice* and the parameters are *Seasons, DayTypes* and *DailyTimeBrackets*. *Seasons* is the number of seasons during the year, *DayTypes* the different types of days in the week (e.g. weekdays and weekends) and *DailyTimeBracket* is the different splits of each day (e.g. day and night). The time split in this study for OSeMOSYS was set-up to be able to capture the hydrological changes occurring over the years. This meant that the *Seasons* were defined to be one for each month of the year, i.e. in total 12 seasons. Furthermore, there was a differentiation between day and night, for instance, to capture the solar power capacity, resulting in two *DailyTimeBracket*. No consideration of differences between weekdays and weekend were done and hence there is only one *DayType*. The number of time slices is defined by Equation 8 and results in a total of 24 *TimeSlices*:

$$TimeSlices = Seasons * DayTypes * DailyTimeBracket \qquad \textbf{Equation 8}$$

The parameters corresponding to the sets above are *DaysInDayType, DaySplit* and *YearSplit*. *DaysInDayType* is the number of days the different types of *DayType* corresponds to, e.g. in this study we do not differ between weekdays and weekends, hence the parameter is set to 7.
DaySplit is the fraction each of these D*ailyTimeBracket* has in a year. Since we consider a split between day and night, both 12 h long, then we will have:

$$DaySplit = \frac{12\ [h]}{24\ [h] * 365\ [days]} = 0.00137\ [days^{-1}] \qquad \textbf{Equation 9}$$

Lastly, the *YearSplit* is defined as the fraction each time slice has in a year and is dependent on the *Season* and *Daysplit*. If we have 12 seasons, all split into two brackets a day, then, for instance, January day would have a year split of 31/(365*2) ≈ 0.0425. The sum of all year splits much equal to 1.

The 24 time slices were differing to the ones in TEMBA, as the latter only considered four time slices. Hence, the *TimeSlices* and parameters with a dependency of the time slices in TEMBA were changed to fit the ones presented here. The *Seasons* in TEMBA are "summer" and "winter", so all values corresponding to summer were given to the seasons April to September, and in the same way for the winter to October to April.

The time slices and the parameters' name in OSEMOSYS are presented in Appendix F.

Demand

The parameters specified for the demand in OSeMOSYS are *SpecifiedAnnualDemand* and *SpecifiedDemandProfile*. The first is the overall demand (in PJ) for each demand site for each year whereas the latter defines the distribution of this demand for each time slice.

The demands were based on the final electricity consumption by the sectors obtained from the IEA (IEA, 2017). The industrial demand was then assumed to increase by 10% annually for the year 2015-2029, 8% for the year 2030-2039 and 6% for the year 2040-2050. The decrease of the industrial annual demand was for this study argued to be due to capture augmented energy efficiency in the future as well as a potential stagnation in industrial development.
The urban and rural demand were based on the target of achieving different Tiers, i.e. electrification rates, by 2050. These tiers are based on the ones proposed by UN DESA (2017) and for this study, the aim was to get urban to Tier 4 and rural to Tier 3 by the end of the modelling period. The electrification rate was obtained for 2010-2014 based on the data from IEA and interpolated to 2050 based on the respective Tier. The electrification rate for the period of 2010-2014 was calculated by using the residential demand from IEA and assuming the rural electrification rate is half of that of the urban. This was in line with the assumption made by Mentis et al (2016) which also assumed the double demand of the urban compared to rural. The total demand for the rural and urban demand sites was finally calculated up by using the population forecast by the World Bank (2017b) available up to the year 2050.

The values for all years of the projected demand can be found in Appendix F.

Capacity factor

CapacityFactor determines how much a power plant can produce in a year over what it would produce if it ran at full capacity during this year. The capacities change during the year, but this yearly variation was assumed to be constant for the power plants during the modelling period. The Kuraz power plant was assumed to have the same capacity as a biomass power plant in TEMBA, which was 0.53. For the hydropower, each respective plant had a capacity factor (CF) calculated as the ratio between the maximum power generated in a year, divided by the installed capacity. E.g. for Gibe 1 with a maximum generation of 722 GWh and installed capacity of 184 MW, the calculation can be viewed in Equation 10.

$$CF = \frac{722\ [GWh] * 1000\ \left[\frac{GW}{MW}\right]}{184\ [MW] * 365\ \left[\frac{Days}{Year}\right] * 24\ \left[\frac{Hours}{Day}\right]} \approx 0.45$$ **Equation 10**

Appendix F presents the capacity factor for the hydropower plants in Omo river basin as well as for the rest of Ethiopia.

Input and output activity ratio

InputActivityRatio is a parameter which is defined as the inverse of the efficiency of a technology and is modelled as the input of a fuel to a technology. For instance, a fuel of biomass feeds a biomass power plant with a specific efficiency. Efficiency for the Kuraz power plant were according to EAPP Masterplan (Ea Energy Analyses and Energinet.dk, 2014b) 17%. Hydropower plants were not fed with a fuel in this model, they are simply discharging the storage, and hence they were not assigned a value of this parameter.

OutputActivityRatio is the parameter which describes the how much of the produced energy that the receiver gets. For instance, it can be the ratio of the output energy from a power plant over what comes out to the transmission line. For the outputs from the power plants, the value is 1. In other words, no losses are considered or assumed to occur at this stage of transmission. However, for the transmission and distribution technology, the output activity ratio accounts for the losses one experiences in the grid. Values for these were assumed to be consistent with the ones given in TEMBA for both the transmission line and distribution network to urban, rural and industrial demand sites. They are further assumed to be constant throughout the model period which may be argued to be unrealistic, as these may by most probable means decrease as part of national targets (National Planning Commission, 2016). However, as the predictions are difficult to make, no increase in efficiency and reduction in losses are considered in this study.

The values used in the model for the two parameters can be found in Appendix F.

Storage module

Storage is a feature in OSeMOSYS which lets the user add a technology that charges the storage (e.g. dam) and a technology which discharge it (e.g. hydropower). Since the dam is a technology like the hydropower, is also requires the same input parameters. However, these are partly a function of hydrological inputs making it possible to couple the models, defined and explained in this section.

Beginning with the dam technologies, the maximum capacity was set to vary in terms of the time-varying volume available in the reservoir. The maximum capacity will be represented by the maximum potential energy in the reservoir. This was assumed to be in accordance with Equation 1, resulting in Equation 1 for this study.

$$E = \rho * g * h_i * V_{i,max} \qquad \textbf{Equation 11}$$

Where E is the potential energy in J, ρ the density of water (1000 kg/m^3), g the gravitational acceleration (9.81 m/s^2), h_i the maximum height of dam I, $V_{i,\,max}$ the maximum volume of dam i. And i = 1, 2, .. 6. In other words, for each dam (1-6) there is a constant height and maximum volume which the reservoir can hold (i.e. total reservoir volume), all together corresponding to a maximum potential energy. Since Gibe II is often referred to as a run-off-river power plant, the reservoir volume does not really exist. Instead it was assumed in the baseline that Gibe II has the same maximum volume as Gibe I since it is fed from it and assumed to have the same availability of water. The volume for Gibe V was not available but assumed to be 1.5 Mm^3, corresponding to volumes observed in earlier modelling by Boulos (2017).

For the dam technologies, the residual capacity will be dependent on the available volume of water in the reservoir, as their energy is in the form of potential energy in close similarity to the maximum capacity. This will be governed by Equation 12:

$$E = \rho * g * h_i * V_{i,t} \qquad \textbf{Equation 12}$$

Where E is the potential energy in J, ρ the density of water (1000 kg/m^3), g the gravitational acceleration (9.81 m/s^2), h_i the height of dam i, $V_{i,t}$ the volume of dam i for time t. And i = 1, 2, .. 6. The height was still assumed to be constant to make room for potential errors and also since the head did not vary too much. In the output however, when calculating backwards; knowing the energy but needing the volume of water, a varying head was used. How this was obtained can be read in the next section "Reservoir module".

A similar approach for the capacity factor of the hydropower applies for the dam technologies. However, for the dams the capacity factor was as a function of volume. The capacity factor was set to the ratio between the available volume in each reservoir for each time slice and the maximum volume which the reservoir can hold (i.e. reservoir volume). For the dams, the capacity hence changes for each time slice in order to capture the changes in volume due to hydrological and other constraints. E.g. for Dam 1, which regulates the production in Gibe 1, for one time slice with a volume available of for instance 710 Mm^3 and a total volume of 839 Mm^3 would yield a capacity factor (CF) as in Equation 13:

$$CF = \frac{710\ [Mm^3]}{839\ [Mm^3]} \approx 0.846 \qquad \textbf{Equation 13}$$

Storage facilities in OSeMOSYS also require an input of the residual capacity, the *ResidualStorageCapacity*. The method for computing this, is the same as for the residual capacity of dam technology (Equation 12) and since it was assumed that the storage
has the same average volume for each year and dam height as its corresponding dam technology, the residual capacity for the dam and storage turns out the same.

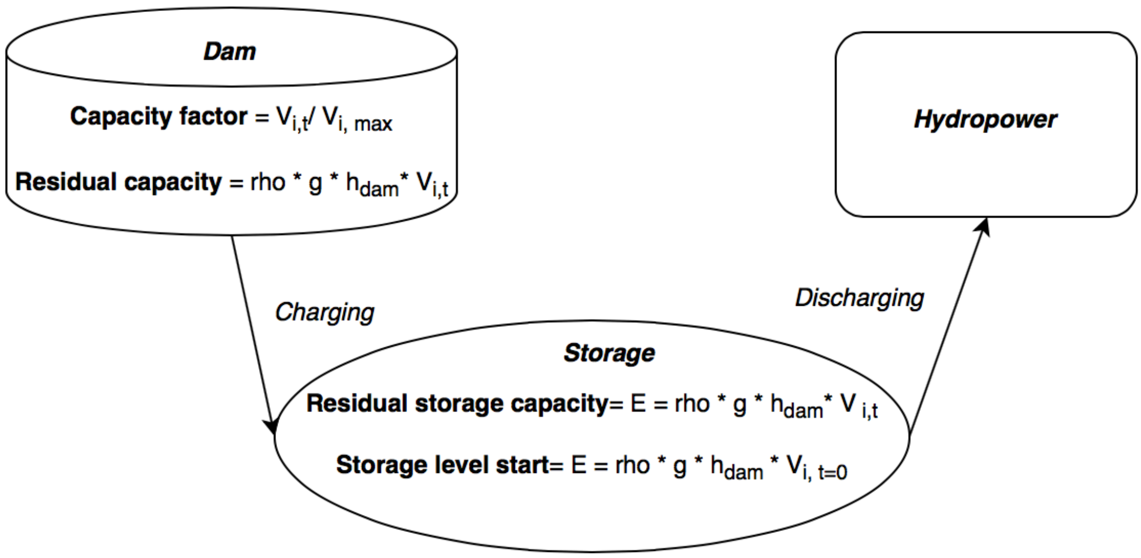
Furthermore, storage also requires a starting level for the first year of the beginnings of the modelling period which is set by *StorageLevelStart*. This one is calculated with Equation 12 too, but using the first available volume for the first year of modelling. Important to note is that this one can never exceed the residual capacity of the storage.

The storage must have a defined minimum storage charge, by which the storage may not be emptied more. This is set as a fraction of the total storage and was assume to be 63.72 %, which was calculated using values from Topkapi-ETH to find the lowest obtained value of the volume. This value was for Gibe III, since it has the lowest ratio of volume compared to the total volume the lowest value. This was applied for all power plants, which is a limitation but one assumed not to cause to much errors.

The maximum rate at which the storage may by be charge or discharged is kept as default value, in order for OSeMOSYS to choose the most optimal solution. Lastly, the operational lives for the dam and storage are assumed to be the same as for its corresponding hydropower.

No costs are assigned to either the dams nor the storages. It was assumed that these costs are considered within the costs of the hydropower technology itself.

Figure below summarizes the equations and connection between dam, storage and hydropower but with the governing equations for them.



The Storage module set-up in OSeMOSYS with the governing equations for dam and storage.

Values for *CapacityFactor, ResidualCapacity* and *ResidualStorageCapacity* Appendix F.

Reservoir module

The reservoir module allows the use to model a cascading scheme directly in the model. If the reservoir is the first one in a series of two or more, then the external inflow is the only inflow. However, if it is the downstream reservoir, then the model will also compute the flow released from the upstream that flows in the river. If the downstream reservoir has another reservoir downstream of itself, the same procedure repeats. However, if it is the last one in the cascading scheme, the reservoir will have an emptying variable composed of the reservoir discharge (water which going to energy production) and spillage.

Note however that the flow between reservoirs also compose of the reservoir discharge and spillage. Hence, when performing a water balance, the inflow to the reservoir equals the water through the turbine and the spillage. The discharge from the reservoir, which is send to the turbine, is calculated within the code using the activity of the hydropower and conversion factors to convert the production to a flow, Equation 14.

$$Reservoir\ discharge_r = \frac{Activity\ of\ hydropower_i}{\rho * g * h_r * \eta * 10^{-9} * K}$$ **Equation 14**

Where r stands for each reservoir and i each hydropower. Activity is in the production from the hydropower, ρ density of water, g the gravitational acceleration, h_r the height of reservoir r, K a conversion factor between W to J. The discharge is hence in the units of m^3.

The additional parameters to the original OSeMOSYS code is shown in below and divided up into conversion, technology and reservoir for their different use.

Additional parameters used in the Reservoir module.

Area	Parameter	Value	Unit	Explanation
Conversion	*RhoWater*	1000	kg/m^3	Density of water
	Gravity	9.81	m/s^2	Gravitational constant
	FlowUnitToYearConversion	31,536,000	s/year	Converts seconds to year
	WattsToModelUnits	10^{-9}	W/GW	Converts output in W to model units (GW)
Technology	*HydroTurbineEfficiency*	0.9	-	Efficiency of turbine
Reservoir	*ReservoirMaxDischarge*	99,999	m^3/s	Maximum discharge of water
	ReservoirMinDischarge	0	m^3/s	Minimum discharge of water
	ReservoirHead	*Varying**	m	Head of reservoir
	ResevoirExternalInflow	*Varying**	m^3/s	External inflow to reservoir
	ReservoirLiveStorage	*Varying**	m^3	Live storage of reservoir

** see Appendix F.*

The turbine efficiency is a constant parameter applied for all hydropower, it was assumed that all turbines (no matter type) had a 90 % efficiency. The live storage was assumed to be the maximum volume the dam could hold and the head was time-varying and calculated through Equation 15, where variable can be viewed in Figure following.

$$H = W_{level} - (W_{level,max} - H_{max})$$ **Equation 15**

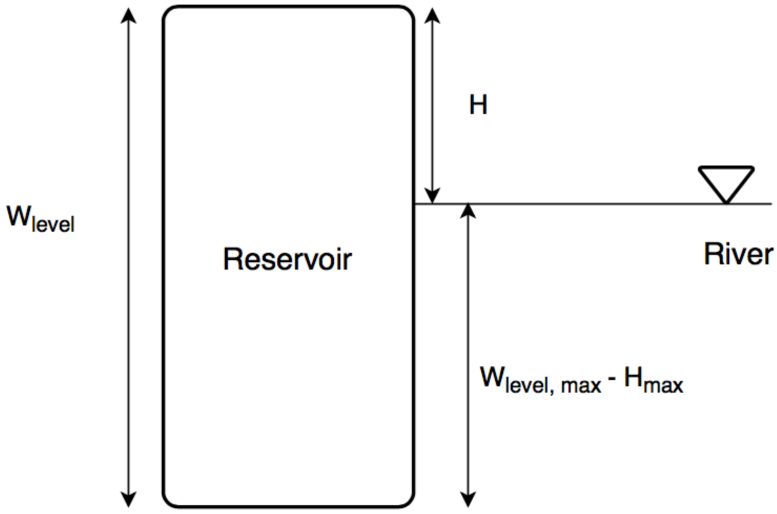


Figure presenting how the head of the reservoir were calculated where W_{level} and H is time-dependent.

External inflow is an input that was calculated from Topkapi-ETH. This inflow is the external sources of water entering the reservoirs, meaning it does not include the upstream release from other reservoirs. The latter is taken into account in the *FlowbetweenReservoir* variable, which gives the discharge and, hence, the outflow from the upstream power plant and through the parameter *DownstreamReservoirTag* makes it flow into the one tagged downstream. The external inflow was calculated from the output from Topkapi-ETH by using a simple water balance. As mentioned in section G, the outputs from Topkapi-ETH are, among others, the outflow from the upstream reservoir and the input to the downstream reservoir. The external inflow was assumed to be the difference between the inflow to the current reservoir and the outflow from the upstream reservoir:

$$Q_{ext} = Q_{inf,n} - Q_{out,n-1} \qquad \textbf{Equation 16}$$

Where n is the current power plant and Q_{inf} is the inflow to the reservoir and Q_{out} is the outflow, both in m^3/s. The reason why this is an assumption more than a correct statement is that any other losses, for instance, evaporation, is not considered. The external inflows were also averaged and can be viewed in Appendix F.

Appendix F – OSeMOSYS input data

OSeMOSYS parameters and default or single-time values for this study.

Parameter	Value	Unit
AccumulatedAnnualDemand	0	PJ
AnnualEmissionLimit	9999	ton
AnnualExogenousEmission	0	ton
AvailabilityFactor	1	Ratio
CapacityFactor	1	Ratio
CapacityOfOneTechnologyUnit	0	GW
CapacityToActivityUnit	1	PJ/GW
CapitalCost	0	MUSD/GW
CapitalCostStorage	0	MUSD/GW
ConversionId	0	-
ConversionIh	0	-
ConversionIs	0	-
DaysInDayType	7	-
DaySplit	0.00137	-
DepreciationMethod	1	-
DiscountRate	0.05	Ratio
EmissionActivityRatio	0	kton/PJ
EmissionPenalty	0	$/ton of emission
FixedCost	0	MUSD/GW
InputActivityRatio	0	Ratio
MinStorageCharge	0.05	Ratio
ModelPeriodEmissionLimit	9999	ton
ModelPeriodExogenousEmission	0	ton
OperationalLife	0	Years
OperationalLifeStorage	0	Years
OutputActivityRatio	0	Ratio
REMinProductionTarget	0	Ratio
ReserveMargin	1.158	Ratio
ReserveMarginTagFuel	0	-
ReserveMarginTagTechnology	0	Ratio
ResidualCapacity	0	GW
ResidualStorageCapacity	0	GW
RETagFuel	0	-
RETagTechnology	0	-
SpecifiedAnnualDemand	0	PJ
SpecifiedDemandProfile	0	Ratio
StorageLevelStart	999	???
StorageMaxChargeRate	99	GW
StorageMaxDischargeRate	99	GW
TechnologyFromStorage	0	-
TechnologyToStorage	0	-
TotalAnnualMaxCapacity	99999	GW
TotalAnnualMaxCapacityInvestment	99999	GW
TotalAnnualMinCapacity	0	GW
TotalAnnualMinCapacityInvestment	0	GW
TotalTechnologyAnnualActivityLowerLimit	0	PJ
TotalTechnologyAnnualActivityUpperLimit	99999	PJ

TotalTechnologyModelPeriodActivityLower Limit	0	PJ
TotalTechnologyModelPeriodActivityUpper Limit	999999	PJ
TradeRoute	0	Binary
VariableCost	0.00001	MUSD/PJ
RhoWater	1000	kg/m3
Gravity	9.81	m/s2
FlowUnittoYearConversion	31536000	s/year
WattsToModelUnits	0.000000001	W/GW
TechnologyFromHydro	0	-
ReservoirMaxDischargeRate	99999	GW
ReservoirMinDischargeRate	0	GW
ReservoirHead	0	m
ReservoirExternalInflow	0	m3/s
ReservoirLevelStart	0	m3
ReservoirLiveStorageVolume	0	m3
DownstreamReservoirTag	0	-

The time split in OSeMOSYS done based on a monthly season.

Month	***TimeSlice* Day**	***TimeSlice* Night**	***YearSplit***
January	JAND	JANN	0.042466
February	FEBD	FEBN	0.038356
March	MARD	MARN	0.042466
April	APRD	APRN	0.041096
May	JUND	JUNN	0.042466
June	JULD	JULN	0.041096
July	AUGD	AUGN	0.042466
August	SEPD	SEPN	0.042466
September	SEPD	SEPN	0.041096
October	OCTD	OCTN	0.042466
November	NOVD	NOVN	0.041096
December	DECD	DECN	0.042466

Forecasted demand (PJ) for industry, rural and urban for year 2010-2050.

PJ	**Demand sites**		
Year	*ELIND*	*ELRUR*	*ELURB*
2010	5.0	6.2	2.6
2011	5.7	7.0	3.0
2012	7.0	8.3	3.7
2013	7.3	10.0	4.6
2014	8.1	10.5	4.9
2015	8.9	11.5	5.7
2016	9.8	12.6	6.6
2017	10.7	13.7	7.5
2018	11.8	14.8	8.5
2019	13.0	15.9	9.6
2020	14.3	17.1	10.7
2021	15.7	18.3	11.9

2022	17.3	19.5	13.2
2023	19.0	20.7	14.6
2024	20.9	22.0	16.1
2025	23.0	23.3	17.6
2026	25.3	24.6	19.3
2027	27.9	26.0	21.0
2028	30.6	27.3	22.9
2029	33.7	28.7	24.8
2030	36.4	30.1	26.9
2031	39.3	31.5	29.0
2032	42.5	32.9	31.3
2033	45.8	34.3	33.6
2034	49.5	35.7	36.1
2035	53.5	37.2	38.7
2036	57.8	38.6	41.4
2037	62.4	40.1	44.1
2038	67.4	41.6	47.0
2039	72.8	43.1	50.1
2040	77.1	44.5	53.2
2041	81.7	46.0	56.5
2042	86.7	47.5	59.9
2043	91.9	49.0	63.4
2044	97.4	50.4	67.1
2045	103.2	51.9	70.8
2046	109.4	53.3	74.8
2047	116.0	54.7	78.8
2048	122.9	56.1	83.0
2049	130.3	57.6	87.4
2050	138.1	58.9	91.8

DaySplit for the *DemandProfile,* applying for all demand sites and all years.

DaySplit	***DemandProfile***
Day*	0.029167
Night*	0.0125

*apply for all seasons

AvailabilityFactor for technologies.

Technology	***AvalibilityFactor***
BMCHP	0.93
COALSCP	0.94
CSP3	0.93
DIESELI	0.9
DIESELR	0.9
DIESELU	0.9
DIESELUT	0.9
GASCC	0.93
GASSC	0.93
GIBEI	0.95
GIBEII	0.95
GIBEIII	0.95
GIBEIV	0.95
GIBEV	0.95
KOYSHA	0.95
HYDM2	0.95

HYDM3	0.95
KURAZ	0.93
OILGCP	0.9
WI25	0.9
WI30	0.85

CapacityFactor for technologies.

Technology	***CapacityFactor* (Day/Night)**
BMCHP	0.53
COALSCP	0.85
CSP1	0.7/0
CSP2	0.7056/0.5544
CSP3	0.92
DIESELI	0.9
DIESELR	0.9
DIESELU	0.9
DIESELUT	0.9
GASCC	0.935
GASSC	0.935
GEOT	0.93
GIBEI	0.447935
GIBEII	0.44439
GIBEIII	0.390692
GIBEIV	0.459494
GIBEV	0.334016
HYDM1	0.25
HYDM2	0.5386
HYDM3	0.5386
KOYSHA	0.34088
KURAZ	0.53
OILGCP	0.9
SOPVR	0.4/0
SOPVR1	0.378/0.072
SOPVR2	0.2865/0.2244
SOPVU	0.4/0
SOPVU1	0.378/0.072
SOPVU2	0.2865/0.2244
SOPVUT	0.5/0
WI25	0.25
WI30	0.3

CapacityToActivityUnit and *OperationalLife* for technologies and storages.

Technology	***CapacityToActivityUnit***	***OperationalLife (OperaltionalLifeStorage)***
	PJ/GW	*Years*
BIOMASSEX	1	35
BIOMASSIM	1	35
BMCHP	31.536	30

COALEX	1	35
COALIM	1	35
COALSCP	31.536	40
CSP1	31.536	25
CSP2	31.536	25
CSP3	31.536	25
DIESELEX	1	30
DIESELI	31.536	20
DIESELIM	1	30
DIESELR	31.536	10
DIESELU	31.536	10
DIESELUT	31.536	25
DISTI	31.536	60
DISTR	31.536	60
DISTU	31.536	60
ELDJH	31.536	50
ELERP	31.536	50
ELKEP	31.536	50
ELSDHP	31.536	50
ELSOP	31.536	50
GASCC	31.536	30
GASEX	1	30
GASIM	1	100
GASSC	31.536	25
GEOT	31.536	25
GIBEI	31.536	50
GIBEII	31.536	50
GIBEIII	31.536	50
GIBEIV	31.536	50
GIBEV	31.536	50
KOYSHA	31.536	50
HYDM1	31.536	50
HYDM2	31.536	50
HYDM3	31.536	50
KURAZ	31.536	30
OILEX	1	25
OILGCP	31.536	25
OILIM	1	25
SOPV	1	100
SOPVR	31.536	25
SOPVR1	31.536	25
SOPVR2	31.536	25
SOPVU	31.536	25
SOPVU1	31.536	25
SOPVU2	31.536	25
SOPVUT	31.536	25
TDAM1	31.536	50 (50)
TDAM2	31.536	50 (50)
TDAM3	31.536	50 (50)
TDAM4	31.536	50 (50)
TDAM5	31.536	50 (50)
TDAM6	31.536	50 (50)
TRANS	31.536	50
WI25	31.536	25
WI30	31.536	25

Emission and *EmissionActivityRatio* for fuels modelled.

Technology	Emission	*EmissionActivityRatio*
COALIM	CO_2	0.0893
COALEX	CO_2	0.0893
DIESELIM	CO_2	0.0693
DIESELEX	CO_2	0.0693
OILIM	CO_2	0.0747
OILEX	CO_2	0.0747
GASIM	CO_2	0.0503
GASEX	CO_2	0.0503

The *TotalTechnologyModelPeriodActivityUpperLimit* (PJ) of the modelling period for certain technologies.

Technology	*TotalTechnologyModelPeriodActivityUpperLimit*
COALEX	0
DIESELEX	1.32
OILEX	1.32
GASEX	953.5

The *TotalTechnologyAnnualActivityUpperLimit* (PJ) of the modelling period for certain technologies.

Technology	*TotalTechnologyAnnualActivityUpperLimit*	For years
GASIM	99999	2026-2050
CSP1	82652.4	2010-2050
CSP2	82652.4	2010-2050
CSP3	82652.4	2010-2050
SOPV	97754.8814	2010-2050
SOPVR1	0	2010-2050
SOPVR2	0	2010-2050
SOPVU1	0	2010-2050
SOPVU2	0	2010-2050
WI25	53416.8	2010-2050
WI30	17939.2653	2010-2050

InpuActivityRatio, also showing which fuels and technologies are connected and in which mode of operation.

Technology	Fuel	*ModeOfOperation*	*InputActivityRatio*
BMCHP	BIOMASS	1	2.63
COALSCP	COAL	1	2.70
DIESELI	DIESEL	1	2.86
DIESELR	DIESEL	1	4.76
DIESELR	DIESEL	2	4.76
DIESELU	DIESEL	1	4.76
DIESELU	DIESEL	2	4.76
DIESELUT	DIESEL	1	2.86

TRANS	EL1	1	1
DISTI	EL2	1	1
DISTR	EL2	1	1
DISTU	EL2	1	1
ELDJH	DJEL1	2	1
ELDJH	EL1	1	1
ELERP	EREL1	2	1
ELERP	EL1	1	1
ELKEP	EL1	1	1
ELKEP	KEEL1	2	1
ELSDHP	EL1	1	1
ELSDHP	SDEL1	2	1
ELSOP	EL1	1	1
ELSOP	SOEL1	2	1
OILGCP	OIL	1	2.86
GASCC	GAS	1	2.08
GASSC	GAS	1	3.33
CSP3	GAS	1	1.89
SOPVUT	SOLARPV	1	1
SOPVR	SOLARPV	1	1
SOPVR1	SOLARPV	1	1
SOPVR2	SOLARPV	1	1
SOPVU	SOLARPV	1	1
SOPVU1	SOLARPV	1	1
SOPVU2	SOLARPV	1	1
DIESELUT	BIOMASS	1	2.63
TRANS	COAL	1	2.70
DISTI	DIESEL	1	2.86

OutputActivityRatio, also showing which fuels and technologies are connected and in which mode of operation.

Technology	Fuel	*ModeOfOpeartion*	*OutputActivityRatio*
BIOMASSIM	BIOMASS	1	1
BIOMASSEX	BIOMASS	1	1
BMCHP	EL1	1	1
COALIM	COAL	1	1
COALEX	COAL	1	1
COALSCP	EL1	1	1
DIESELIM	DIESEL	1	1
DIESELEX	DIESEL	1	1
DIESELI	ELIND	1	1
DIESELR	ELIND	1	1
DIESELR	ELRUR	2	1
DIESELU	ELIND	1	1
DIESELU	ELURB	2	1
DIESELUT	EL1	1	1
TRANS	EL2	1	1
DISTI	ELIND	1	0.9663
DISTR	ELRUR	1	0.96
DISTU	ELURB	1	0.88
ELDJH	DJEL1	1	0.956
ELDJH	EL1	1	0.95
ELERP	EREL1	2	0.95
ELERP	EL1	1	0.95
ELKEP	EL1	2	0.95
ELKEP	KEEL1	2	0.95

ELSDHP	EL1	1	0.95
ELSDHP	SDEL1	2	0.95
ELSOP	EL1	1	0.95
ELSOP	SOEL1	2	0.95
GEOT	EL1	1	0.95
OILIM	OIL	1	1
OILEX	OIL	1	1
OILGCP	EL1	1	1
HYDM1	EL1	1	1
HYDM2	EL1	1	1
HYDM3	EL1	1	1
GASIM	GAS	1	1
GASEX	GAS	1	1
GASCC	EL1	1	1
GASSC	EL1	1	1
CSP1	EL1	1	1
CSP2	EL1	1	1
CSP3	EL1	1	1
SOPV	SOLARPV	1	1
SOPVUT	EL1	1	1
SOPVR	ELIND	1	1
SOPVR	ELRUR	2	1
SOPVR1	ELRUR	1	1
SOPVR2	ELRUR	1	1
SOPVU	ELIND	1	1
SOPVU	ELURB	2	1
SOPVU1	ELURB	1	1
SOPVU2	ELURB	1	1
WI25	EL1	1	1
WI30	EL1	1	1

TotalAnnualMaxCapacity (GW) of technologies for year 2010-2019.

Tech	**Year**									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELERP	0	0	0	0	0	0	0	0	0	0
ELKEP	0	0	0	0	0	0	0	0	0	0
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELSOP	0	0	0	0	0	0	0	0	0	0
GEOT	3	3	3	4.5	4.5	4.5	4.5	4.5	4.5	4.5
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	0	0	0	0	0	0	1.87	1.87	1.87	1.87
GIBEIV	0	0	0	0	0	0	0	0	0	0
GIBEV	0	0	0	0	0	0	0	0	0	0
KOYSHA	0.003	0.003	0.003	0.003	0.003	0.003	0.010	0.010	0.010	0.010
HYDM1	0.085	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182
HYDM2	1.366	1.366	1.366	1.366	1.366	1.553	3.491	4.191	8.241	8.241
HYDM3	0.100	0.180	0.180	0.220	0.220	0.220	0.220	0.220	0.220	0.220
KURAZ	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM1	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
TDAM2	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111
TDAM3	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
TDAM4	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
TDAM5	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TDAM6	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

TotalAnnualMaxCapacity (GW) of technologies for year 2019-2029.

Tech	Year									
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELERP	0	0	0	0	0	0	0	0	0	0
ELKEP	0	0	0	0	0	0	0	0	0	0
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELSOP	0	0	0	0	0	0	0	0	0	0
GEOT	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
GIBEIV	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472
GIBEV	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
KOYSHA	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HYDM1	0.182	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312
HYDM2	8.241	17.434	17.434	17.434	17.434	17.434	22.434	22.434	22.434	22.434
HYDM3	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
KURAZ	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM1	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
TDAM2	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111
TDAM3	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
TDAM4	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
TDAM5	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
TDAM6	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

TotalAnnualMaxCapacity (GW) of technologies for year 2029-2039.

Tech	Year									
	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELERP	0	0	0	0	0	0	0	0	0	0
ELKEP	0	0	0	0	0	0	0	0	0	0
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELSOP	0	0	0	0	0	0	0	0	0	0
GEOT	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
GIBEIV	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472
GIBEV	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
KOYSHA	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HYDM1	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312
HYDM2	22.434	27.434	27.434	27.434	27.434	32.434	32.434	32.434	32.434	32.434
HYDM3	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
KURAZ	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM1	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
TDAM2	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111
TDAM3	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
TDAM4	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
TDAM5	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
TDAM6	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

TotalAnnualMaxCapacity (GW) of technologies for year 2039-2050.

Tech	**Year**										
	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELERP	0	0	0	0	0	0	0	0	0	0	0
ELKEP	0	0	0	0	0	0	0	0	0	0	0
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELSOP	0	0	0	0	0	0	0	0	0	0	0
GEOT	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
GIBEIV	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472
GIBEV	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
KOYSHA	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HYDM1	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312
HYDM2	37.434	37.434	37.434	37.434	37.434	42.434	42.434	42.434	42.434	42.434	42.434
HYDM3	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
KURAZ	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM1	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
TDAM2	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111	1.111
TDAM3	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
TDAM4	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
TDAM5	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
TDAM6	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

ResidualCapacity (GW) of technologies for year 2010-2018.

Tech	**Year**								
	2010	2011	2012	2013	2014	2015	2016	2017	2018
BMCHP	0.001	0.001	0.001	0.001	0.001	0.001	0.0009	0.0008	0.0007
DIESELUT	0.108034	0.108034	0.108034	0.108034	0.108034	0.108034	0.106132	0.104374	0.102461
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
GEOT	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	0	0	0	0	0	0	1.87	1.87	1.87
GIBEIV	0	0	0	0	0	0	0	0	0
GIBEV	0	0	0	0	0	0	0	0	0
KOYSHA	0	0	0	0	0	0	0	0	0
HYDM1	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008
HYDM2	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512
HYDM3	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064
KURAZ	0.1	0.18	0.18	0.22	0.22	0.22	0.22	0.22	0.22
SOPVUT	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015

ResidualCapacity (GW) of technologies for year 2019-2027.

Tech	Year								
	2019	2020	2021	2022	2023	2024	2025	2026	2027
BMCHP	0.0006	0.0005	0.0004	0.0003	0.0002	0.0001	0	0	0
DIESELUT	0.099223	0.095382	0.092013	0.09041	0.088807	0.084804	0.083201	0.083201	0.083201
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
GEOT	0.0085	0.0085	0.0085	0.0085	0.0046	0.0046	0.0046	0	0
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
GIBEIV	0	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472
GIBEV	0	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
KOYSHA									
HYDM1	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008
HYDM2	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512
HYDM3	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064
KURAZ	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
SOPVUT	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015

ResidualCapacity (GW) of technologies for year 2028-2036.

Tech	Year								
	2028	2029	2030	2031	2032	2033	2034	2035	2036
BMCHP	0	0	0	0	0	0	0	0	0
DIESELUT	0.002	0.002	0.002	0.002	0.002	0.002	0	0	0
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
GEOT	0	0	0	0	0	0	0	0	0
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
GIBEIV	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472
GIBEV	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
KOYSHA									
HYDM1	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008
HYDM2	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512
HYDM3	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064
KURAZ	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
SOPVUT	0.00015	0.00015	0.00015	0.00015	0.00015	0	0	0	0

ResidualCapacity (GW) of technologies for year 2037-2045.

Tech	Year								
	2037	2038	2039	2040	2041	2042	2043	2044	2045
BMCHP	0	0	0	0	0	0	0	0	0
DIESELUT	0	0	0	0	0	0	0	0	0
ELDJH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
ELSDHP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
GEOT	0	0	0	0	0	0	0	0	0
GIBEI	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
GIBEIV	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472	1.472
GIBEV	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66

KOYSHA									
HYDM1	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008	0.003008
HYDM2	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512	0.08512
HYDM3	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064
KURAZ	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
SOPVUT	0	0	0	0	0	0	0	0	0

ResidualCapacity (GW) of technologies for year 2046-2050.

Tech	**Year**				
	2046	2047	2048	2049	2050
BMCHP	0	0	0	0	0
DIESELUT	0	0	0	0	0
ELDJH	0.18	0.18	0.18	0.18	0.18
ELSDHP	0.2	0.2	0.2	0.2	0.2
GEOT	0	0	0	0	0
GIBEI	0.184	0.184	0.184	0.184	0.184
GIBEII	0.42	0.42	0.42	0.42	0.42
GIBEIII	1.87	1.87	1.87	1.87	1.87
GIBEIV	1.472	1.472	1.472	1.472	1.472
GIBEV	0.66	0.66	0.66	0.66	0.66
KOYSHA					
HYDM1	0.003008	0.003008	0.003008	0.003008	0.003008
HYDM2	0.08512	0.08512	0.08512	0.08512	0.08512
HYDM3	0.9064	0.9064	0.9064	0.9064	0.9064
KURAZ	0.22	0.22	0.22	0.22	0.22
SOPVUT	0	0	0	0	0

*TotalAnnualMaxCapacityInvestment (*GW) of technologies for year 2010-2020.

Tech	**Year**										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BMCHP	0	0	0	0	0	0	0	0	0	0	0
COALSCP	0	0	0	0	0	0	0	0	0	0	0
CSP1	0	0	0	0	0	0	0	0	0	0	0.5
CSP2	0	0	0	0	0	0	0	0	0	0	0.5
CSP3	0	0	0	0	0	0	0	0	0	0	0.5
DIESELUT	0	0	0	0	0	0	0	0	0	0	0.5
ELDJH	0	0	0	0	0	0	0	0	0	0	0
ELERP	0	0	0	0	0	0	0	0	0	0	0
ELKEP	0	0	0	0	0	0	0	0	2	2	2
ELSDHP	0	0	0	0	0	0	3.2	3.2	3.2	4.4	4.8
ELSOP	0	0	0	0	0	0	0	0	0	0	0
GASCC	0	0	0	0	0	0	0	0	0	0	0.5
GASSC	0	0	0	0	0	0	0	0	0	0	0.5
GEOT	0	0	0	0	0	0.06	0.01	0.09	0	0	0
HYDM1	0	0	0	0	0	0	0.0066	0	0	0	0
HYDM2	0	0.097	0	0	0	0	0	0	0	0	0
HYDM3	0.46	0	0	0	0	0.187	1.9371	0.7	4.05	0	0
OILGCP	0	0	0	0	0	0	0	0	0	0	0.5
SOPVR	0	0	0	0	0	0	0	0	0	0	0.5
SOPVR1	0	0	0	0	0	0	0	0	0	0.05	0.1707
SOPVR2	0	0	0	0	0	0	0	0	0	0.05	0.1707
SOPVU	0	0	0	0	0	0	0	0	0	0	0.5
SOPVU1	0	0	0	0	0	0	0	0	0	0.05	0.1707
SOPVU2	0	0	0	0	0	0	0	0	0	0.05	0.1707
SOPVUT	0.0001	0	0	0	0	0	0	0	0	0	0.5
WI25	0	0	0	0	0	0	0	0	0	0	0.5
WI30	0	0.03	0.051	0.0902	0	0.051	0	0	0	0	0.5

TotalAnnualMaxCapacityInvestment (GW) of technologies for year 2021-2031.

Tech	Year										
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
BMCHP	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
COALSCP	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
CSP1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
CSP2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
CSP3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
DIESELUT	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
ELDJH	0	0	0	0	0	0	0	0	0	0	0
ELERP	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELKEP	2	2	2	2	2	2	2	2	2	2	2
ELSDHP	4.8	4.8	4.8	4.8	6.4	6.4	6.4	6.4	6.4	6.4	6.4
ELSOP	0	0	0	0	0	0	0	0	0	0.4	0.4
GASCC	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
GASSC	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
GEOT	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
HYDM1	0	0	0	0	0	0	0	0	0	0	0
HYDM2	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
HYDM3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
OILGCP	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
SOPVR	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
SOPVR1	0.2915	0.4122	0.5329	0.6537	0.7744	0.8951	1.0159	1.1366	1.2573	1.378	1.4988
SOPVR2	0.2915	0.4122	0.5329	0.6537	0.7744	0.8951	1.0159	1.1366	1.2573	1.378	1.4988
SOPVU	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
SOPVU1	0.2915	0.4122	0.5329	0.6537	0.7744	0.8951	1.0159	1.1366	1.2573	1.378	1.4988
SOPVU2	0.2915	0.4122	0.5329	0.6537	0.7744	0.8951	1.0159	1.1366	1.2573	1.378	1.4988
SOPVUT	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
WI25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5
WI30	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5

TotalAnnualMaxCapacityInvestment (GW) of technologies for year 2032-2042.

Tech	Year										
	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
BMCHP	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
COALSCP	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
CSP1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
CSP2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
CSP3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
DIESELUT	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
ELDJH	0	0	0	0	0	0	0	0	0	0	0
ELERP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELKEP	2	2	2	2	2	2	2	2	2	2	2
ELSDHP	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
ELSOP	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
GASCC	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
GASSC	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
GEOT	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
HYDM1	0	0	0	0	0	0	0	0	0	0	0

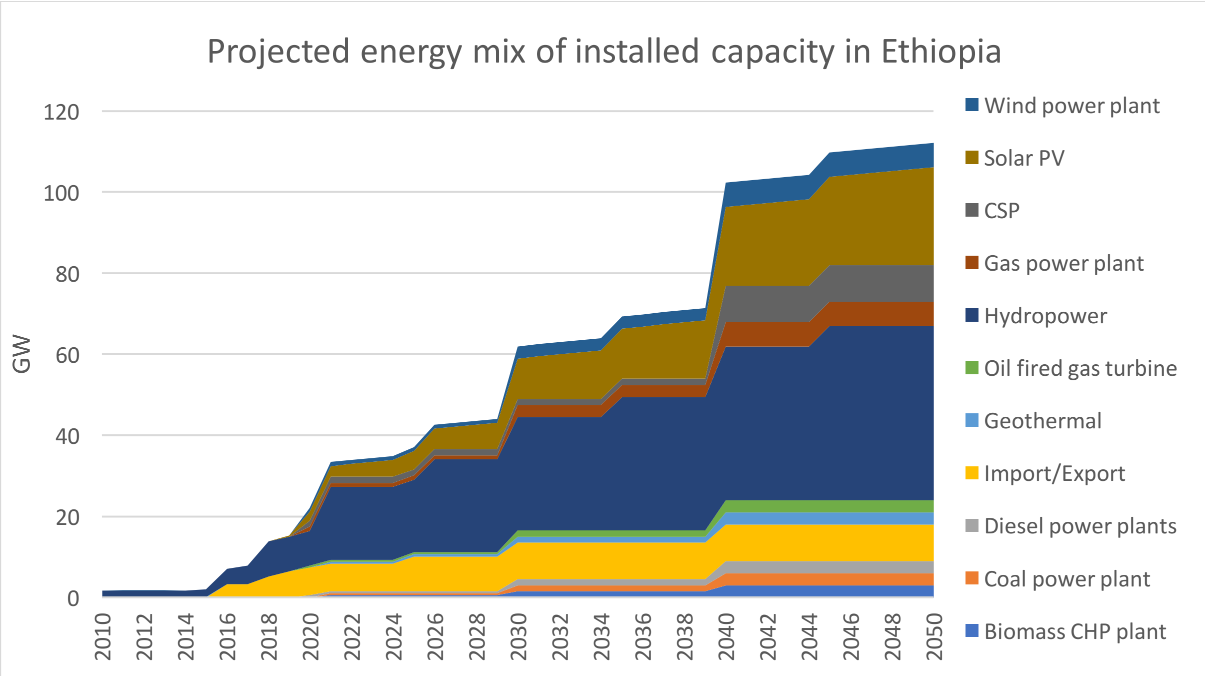
HYDM2	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
HYDM3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
OILGCP	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
SOPVR	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
SOPVR1	1.6195	1.7402	1.861	1.9817	2.1024	2.2232	2.3439	2.4646	2.5854	2.7061	2.8268
SOPVR2	1.6195	1.7402	1.861	1.9817	2.1024	2.2232	2.3439	2.4646	2.5854	2.7061	2.8268
SOPVU	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
SOPVU1	1.6195	1.7402	1.861	1.9817	2.1024	2.2232	2.3439	2.4646	2.5854	2.7061	2.8268
SOPVU2	1.6195	1.7402	1.861	1.9817	2.1024	2.2232	2.3439	2.4646	2.5854	2.7061	2.8268
SOPVUT	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
WI25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3
WI30	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	3

TotalAnnualMaxCapacityInvestment (GW) of technologies for year 2043-2050.

Tech	**Year**							
	2043	2044	2045	2046	2047	2048	2049	2050
BMCHP	3	3	3	3	3	3	3	3
COALSCP	3	3	3	3	3	3	3	3
CSP1	3	3	3	3	3	3	3	3
CSP2	3	3	3	3	3	3	3	3
CSP3	3	3	3	3	3	3	3	3
DIESELUT	3	3	3	3	3	3	3	3
ELDJH	0	0	0	0	0	0	0	0
ELERP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ELKEP	2	2	2	2	2	2	2	2
ELSDHP	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
ELSOP	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
GASCC	3	3	3	3	3	3	3	3
GASSC	3	3	3	3	3	3	3	3
GEOT	3	3	3	3	3	3	3	3
HYDM1	0	0	0	0	0	0	0	0
HYDM2	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
HYDM3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
OILGCP	3	3	3	3	3	3	3	3
SOPVR	3	3	3	3	3	3	3	3
SOPVR1	2.9476	3.0683	3.189	3.3098	3.4305	3.5512	3.672	3.7927
SOPVR2	2.9476	3.0683	3.189	3.3098	3.4305	3.5512	3.672	3.7927
SOPVU	3	3	3	3	3	3	3	3
SOPVU1	2.9476	3.0683	3.189	3.3098	3.4305	3.5512	3.672	3.7927
SOPVU2	2.9476	3.0683	3.189	3.3098	3.4305	3.5512	3.672	3.7927
SOPVUT	3	3	3	3	3	3	3	3
WI25	3	3	3	3	3	3	3	3
WI30	3	3	3	3	3	3	3	3

TotalAnnualMinCapacityInvestment (GW) of technologies for year 2010-2020.

Tech	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019-2050
GEOT	0	0	0	0	0	0.06	0.01	0.09	0	0
HYDM1	0	0	0	0	0	0	0.0066	0	0	0
HYDM2	0	0.097	0	0	0	0	0	0	0	0
HYDM3	0.46	0	0	0	0	0.187	1.9371	0.7	4.05	0
SOPVUT	0.0001	0	0	0	0	0	0	0	0	0
WI30	0	0.03	0.051	0.0902	0	0.051	0	0	0	0



Projected Energy mix in Ethiopia in the TEMBA model. Consist of the TotalAnnualMaxCapacityInvestment and TotalAnnualMaxCapacity

Projected *CapitalCost* (MUSD/GW) for the technologies for year 2010-2019.

Tech	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
BMCHP	5148.0	5148.0	5148.0	5130.3	5112.6	5095.0	5077.3	5059.7	5042.0	5024.3
COALSCP	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3
CSP1	5773.7	5773.7	5773.7	5578.8	5383.9	5189.0	4994.2	4799.3	4604.4	4409.6
CSP2	7845.2	7845.2	7845.2	7448.4	7051.5	6654.7	6257.8	5860.9	5464.1	5067.2
CSP3	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6
DIESELI	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6
DIESELR	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5
DIESELU	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9
DIESELUT	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
DISTI	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4
DISTR	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6
DISTU	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3
ELDJH	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9
ELERP	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0
ELKEP	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7

ELSDHP	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0
ELSOP	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4
GASCC	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9
GASSC	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
GEOT	5953.5	5953.5	5953.5	5933.9	5914.2	5894.6	5874.9	5855.3	5835.6	5816.0
GIBEI	2936.0	2936.0	2936.0	2943.9	2951.7	2959.6	2967.4	2975.3	2983.1	2991.0
GIBEII	2936.0	2936.0	2936.0	2943.9	2951.7	2959.6	2967.4	2975.3	2983.1	2991.0
GIBEIII	2936.0	2936.0	2936.0	2943.9	2951.7	2959.6	2967.4	2975.3	2983.1	2991.0
GIBEIV	2290.0	2290.0	2290.0	2296.1	2302.2	2308.4	2314.5	2320.6	2326.7	2332.9
GIBEV	2040.0	2040.0	2040.0	2045.5	2050.9	2056.4	2061.8	2067.3	2072.7	2078.2
KOYSHA	2936.0	2936.0	2936.0	2943.9	2951.7	2959.6	2967.4	2975.3	2983.1	2991.0
HYDM1	6231.9	6231.9	6231.9	6224.0	6216.1	6208.2	6200.2	6192.3	6184.4	6176.5
HYDM2	2159.3	2159.3	2159.3	2165.1	2170.9	2176.7	2182.4	2188.2	2194.0	2199.8
HYDM3	2159.3	2159.3	2159.3	2165.1	2170.9	2176.7	2182.4	2188.2	2194.0	2199.8
KURAZ	6000.0	6000.0	6000.0	5979.4	5958.8	5938.3	5917.7	5897.1	5876.5	5855.9
OILGCP	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4
SOPVR	2075.9	2075.9	2075.9	2008.2	1940.5	1872.8	1805.1	1737.4	1669.7	1602.1
SOPVR1	4258.0	4258.0	4100.6	3943.2	3785.8	3628.4	3471.0	3373.0	3275.0	3177.0
SOPVR2	6275.0	6275.0	6053.2	5831.4	5609.6	5387.8	5166.0	5011.6	4857.2	4702.8
SOPVU	2075.9	2075.9	2075.9	2008.2	1940.5	1872.8	1805.1	1737.4	1669.7	1602.1
SOPVU1	4258.0	4258.0	4100.6	3943.2	3785.8	3628.4	3471.0	3373.0	3275.0	3177.0
SOPVU2	6275.0	6275.0	6053.2	5831.4	5609.6	5387.8	5166.0	5011.6	4857.2	4702.8
SOPVUT	1680.6	1680.6	1680.6	1626.3	1572.0	1517.7	1463.5	1409.2	1354.9	1300.6
TRANS	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0
WI25	2191.7	2191.7	2191.7	2169.8	2148.0	2126.2	2104.3	2082.5	2060.7	2038.8
WI30	2191.7	2191.7	2191.7	2169.8	2148.0	2126.2	2104.3	2082.5	2060.7	2038.8

Projected *CapitalCost* (MUSD/GW) for the technologies for year 2020-2029.

Tech	**Year**									
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
BMCHP	5006.7	4989.7	4972.7	4955.7	4938.8	4921.8	4904.8	4887.8	4870.8	4853.8
COALSCP	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3
CSP1	4214.7	4149.1	4083.4	4017.8	3952.2	3886.6	3821.0	3755.4	3689.8	3624.1
CSP2	4670.4	4591.2	4512.0	4432.9	4353.7	4274.6	4195.4	4116.2	4037.1	3957.9
CSP3	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6
DIESELI	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6
DIESELR	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5
DIESELU	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9
DIESELUT	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
DISTI	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4
DISTR	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6
DISTU	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3
ELDJH	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9
ELERP	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0
ELKEP	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7
ELSDHP	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0
ELSOP	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4
GASCC	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9
GASSC	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
GEOT	5796.3	5762.9	5729.5	5696.1	5662.6	5629.2	5595.8	5562.4	5528.9	5495.5
GIBEI	2998.8	3011.4	3023.9	3036.5	3049.0	3061.6	3074.2	3086.7	3099.3	3111.8
GIBEII	2998.8	3011.4	3023.9	3036.5	3049.0	3061.6	3074.2	3086.7	3099.3	3111.8
GIBEIII	2998.8	3011.4	3023.9	3036.5	3049.0	3061.6	3074.2	3086.7	3099.3	3111.8
GIBEIV	2339.0	2348.8	2358.6	2368.4	2378.2	2388.0	2397.8	2407.6	2417.4	2427.2
GIBEV	2083.6	2092.4	2101.1	2109.8	2118.5	2127.3	2136.0	2144.7	2153.5	2162.2
KOYSHA	2998.8	3011.4	3023.9	3036.5	3049.0	3061.6	3074.2	3086.7	3099.3	3111.8
HYDM1	6168.6	6164.5	6160.4	6156.3	6152.3	6148.2	6144.1	6140.0	6136.0	6131.9
HYDM2	2205.5	2214.8	2224.0	2233.2	2242.5	2251.7	2261.0	2270.2	2279.4	2288.7
HYDM3	2205.5	2214.8	2224.0	2233.2	2242.5	2251.7	2261.0	2270.2	2279.4	2288.7
KURAZ	5835.3	5815.6	5795.8	5776.0	5756.2	5736.4	5716.6	5696.8	5677.0	5657.2
OILGCP	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4

SOPVR	1534.4	1514.3	1494.2	1474.2	1454.1	1434.0	1413.9	1393.9	1373.8	1353.7
SOPVR1	3079.0	2981.0	2926.5	2872.0	2817.5	2763.0	2708.5	2654.0	2599.5	2545.0
SOPVR2	4548.4	4394.0	4313.6	4233.2	4152.8	4072.4	3992.0	3911.6	3831.2	3750.8
SOPVU	1534.4	1514.3	1494.2	1474.2	1454.1	1434.0	1413.9	1393.9	1373.8	1353.7
SOPVU1	3079.0	2981.0	2926.5	2872.0	2817.5	2763.0	2708.5	2654.0	2599.5	2545.0
SOPVU2	4548.4	4394.0	4313.6	4233.2	4152.8	4072.4	3992.0	3911.6	3831.2	3750.8
SOPVUT	1246.3	1230.3	1214.2	1198.2	1182.1	1166.1	1150.0	1134.0	1117.9	1101.9
TRANS	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0
WI25	2017.0	2007.6	1998.1	1988.7	1979.3	1969.8	1960.4	1951.0	1941.5	1932.1
WI30	2017.0	2007.6	1998.1	1988.7	1979.3	1969.8	1960.4	1951.0	1941.5	1932.1

Projected *CapitalCost* (MUSD/GW) for the technologies for year 2030-2039.

Tech	**Year**									
	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
BMCHP	4836.9	4819.9	4802.9	4785.9	4768.9	4751.9	4751.9	4751.9	4751.9	4751.9
COALSCP	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3
CSP1	3558.5	3492.9	3427.3	3361.7	3296.1	3230.5	3230.5	3230.5	3230.5	3230.5
CSP2	3878.8	3799.6	3720.4	3641.3	3562.1	3482.9	3482.9	3482.9	3482.9	3482.9
CSP3	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6
DIESELI	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6
DIESELR	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5
DIESELU	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9
DIESELUT	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
DISTI	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4
DISTR	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6
DISTU	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3
ELDJH	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9
ELERP	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0
ELKEP	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7
ELSDHP	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0
ELSOP	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4
GASCC	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9
GASSC	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
GEOT	5462.1	5428.7	5395.2	5361.8	5328.4	5295.0	5295.0	5295.0	5295.0	5295.0
GIBEI	3124.4	3137.0	3149.5	3162.1	3174.6	3187.2	3187.2	3187.2	3187.2	3187.2
GIBEII	3124.4	3137.0	3149.5	3162.1	3174.6	3187.2	3187.2	3187.2	3187.2	3187.2
GIBEIII	3124.4	3137.0	3149.5	3162.1	3174.6	3187.2	3187.2	3187.2	3187.2	3187.2
GIBEIV	2437.0	2446.7	2456.5	2466.3	2476.1	2485.9	2485.9	2485.9	2485.9	2485.9
GIBEV	2170.9	2179.6	2188.4	2197.1	2205.8	2214.5	2214.5	2214.5	2214.5	2214.5
KOYSHA	3124.4	3137.0	3149.5	3162.1	3174.6	3187.2	3187.2	3187.2	3187.2	3187.2
HYDM1	6127.8	6123.7	6119.7	6115.6	6111.5	6107.4	6107.4	6107.4	6107.4	6107.4
HYDM2	2297.9	2307.2	2316.4	2325.6	2334.9	2344.1	2344.1	2344.1	2344.1	2344.1
HYDM3	2297.9	2307.2	2316.4	2325.6	2334.9	2344.1	2344.1	2344.1	2344.1	2344.1
KURAZ	5637.4	5617.6	5597.8	5578.0	5558.2	5538.4	5538.4	5538.4	5538.4	5538.4
OILGCP	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4
SOPVR	1333.6	1313.6	1293.5	1273.4	1253.3	1233.3	1233.3	1233.3	1233.3	1233.3
SOPVR1	2490.5	2436.0	2413.8	2391.6	2369.4	2347.2	2325.0	2302.8	2280.6	2258.4
SOPVR2	3670.4	3590.0	3557.3	3524.6	3491.9	3459.2	3426.5	3393.8	3361.1	3328.4
SOPVU	1333.6	1313.6	1293.5	1273.4	1253.3	1233.3	1233.3	1233.3	1233.3	1233.3
SOPVU1	2490.5	2436.0	2413.8	2391.6	2369.4	2347.2	2325.0	2302.8	2280.6	2258.4
SOPVU2	3670.4	3590.0	3557.3	3524.6	3491.9	3459.2	3426.5	3393.8	3361.1	3328.4
SOPVUT	1085.8	1069.8	1053.7	1037.7	1021.6	1005.6	1005.6	1005.6	1005.6	1005.6
TRANS	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0
WI25	1922.7	1913.2	1903.8	1894.3	1884.9	1875.5	1875.5	1875.5	1875.5	1875.5
WI30	1922.7	1913.2	1903.8	1894.3	1884.9	1875.5	1875.5	1875.5	1875.5	1875.5

Projected *CapitalCost* (MUSD/GW) for the technologies for year 2040-2049.

Tech	Year									
	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049
BMCHP	4751.9	4751.9	4751.9	4751.9	4751.9	4751.9	4751.9	4751.9	4751.9	4751.9
COALSCP	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3	2528.3
CSP1	3230.5	3230.5	3230.5	3230.5	3230.5	3230.5	3230.5	3230.5	3230.5	3230.5
CSP2	3482.9	3482.9	3482.9	3482.9	3482.9	3482.9	3482.9	3482.9	3482.9	3482.9
CSP3	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6	1590.6
DIESELI	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6	691.6
DIESELR	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5	726.5
DIESELU	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9	691.9
DIESELUT	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
DISTI	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4	840.4
DISTR	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6	4233.6
DISTU	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3	2433.3
ELDJH	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9	432.9
ELERP	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0	746.0
ELKEP	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7	422.7
ELSDHP	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0
ELSOP	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4	1044.4
GASCC	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9	1181.9
GASSC	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6	780.6
GEOT	5295.0	5295.0	5295.0	5295.0	5295.0	5295.0	5295.0	5295.0	5295.0	5295.0
GIBEI	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2
GIBEII	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2
GIBEIII	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2
GIBEIV	2485.9	2485.9	2485.9	2485.9	2485.9	2485.9	2485.9	2485.9	2485.9	2485.9
GIBEV	2214.5	2214.5	2214.5	2214.5	2214.5	2214.5	2214.5	2214.5	2214.5	2214.5
KOYSHA	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2	3187.2
HYDM1	6107.4	6107.4	6107.4	6107.4	6107.4	6107.4	6107.4	6107.4	6107.4	6107.4
HYDM2	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1
HYDM3	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1	2344.1
KURAZ	5538.4	5538.4	5538.4	5538.4	5538.4	5538.4	5538.4	5538.4	5538.4	5538.4
OILGCP	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4	1488.4
SOPVR	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3
SOPVR1	2236.2	2214.0	2191.8	2169.6	2147.4	2125.2	2103.0	2080.8	2058.6	2036.4
SOPVR2	3295.7	3263.0	3230.3	3197.6	3164.9	3132.2	3099.5	3066.8	3034.1	3001.4
SOPVU	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3	1233.3
SOPVU1	2236.2	2214.0	2191.8	2169.6	2147.4	2125.2	2103.0	2080.8	2058.6	2036.4
SOPVU2	3295.7	3263.0	3230.3	3197.6	3164.9	3132.2	3099.5	3066.8	3034.1	3001.4
SOPVUT	1005.6	1005.6	1005.6	1005.6	1005.6	1005.6	1005.6	1005.6	1005.6	1005.6
TRANS	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0	365.0
WI25	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5
WI30	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5	1875.5

Projected *CapitalCost* (MUSD/GW) for the technologies for year 2050.

Tech	Year
	2050
BMCHP	4751.9
COALSCP	2528.3
CSP1	3230.5
CSP2	3482.9
CSP3	1590.6
DIESELI	691.6
DIESELR	726.5
DIESELU	691.9
DIESELUT	780.6
DISTI	840.4
DISTR	4233.6

DISTU	2433.3
ELDJH	432.9
ELERP	746.0
ELKEP	422.7
ELSDHP	190.0
ELSOP	1044.4
GASCC	1181.9
GASSC	780.6
GEOT	5295.0
GIBEI	3187.2
GIBEII	3187.2
GIBEIII	3187.2
GIBEIV	2485.9
GIBEV	2214.5
KOYSHA	3187.2
HYDM1	6107.4
HYDM2	2344.1
HYDM3	2344.1
KURAZ	5538.4
OILGCP	1488.4
SOPVR	1233.3
SOPVR1	2014.2
SOPVR2	2968.7
SOPVU	1233.3
SOPVU1	2014.2
SOPVU2	2968.7
SOPVUT	1005.6
TRANS	365.0
WI25	1875.5
WI30	1875.5

Projected *FixedCost* (MUSD/GW) for the technologies for 2010-2020.

Tech	**Year**										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BMCHP	58.6	58.6	58.6	58.3	58.0	57.7	57.3	57.0	56.7	56.4	56.0
COALSCP	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
CSP1	199.5	199.5	199.5	193.0	186.4	179.9	173.4	166.8	160.3	153.8	147.3
CSP2	61.4	61.4	61.4	59.0	56.5	54.1	51.6	49.2	46.7	44.2	41.8
DIESELUT	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
GASCC	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
GASSC	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
GEOT	49.0	49.0	49.0	48.9	48.8	48.6	48.5	48.4	48.3	48.1	48.0
GIBEI	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
GIBEII	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
GIBEIII	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
GIBEIV	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
GIBEV	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
KOYSHA	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
HYDM1	41.0	41.0	41.0	40.9	40.8	40.7	40.6	40.5	40.4	40.3	40.2
HYDM2	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
HYDM3	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
KURAZ	44.9	44.9	44.9	44.6	44.4	44.1	43.9	43.6	43.4	43.1	42.9
SOPVR	33.0	33.0	33.0	32.8	32.5	32.3	32.0	31.8	31.5	31.3	31.0
SOPVU	33.0	33.0	33.0	32.8	32.5	32.3	32.0	31.8	31.5	31.3	31.0
SOPVUT	25.0	25.0	25.0	24.8	24.5	24.3	24.0	23.8	23.5	23.3	23.0
WI25	37.0	37.0	37.0	36.6	36.3	35.9	35.5	35.1	34.8	34.4	34.0
WI30	37.0	37.0	37.0	36.6	36.3	35.9	35.5	35.1	34.8	34.4	34.0

Projected *FixedCost* (MUSD/GW) for the technologies for 2021-2031.

Tech	Year										
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
BMCHP	55.9	55.8	55.7	55.6	55.5	55.4	55.3	55.2	55.1	55.0	54.9
COALSCP	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
CSP1	145.0	142.8	140.6	138.4	136.2	134.0	131.7	129.5	127.3	125.1	122.9
CSP2	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8
DIESELUT	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
GASCC	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
GASSC	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
GEOT	47.7	47.5	47.2	46.9	46.7	46.4	46.1	45.9	45.6	45.3	45.1
GIBEI	45.8	46.1	46.4	46.7	47.0	47.3	47.6	47.9	48.2	48.5	48.8
GIBEII	45.8	46.1	46.4	46.7	47.0	47.3	47.6	47.9	48.2	48.5	48.8
GIBEIII	45.8	46.1	46.4	46.7	47.0	47.3	47.6	47.9	48.2	48.5	48.8
GIBEIV	45.8	46.1	46.4	46.7	47.0	47.3	47.6	47.9	48.2	48.5	48.8
GIBEV	45.8	46.1	46.4	46.7	47.0	47.3	47.6	47.9	48.2	48.5	48.8
KOYSHA	45.8	46.1	46.4	46.7	47.0	47.3	47.6	47.9	48.2	48.5	48.8
HYDM1	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2
HYDM2	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
HYDM3	22.3	22.4	22.6	22.7	22.9	23.0	23.2	23.3	23.5	23.6	23.8
KURAZ	42.8	42.7	42.6	42.6	42.5	42.4	42.3	42.2	42.1	42.1	42.0
SOPVR	30.9	30.7	30.6	30.5	30.3	30.2	30.1	29.9	29.8	29.7	29.5
SOPVU	30.9	30.7	30.6	30.5	30.3	30.2	30.1	29.9	29.8	29.7	29.5
SOPVUT	22.9	22.9	22.8	22.7	22.7	22.6	22.5	22.5	22.4	22.3	22.3
WI25	33.9	33.9	33.8	33.7	33.7	33.6	33.5	33.5	33.4	33.3	33.3
WI30	33.9	33.9	33.8	33.7	33.7	33.6	33.5	33.5	33.4	33.3	33.3

Projected *FixedCost* (MUSD/GW) for the technologies for 2032-2042.

Tech	Year										
	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
BMCHP	54.7	54.6	54.5	54.4	54.4	54.4	54.4	54.4	54.4	54.4	54.4
COALSCP	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
CSP1	120.7	118.4	116.2	114.0	114.0	114.0	114.0	114.0	114.0	114.0	114.0
CSP2	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8
DIESELUT	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
GASCC	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
GASSC	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
GEOT	44.8	44.5	44.3	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
GIBEI	49.2	49.5	49.8	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEII	49.2	49.5	49.8	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEIII	49.2	49.5	49.8	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEIV	49.2	49.5	49.8	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEV	49.2	49.5	49.8	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
KOYSHA	49.2	49.5	49.8	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
HYDM1	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2
HYDM2	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
HYDM3	23.9	24.1	24.2	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4
KURAZ	41.9	41.8	41.7	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6
SOPVR	29.4	29.3	29.1	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
SOPVU	29.4	29.3	29.1	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
SOPVUT	22.2	22.1	22.1	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
WI25	33.2	33.1	33.1	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
WI30	33.2	33.1	33.1	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0

Projected *FixedCost* (MUSD/GW) for the technologies for 2043-2050.

Tech	Year							
	2043	2044	2045	2046	2047	2048	2049	2050
BMCHP	54.4	54.4	54.4	54.4	54.4	54.4	54.4	54.4
COALSCP	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
CSP1	114.0	114.0	114.0	114.0	114.0	114.0	114.0	114.0
CSP2	41.8	41.8	41.8	41.8	41.8	41.8	41.8	41.8
DIESELUT	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
GASCC	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
GASSC	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
GEOT	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
GIBEI	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEII	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEIII	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEIV	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
GIBEV	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
KOYSHA	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
HYDM1	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2
HYDM2	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
HYDM3	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4
KURAZ	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6
SOPVR	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
SOPVU	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
SOPVUT	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
WI25	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
WI30	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0

Projected *VariableCost* (MUSD/PJ) for the technologies for 2010-2020.

Tech	Year										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BIOMASSEX	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
BIOMASSIM	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
BMCHP	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
COALEX	2.1	2.5	2.0	1.8	1.6	1.3	1.1	1.1	1.1	1.1	1.2
COALIM	4.8	5.6	4.5	4.0	3.6	2.8	2.4	2.5	2.5	2.6	2.6
COALSCP	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
CSP1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CSP2	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5
CSP3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
DIESELEX	24.7	29.8	30.5	30.6	28.4	15.0	10.7	13.7	14.4	15.2	16.0
DIESELI	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
DIESELIM	26.0	31.4	32.1	32.2	29.9	15.8	11.3	14.4	15.2	16.0	16.8
DIESELR	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELU	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELUT	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GASCC	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
GASEX	12.5	14.6	16.1	16.7	14.3	10.4	8.4	8.6	8.7	8.7	8.9
GASIM	13.1	15.4	16.9	17.6	15.0	10.9	8.9	9.0	9.2	9.2	9.3
GASSC	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GEOT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GIBEI	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
GIBEII	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
GIBEIII	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
GIBEIV	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

GIBEV	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
HYDM1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
HYDM2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
HYDM3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
KOYSHA	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
KURAZ	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OILEX	14.5	17.6	18.0	18.0	16.7	8.8	6.3	8.1	8.5	8.9	9.4
OILGCP	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
OILIM	15.3	18.5	18.9	19.0	17.6	9.3	6.7	8.5	8.9	9.4	9.9
SOPV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVR2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVU1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVU2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Projected *VariableCost* (MUSD/PJ) for the technologies for 2021-2031.

Tech	**Year**										
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
BIOMASSEX	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
BIOMASSIM	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
BMCHP	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
COALEX	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4
COALIM	2.7	2.7	2.8	2.9	2.9	2.9	3.0	3.0	3.0	3.0	3.1
COALSCP	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
CSP1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CSP2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CSP3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
DIESELEX	16.8	17.7	18.7	19.6	20.7	21.2	21.7	22.2	22.7	23.2	23.7
DIESELI	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
DIESELIM	17.7	18.7	19.6	20.7	21.8	22.3	22.8	23.3	23.9	24.4	24.9
DIESELR	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELU	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELUT	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GASCC	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
GASEX	9.0	9.2	9.3	9.5	9.6	10.0	10.4	10.8	11.2	11.6	11.9
GASIM	9.5	9.7	9.8	10.0	10.1	10.5	10.9	11.4	11.8	12.2	12.5
GASSC	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GEOT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GIBEI	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
GIBEII	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
GIBEIII	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
GIBEIV	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
GIBEV	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
HYDM1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
HYDM2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
HYDM3	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2
KOYSHA	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0
KURAZ	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OILEX	9.9	10.4	11.0	11.6	12.2	12.5	12.8	13.1	13.4	13.7	14.0
OILGCP	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
OILIM	10.4	11.0	11.6	12.2	12.8	13.1	13.5	13.8	14.1	14.4	14.7

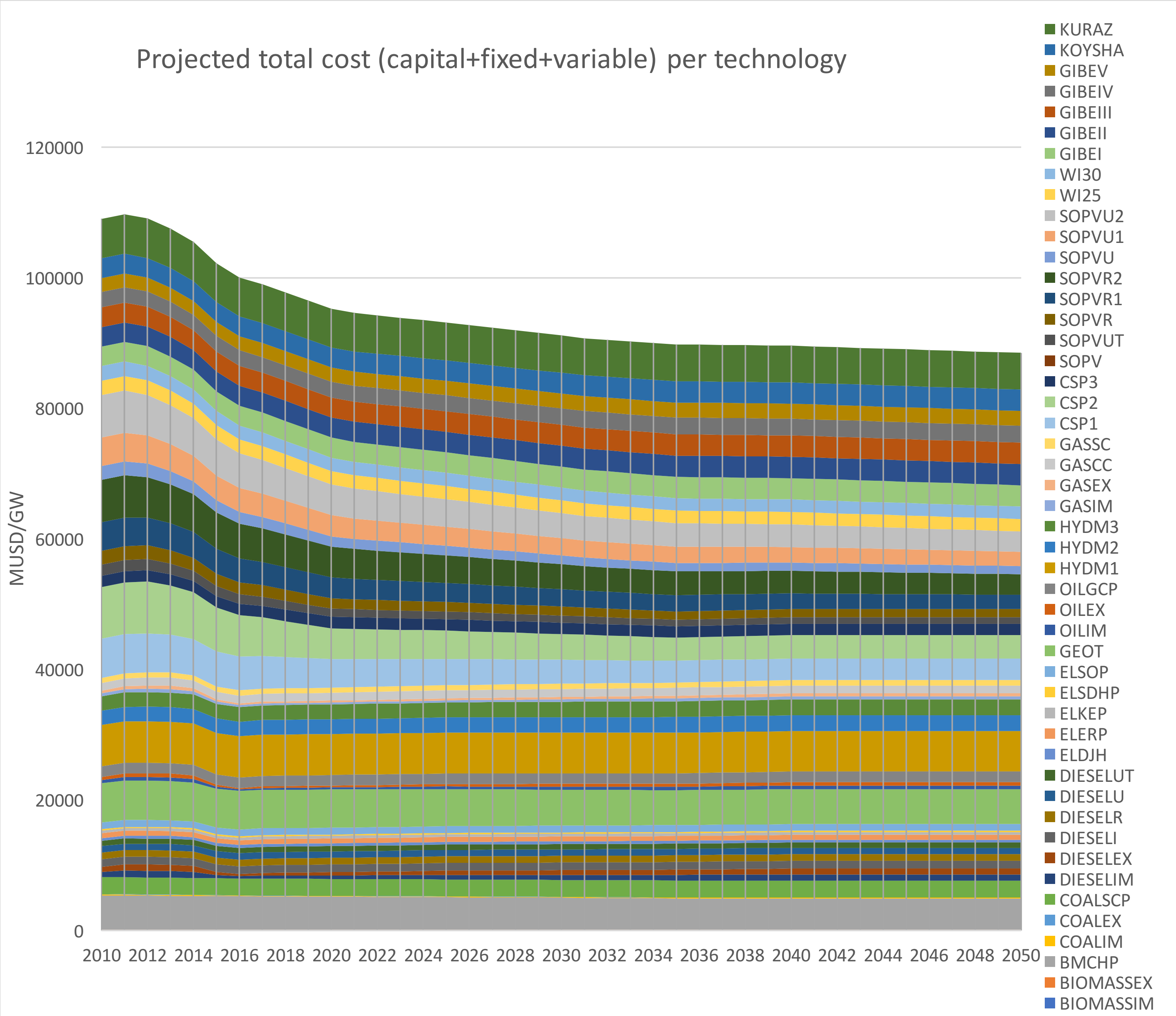
SOPV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVR2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVU1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVU2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Projected *VariableCost* (MUSD/PJ) for the technologies for 2032-2042.

Tech	**Year**										
	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
BIOMASSEX	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
BIOMASSIM	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
BMCHP	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
COALEX	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
COALIM	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.2	3.2
COALSCP	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
CSP1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CSP2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CSP3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
DIESELEX	24.2	24.7	25.2	25.7	26.2	26.6	27.1	27.6	28.1	28.1	28.1
DIESELI	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
DIESELIM	25.4	26.0	26.5	27.0	27.5	28.1	28.6	29.1	29.6	29.6	29.6
DIESELR	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELU	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELUT	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GASCC	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
GASEX	12.2	12.5	12.9	13.2	13.5	13.8	14.2	14.5	14.8	14.8	14.8
GASIM	12.9	13.2	13.6	13.9	14.2	14.6	14.9	15.3	15.6	15.6	15.6
GASSC	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GEOT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GIBEI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEII	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEIII	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEIV	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEV	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
HYDM1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
HYDM2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
HYDM3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
KOYSHA	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
KURAZ	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OILEX	14.2	14.5	14.8	15.1	15.4	15.7	16.0	16.3	16.6	16.6	16.6
OILGCP	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
OILIM	15.0	15.3	15.6	15.9	16.2	16.5	16.8	17.2	17.5	17.5	17.5
SOPV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVR2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVU1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVU2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Projected *VariableCost* (MUSD/PJ) for the technologies for 2043-2050.

Tech	Year							
	2043	2044	2045	2046	2047	2048	2049	2050
BIOMASSEX	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
BIOMASSIM	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
BMCHP	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
COALEX	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
COALIM	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
COALSCP	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
CSP1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CSP2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CSP3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
DIESELEX	28.1	28.1	28.1	28.1	28.1	28.1	28.1	28.1
DIESELI	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
DIESELIM	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
DIESELR	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELU	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
DIESELUT	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GASCC	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
GASEX	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
GASIM	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
GASSC	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GEOT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GIBEI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEII	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEIII	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEIV	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GIBEV	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
HYDM1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
HYDM2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
HYDM3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
KOYSHA	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
KURAZ	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OILEX	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6
OILGCP	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
OILIM	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
SOPV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVR1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVR2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOPVU1	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
SOPVU2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
SOPVUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WI30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0



Projected total cost (capital, fixed and variable summarizes) for different technologies and fuels in the model. The variable cost was converted from MUSD/PJ to MUSD/GW.

LiveStorage in the reservoirs used in the Reservoir module.

Reservoir	Live Storage (m^3)
RES1	839,000,000
RES2	839,000,000
RES3	14,700,000,000
RES4	10,000,000,000
RES5	1,500,000,000
RES6	6,000,000,000

The input values for *ResidualCapacity* for the dams, *ResidualStorageCapacity*, *StorageLevelAtStart*, *CapacityFactor, ReservoirHead* and *ReservoirExternalInflow* (Q_{ext}) are presented below. However, due to large amount of data, since they are available for each hydropower set-up, each year and each season, only the values which are based on the available simulated 10 years from Topkapi-ETH are presented here. Hence, the years 1-11 corresponds to the Topkapi-ETH values they are based on for the years 1991-2008. After these 11 years, the values were, as mentioned in the methodology, randomised based on these previous values, so no new data is appearing. If this extended data for all years is of interest, please contact the author of this thesis and it will be made available.

CapacityFactor for Gibe I in the Gibe I-III set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8463	0.9985	0.9985	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999
Feb	0.8401	0.9923	0.9927	0.9988	0.9993	0.9993	0.9995	0.9989	0.9996	0.9999	0.9987
Mar	0.8369	0.9898	0.9850	0.9992	0.9997	0.9998	0.9984	0.9993	0.9998	0.9997	0.9956
Apr	0.8315	0.9852	0.9867	0.9998	0.9998	0.9998	0.9999	0.9997	0.9999	0.9999	0.9989
May	0.8393	0.9925	0.9995	0.9999	0.9998	0.9998	0.9997	0.9999	0.9999	0.9999	0.9999
Jun	0.8380	0.9995	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Jul	0.8523	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Aug	0.8880	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Sep	0.9308	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Oct	0.9852	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Nov	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Dec	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

CapacityFactor for Gibe I in the Gibe I-IV set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8463	0.9985	0.9985	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999
Feb	0.8401	0.9923	0.9927	0.9988	0.9993	0.9993	0.9995	0.9989	0.9996	0.9999	0.9987
Mar	0.8369	0.9898	0.9850	0.9992	0.9997	0.9998	0.9984	0.9993	0.9998	0.9997	0.9956
Apr	0.8315	0.9852	0.9867	0.9998	0.9998	0.9998	0.9999	0.9997	0.9999	0.9999	0.9989

May	0.8393	0.9925	0.9995	0.9999	0.9998	0.9998	0.9997	0.9999	0.9999	0.9999	0.9999
Jun	0.8380	0.9995	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Jul	0.8523	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Aug	0.8880	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Sep	0.9308	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Oct	0.9852	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Nov	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Dec	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

CapacityFactor *for* Gibe I in the Gibe I-III & Koysha set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8463	0.9985	0.9985	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999
Feb	0.8401	0.9923	0.9927	0.9988	0.9993	0.9993	0.9995	0.9989	0.9996	0.9999	0.9987
Mar	0.8369	0.9898	0.9850	0.9992	0.9997	0.9998	0.9984	0.9993	0.9998	0.9997	0.9956
Apr	0.8315	0.9852	0.9867	0.9998	0.9998	0.9998	0.9999	0.9997	0.9999	0.9999	0.9989
May	0.8393	0.9925	0.9995	0.9999	0.9998	0.9998	0.9997	0.9999	0.9999	0.9999	0.9999
Jun	0.8380	0.9995	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Jul	0.8523	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Aug	0.8880	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Sep	0.9308	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Oct	0.9852	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Nov	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Dec	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

CapacityFactor for Gibe II in the Gibe I-III set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8463	0.9985	0.9985	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999
Feb	0.8401	0.9923	0.9927	0.9988	0.9993	0.9993	0.9995	0.9989	0.9996	0.9999	0.9987
Mar	0.8369	0.9898	0.9850	0.9992	0.9997	0.9998	0.9984	0.9993	0.9998	0.9997	0.9956

Apr	0.8315	0.9852	0.9867	0.9998	0.9998	0.9998	0.9999	0.9997	0.9999	0.9999	0.9989
May	0.8393	0.9925	0.9995	0.9999	0.9998	0.9998	0.9997	0.9999	0.9999	0.9999	0.9999
Jun	0.8380	0.9995	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Jul	0.8523	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Aug	0.8880	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Sep	0.9308	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Oct	0.9852	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Nov	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Dec	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

CapacityFactor for Gibe II in the Gibe I-IV set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8463	0.9985	0.9985	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999
Feb	0.8401	0.9923	0.9927	0.9988	0.9993	0.9993	0.9995	0.9989	0.9996	0.9999	0.9987
Mar	0.8369	0.9898	0.9850	0.9992	0.9997	0.9998	0.9984	0.9993	0.9998	0.9997	0.9956
Apr	0.8315	0.9852	0.9867	0.9998	0.9998	0.9998	0.9999	0.9997	0.9999	0.9999	0.9989
May	0.8393	0.9925	0.9995	0.9999	0.9998	0.9998	0.9997	0.9999	0.9999	0.9999	0.9999
Jun	0.8380	0.9995	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Jul	0.8523	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Aug	0.8880	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Sep	0.9308	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Oct	0.9852	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Nov	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Dec	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

CapacityFactor for Gibe II in the Gibe I-III & Koysha set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8463	0.9985	0.9985	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999
Feb	0.9993	0.9993	0.9995	0.9989	0.9996	0.9999	0.9987	0.9995	0.9989	0.9999	0.8401

Mar	0.9997	0.9998	0.9984	0.9993	0.9998	0.9997	0.9956	0.9984	0.9993	0.9997	0.8369
Apr	0.9998	0.9998	0.9999	0.9997	0.9999	0.9999	0.9989	0.9999	0.9997	0.9999	0.8315
May	0.9998	0.9998	0.9997	0.9999	0.9999	0.9999	0.9999	0.9997	0.9999	0.9999	0.8393
Jun	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.8380
Jul	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.8523
Aug	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.8880
Sep	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9308
Oct	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9852
Nov	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
Dec	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

CapacityFactor for Gibe III in the Gibe I-III set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.7951	0.7754	0.7698	0.7618	0.7816	0.7748	0.7679	0.7642	0.7471	0.7652	0.7425
Feb	0.7590	0.7271	0.7124	0.6919	0.7394	0.7273	0.7244	0.7071	0.6681	0.7133	0.6568
Mar	0.7154	0.6840	0.6525	0.6282	0.6952	0.6803	0.6673	0.6581	0.6064	0.6553	0.5669
Apr	0.6704	0.6378	0.6029	0.5775	0.6615	0.6427	0.6242	0.6219	0.5588	0.6176	0.4870
May	0.6536	0.6033	0.5866	0.5484	0.6257	0.6163	0.5956	0.6260	0.5184	0.6004	0.4448
Jun	0.6322	0.5841	0.5734	0.5446	0.6104	0.5944	0.5667	0.6246	0.4886	0.5981	0.4307
Jul	0.6580	0.6226	0.5908	0.5906	0.6270	0.6293	0.5668	0.6435	0.5259	0.6145	0.4717
Aug	0.7256	0.7068	0.6639	0.6967	0.7052	0.6999	0.6505	0.7550	0.6314	0.7292	0.6014
Sep	0.7784	0.7601	0.7334	0.8244	0.8091	0.8150	0.7811	0.8562	0.7453	0.8454	0.7709
Oct	0.8369	0.8258	0.7930	0.8583	0.8314	0.8557	0.8310	0.9005	0.8027	0.9169	0.7972
Nov	0.8510	0.8529	0.8314	0.8680	0.8123	0.8267	0.8246	0.8738	0.8025	0.8791	0.8581
Dec	0.8212	0.8186	0.8137	0.8246	0.7901	0.8088	0.8004	0.8214	0.8026	0.8189	0.8196

CapacityFactor for Gibe III in the Gibe I-IV set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.7951	0.7754	0.7698	0.7618	0.7816	0.7748	0.7679	0.7642	0.7471	0.7652	0.7425
Feb	0.7590	0.7271	0.7124	0.6919	0.7394	0.7273	0.7244	0.7071	0.6681	0.7133	0.6568

Mar	0.7154	0.6840	0.6525	0.6282	0.6952	0.6803	0.6673	0.6581	0.6064	0.6553	0.5669
Apr	0.6704	0.6378	0.6029	0.5775	0.6615	0.6427	0.6242	0.6219	0.5588	0.6176	0.4870
May	0.6536	0.6033	0.5866	0.5484	0.6257	0.6163	0.5956	0.6260	0.5184	0.6004	0.4448
Jun	0.6322	0.5841	0.5734	0.5446	0.6104	0.5944	0.5667	0.6246	0.4886	0.5981	0.4307
Jul	0.6580	0.6226	0.5908	0.5906	0.6270	0.6293	0.5668	0.6435	0.5259	0.6145	0.4717
Aug	0.7256	0.7068	0.6639	0.6967	0.7052	0.6999	0.6505	0.7550	0.6314	0.7292	0.6014
Sep	0.7784	0.7601	0.7334	0.8244	0.8091	0.8150	0.7811	0.8562	0.7453	0.8454	0.7709
Oct	0.8369	0.8258	0.7930	0.8583	0.8314	0.8557	0.8310	0.9005	0.8027	0.9169	0.7972
Nov	0.8510	0.8529	0.8314	0.8680	0.8123	0.8267	0.8246	0.8738	0.8025	0.8791	0.8581
Dec	0.8212	0.8186	0.8137	0.8246	0.7901	0.8088	0.8004	0.8214	0.8026	0.8189	0.8196

CapacityFactor for Gibe III in the Gibe I-III & Koysha set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.7951	0.7754	0.7698	0.7618	0.7816	0.7748	0.7679	0.7642	0.7471	0.7652	0.7425
Feb	0.7590	0.7271	0.7124	0.6919	0.7394	0.7273	0.7244	0.7071	0.6681	0.7133	0.6568
Mar	0.7154	0.6840	0.6525	0.6282	0.6952	0.6803	0.6673	0.6581	0.6064	0.6553	0.5669
Apr	0.6704	0.6378	0.6029	0.5775	0.6615	0.6427	0.6242	0.6219	0.5588	0.6176	0.4870
May	0.6536	0.6033	0.5866	0.5484	0.6257	0.6163	0.5956	0.6260	0.5184	0.6004	0.4448
Jun	0.6322	0.5841	0.5734	0.5446	0.6104	0.5944	0.5667	0.6246	0.4886	0.5981	0.4307
Jul	0.6580	0.6226	0.5908	0.5906	0.6270	0.6293	0.5668	0.6435	0.5259	0.6145	0.4717
Aug	0.7256	0.7068	0.6639	0.6967	0.7052	0.6999	0.6505	0.7550	0.6314	0.7292	0.6014
Sep	0.7784	0.7601	0.7334	0.8244	0.8091	0.8150	0.7811	0.8562	0.7453	0.8454	0.7709
Oct	0.8369	0.8258	0.7930	0.8583	0.8314	0.8557	0.8310	0.9005	0.8027	0.9169	0.7972
Nov	0.8510	0.8529	0.8314	0.8680	0.8123	0.8267	0.8246	0.8738	0.8025	0.8791	0.8581
Dec	0.8212	0.8186	0.8137	0.8246	0.7901	0.8088	0.8004	0.8214	0.8026	0.8189	0.8196

CapacityFactor for Gibe IV in the Gibe I-IV set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.4386	0.4210	0.4122	0.4093	0.4214	0.4156	0.4156	0.4038	0.3785	0.3908	0.3612
Feb	0.4290	0.3972	0.3739	0.3712	0.3952	0.3844	0.3931	0.3666	0.3287	0.3610	0.3124
Mar	0.4101	0.3807	0.3350	0.3385	0.3759	0.3551	0.3579	0.3444	0.3042	0.3233	0.2615
Apr	0.3953	0.3770	0.3076	0.3264	0.3726	0.3358	0.3413	0.3309	0.2848	0.3106	0.2313
May	0.4063	0.3715	0.3152	0.3420	0.3721	0.3361	0.3544	0.3650	0.2805	0.3264	0.2358
Jun	0.4068	0.3556	0.3037	0.3450	0.3633	0.3414	0.3350	0.3694	0.2597	0.3366	0.2501
Jul	0.4145	0.3669	0.3105	0.3573	0.3584	0.3520	0.3259	0.3694	0.2705	0.3390	0.2724
Aug	0.4429	0.3997	0.3464	0.3893	0.3825	0.3918	0.3533	0.4264	0.3094	0.3941	0.3134
Sep	0.4471	0.4084	0.3638	0.4357	0.4056	0.4467	0.3987	0.4641	0.3230	0.4335	0.3551
Oct	0.4604	0.4359	0.3988	0.4440	0.4143	0.4453	0.4116	0.4845	0.3404	0.4568	0.3740
Nov	0.4642	0.4512	0.4463	0.4646	0.4102	0.4300	0.4167	0.4658	0.3619	0.4427	0.4301
Dec	0.4456	0.4391	0.4406	0.4450	0.4132	0.4374	0.4282	0.4298	0.4019	0.4081	0.4056

CapacityFactor for Gibe V in the Gibe I-IV set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.9131	0.8875	0.8781	0.8732	0.8861	0.8807	0.8842	0.8701	0.8601	0.8732	0.8670
Feb	0.9017	0.8614	0.8416	0.8372	0.8563	0.8432	0.8606	0.8363	0.8125	0.8508	0.8310
Mar	0.8763	0.8454	0.8050	0.8105	0.8386	0.8118	0.8247	0.8174	0.7893	0.8229	0.7929
Apr	0.8733	0.8608	0.7860	0.8189	0.8432	0.7884	0.8108	0.8250	0.7731	0.8423	0.7778
May	0.8858	0.8656	0.7996	0.8535	0.8566	0.7904	0.8260	0.8745	0.7737	0.8696	0.7860
Jun	0.8854	0.8461	0.7893	0.8553	0.8450	0.7993	0.8107	0.8918	0.7582	0.8791	0.8025
Jul	0.9105	0.8487	0.7956	0.8453	0.8267	0.8023	0.7963	0.8877	0.7511	0.8752	0.8089
Aug	0.9373	0.8742	0.8212	0.8660	0.8400	0.8352	0.8156	0.9140	0.7802	0.9073	0.8293
Sep	0.9306	0.8746	0.8243	0.8962	0.8367	0.8811	0.8302	0.9452	0.7742	0.9260	0.8519
Oct	0.9370	0.9002	0.8699	0.9158	0.8466	0.8770	0.8293	0.9499	0.7706	0.9336	0.8762
Nov	0.9377	0.9133	0.9113	0.9340	0.8530	0.8710	0.8484	0.9381	0.8070	0.9341	0.9202
Dec	0.9141	0.9051	0.9045	0.9096	0.8736	0.9023	0.8837	0.9086	0.8698	0.9073	0.9002

CapacityFactor for Koysha in the Gibe I-III & Koysha set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
Jan	0.8084	0.7826	0.7670	0.7611	0.7833	0.7731	0.7724	0.7516	0.7086	0.7325	0.6801
Feb	0.7922	0.7413	0.7004	0.6939	0.7375	0.7181	0.7329	0.6861	0.6209	0.6802	0.5945
Mar	0.7599	0.7123	0.6326	0.6364	0.7030	0.6662	0.6714	0.6459	0.5767	0.6141	0.5051
Apr	0.7345	0.7065	0.5845	0.6150	0.6966	0.6311	0.6412	0.6227	0.5415	0.5914	0.4510
May	0.7539	0.6973	0.5965	0.6427	0.6956	0.6305	0.6638	0.6820	0.5324	0.6188	0.4576
Jun	0.7554	0.6692	0.5761	0.6472	0.6800	0.6386	0.6301	0.6918	0.4954	0.6364	0.4820
Jul	0.7690	0.6869	0.5866	0.6667	0.6698	0.6560	0.6130	0.6904	0.5111	0.6401	0.5192
Aug	0.8186	0.7438	0.6482	0.7230	0.7109	0.7252	0.6597	0.7893	0.5799	0.7358	0.5905
Sep	0.8264	0.7591	0.6786	0.8049	0.7509	0.8236	0.7381	0.8575	0.6037	0.8044	0.6644
Oct	0.8487	0.8060	0.7394	0.8206	0.7661	0.8208	0.7599	0.8932	0.6323	0.8454	0.6998
Nov	0.8563	0.8340	0.8251	0.8579	0.7602	0.7947	0.7698	0.8614	0.6736	0.8223	0.7994
Dec	0.8250	0.8136	0.8163	0.8240	0.7666	0.8100	0.7937	0.7991	0.7486	0.7629	0.7583

ResidualCapacity & *ResidualStorageCapacity* (GW) for the dams in the Gibe I-III set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
TDAM1 & SDAM1	0.056	0.062	0.062	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM2 & SDAM2	0.117	0.131	0.131	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
TDAM3 & SDAM3	0.824	0.796	0.771	0.779	0.804	0.803	0.778	0.820	0.731	0.811	0.708

ResidualCapacity & *ResidualStorageCapacity* (GW) for the dams in the Gibe I-III set-up.

Month	Year										
	1	2	3	4	5	6	7	8	9	10	11
TDAM1 & SDAM1	0.056	0.062	0.062	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM2	0.117	0.131	0.131	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132

& SDAM2											
TDAM3 & SDAM3	0.824	0.796	0.771	0.779	0.804	0.803	0.778	0.820	0.731	0.811	0.708
TDAM4 & SDAM4	0.219	0.204	0.185	0.199	0.199	0.199	0.193	0.205	0.163	0.192	0.162
TDAM5 & SDAM5	0.025	0.024	0.023	0.024	0.024	0.024	0.023	0.025	0.022	0.025	0.023

ResidualCapacity & *ResidualStorageCapacity* (GW) for the dams in the Gibe I-III set-up.

Month	**Year**										
	1	2	3	4	5	6	7	8	9	10	11
TDAM1 & SDAM1	0.056	0.062	0.062	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
TDAM2 & SDAM2	0.117	0.131	0.131	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
TDAM3 & SDAM3	0.824	0.796	0.771	0.779	0.804	0.803	0.778	0.820	0.731	0.811	0.708
TDAM6 & SDAM6	0.275	0.271	0.272	0.275	0.255	0.270	0.264	0.266	0.249	0.254	0.253

StorageLevelStart (GW) for the dams and the different hydropower set-ups.

Dam	***StorageLevelStart* (GW)**	**Set-up**
TDAM1	0.056	Gibe I-III
TDAM1	0.056	Gibe I-V
TDAM1	0.056	Gibe I-III & Koysha
TDAM2	0.11	Gibe I-III
TDAM2	0.117	Gibe I-V
TDAM2	0.117	Gibe I-III & Koysha
TDAM3	0.824	Gibe I-III
TDAM3	0.824	Gibe I-V
TDAM3	0.824	Gibe I-III & Koysha
TDAM4	0.219	Gibe I-V
TDAM5	0.025	Gibe I-V
TDAM6	0.275	Gibe I-III & Koysha

ReservoirExternalInflow (m^3/s) for RES1 in the Gibe I-III set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	3.1	3.3	3.3	5.4	12.9	10.4	8.0	8.7	5.4	15.1	6.0
2	2.9	2.1	2.4	4.4	4.4	5.2	5.3	4.0	6.2	10.3	4.0
3	3.4	4.6	2.8	8.7	7.5	7.1	5.4	12.7	12.8	8.6	4.5
4	5.1	4.4	8.9	8.7	8.3	10.3	9.6	10.4	12.0	24.8	8.1
5	6.6	8.7	10.2	20.5	10.4	6.4	8.5	65.4	23.9	49.5	19.6
6	6.2	10.2	12.3	29.3	16.6	19.0	13.8	20.1	31.5	56.2	32.4
7	10.5	25.6	27.5	88.4	32.7	45.0	30.1	135.2	114.7	126.7	90.3
8	21.5	30.8	52.3	124.4	91.4	99.3	87.6	197.8	166.7	163.1	194.2
9	15.3	24.2	49.7	109.0	63.9	80.0	94.7	98.7	114.3	198.7	145.0
10	25.3	53.6	91.2	82.7	31.4	29.7	91.5	85.3	111.3	50.0	45.4
11	10.4	13.3	32.7	37.8	10.3	12.5	26.1	25.8	70.0	11.6	125.3
12	4.8	7.1	15.5	11.2	41.8	27.2	30.1	9.3	64.3	8.7	11.9

ReservoirExternalInflow (m^3/s) for RES1 I in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	3.1	3.3	3.3	5.4	12.9	10.4	8.0	8.7	5.4	15.1	6.0
2	2.9	2.1	2.4	4.4	4.4	5.2	5.3	4.0	6.2	10.3	4.0
3	3.4	4.6	2.8	8.7	7.5	7.1	5.4	12.7	12.8	8.6	4.5
4	5.1	4.4	8.9	8.7	8.3	10.3	9.6	10.4	12.0	24.8	8.1
5	6.6	8.7	10.2	20.5	10.4	6.4	8.5	65.4	23.9	49.5	19.6
6	6.2	10.2	12.3	29.3	16.6	19.0	13.8	20.1	31.5	56.2	32.4
7	10.5	25.6	27.5	88.4	32.7	45.0	30.1	135.2	114.7	126.7	90.3
8	21.5	30.8	52.3	124.4	91.4	99.3	87.6	197.8	166.7	163.1	194.2
9	15.3	24.2	49.7	109.0	63.9	80.0	94.7	98.7	114.3	198.7	145.0
10	25.3	53.6	91.2	82.7	31.4	29.7	91.5	85.3	111.3	50.0	45.4
11	10.4	13.3	32.7	37.8	10.3	12.5	26.1	25.8	70.0	11.6	125.3
12	4.8	7.1	15.5	11.2	41.8	27.2	30.1	9.3	64.3	8.7	11.9

ReservoirExternalInflow (m^3/s) for RES1 in the Gibe I-III & Koysha set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	3.1	3.3	3.3	5.4	12.9	10.4	8.0	8.7	5.4	15.1	6.0
2	2.9	2.1	2.4	4.4	4.4	5.2	5.3	4.0	6.2	10.3	4.0
3	3.4	4.6	2.8	8.7	7.5	7.1	5.4	12.7	12.8	8.6	4.5
4	5.1	4.4	8.9	8.7	8.3	10.3	9.6	10.4	12.0	24.8	8.1
5	6.6	8.7	10.2	20.5	10.4	6.4	8.5	65.4	23.9	49.5	19.6
6	6.2	10.2	12.3	29.3	16.6	19.0	13.8	20.1	31.5	56.2	32.4
7	10.5	25.6	27.5	88.4	32.7	45.0	30.1	135.2	114.7	126.7	90.3
8	21.5	30.8	52.3	124.4	91.4	99.3	87.6	197.8	166.7	163.1	194.2

9	15.3	24.2	49.7	109.0	63.9	80.0	94.7	98.7	114.3	198.7	145.0
10	25.3	53.6	91.2	82.7	31.4	29.7	91.5	85.3	111.3	50.0	45.4
11	10.4	13.3	32.7	37.8	10.3	12.5	26.1	25.8	70.0	11.6	125.3
12	4.8	7.1	15.5	11.2	41.8	27.2	30.1	9.3	64.3	8.7	11.9

ReservoirExternalInflow (m^3/s) for RES3 in the Gibe I-III set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	234.2	73.3	62.9	84.5	180.2	142.2	143.0	151.5	56.5	168.8	74.0
2	66.0	41.7	41.4	62.5	61.5	73.8	99.6	67.3	89.1	139.3	42.0
3	83.0	108.3	39.3	175.5	139.2	117.7	82.7	272.6	241.2	155.4	44.5
4	123.7	90.2	188.3	173.8	157.0	235.4	224.1	227.4	223.0	261.0	155.8
5	262.0	196.8	311.7	396.0	193.0	148.6	198.9	548.0	296.0	385.5	380.8
6	277.1	343.5	322.5	489.7	329.4	367.3	303.3	317.2	401.3	364.3	532.7
7	637.3	704.6	636.3	911.2	585.2	699.4	586.9	708.0	935.0	711.4	921.7
8	737.4	759.9	766.2	997.7	918.8	818.4	990.7	1028.7	1021.6	946.1	1347.4
9	499.4	472.9	631.6	860.9	623.8	814.0	731.5	629.4	827.1	960.8	1057.5
10	681.6	774.1	693.3	524.2	279.8	301.6	555.7	453.7	597.4	397.8	396.7
11	236.6	193.9	351.3	314.0	176.3	166.3	201.5	183.1	411.2	134.1	794.5
12	95.5	113.2	180.6	144.8	317.7	244.1	233.6	91.8	372.4	84.5	143.2

ReservoirExternalInflow (m^3/s) for RES3 in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	234.2	73.3	62.9	84.5	180.2	142.2	143.0	151.5	56.5	168.8	74.0
2	66.0	41.7	41.4	62.5	61.5	73.8	99.6	67.3	89.1	139.3	42.0
3	83.0	108.3	39.3	175.5	139.2	117.7	82.7	272.6	241.2	155.4	44.5
4	123.7	90.2	188.3	173.8	157.0	235.4	224.1	227.4	223.0	261.0	155.8
5	262.0	196.8	311.7	396.0	193.0	148.6	198.9	548.0	296.0	385.5	380.8
6	277.1	343.5	322.5	489.7	329.4	367.3	303.3	317.2	401.3	364.3	532.7
7	637.3	704.6	636.3	911.2	585.2	699.4	586.9	708.0	935.0	711.4	921.7
8	737.4	759.9	766.2	997.7	918.8	818.4	990.7	1028.7	1021.6	946.1	1347.4
9	499.4	472.9	631.6	860.9	623.8	814.0	731.5	629.4	827.1	960.8	1057.5
10	681.6	774.1	693.3	524.2	279.8	301.6	555.7	453.7	597.4	397.8	396.7
11	236.6	193.9	351.3	314.0	176.3	166.3	201.5	183.1	411.2	134.1	794.5
12	95.5	113.2	180.6	144.8	317.7	244.1	233.6	91.8	372.4	84.5	143.2

ReservoirExternalInflow (m^3/s) for RES3 in the Gibe I-III & Koysha set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11

1	234.2	73.3	62.9	84.5	180.2	142.2	143.0	151.5	56.5	168.8	74.0
2	66.0	41.7	41.4	62.5	61.5	73.8	99.6	67.3	89.1	139.3	42.0
3	83.0	108.3	39.3	175.5	139.2	117.7	82.7	272.6	241.2	155.4	44.5
4	123.7	90.2	188.3	173.8	157.0	235.4	224.1	227.4	223.0	261.0	155.8
5	262.0	196.8	311.7	396.0	193.0	148.6	198.9	548.0	296.0	385.5	380.8
6	277.1	343.5	322.5	489.7	329.4	367.3	303.3	317.2	401.3	364.3	532.7
7	637.3	704.6	636.3	911.2	585.2	699.4	586.9	708.0	935.0	711.4	921.7
8	737.4	759.9	766.2	997.7	918.8	818.4	990.7	1028.7	1021.6	946.1	1347.4
9	499.4	472.9	631.6	860.9	623.8	814.0	731.5	629.4	827.1	960.8	1057.5
10	681.6	774.1	693.3	524.2	279.8	301.6	555.7	453.7	597.4	397.8	396.7
11	236.6	193.9	351.3	314.0	176.3	166.3	201.5	183.1	411.2	134.1	794.5
12	95.5	113.2	180.6	144.8	317.7	244.1	233.6	91.8	372.4	84.5	143.2

ReservoirExternalInflow (m^3/s) for RES4 in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	136.9	26.0	16.5	35.6	74.4	59.0	85.7	81.9	23.4	88.4	31.5
2	53.9	11.5	11.6	40.4	22.3	27.0	34.7	32.9	79.3	83.2	20.1
3	35.0	78.6	20.8	93.3	120.0	66.1	38.0	215.3	176.3	88.3	32.5
4	131.7	110.2	96.8	167.0	111.1	138.3	184.5	177.5	158.5	221.4	165.8
5	138.3	73.0	205.0	248.1	158.4	142.9	153.2	437.9	204.6	273.3	252.5
6	134.3	75.9	125.5	223.8	97.8	198.7	99.4	131.1	168.3	196.7	264.8
7	201.3	221.3	259.0	293.5	179.7	245.5	212.6	379.3	373.1	308.4	349.8
8	218.7	214.2	303.2	316.0	283.6	447.8	322.8	435.1	384.7	387.8	423.3
9	91.4	114.4	166.6	322.8	170.6	181.7	225.4	299.3	192.1	379.9	340.3
10	210.3	283.2	442.8	268.0	165.0	136.7	202.6	227.9	369.7	192.2	273.5
11	88.1	65.4	188.0	171.7	78.7	111.3	261.7	131.9	297.0	120.8	358.5
12	25.8	63.4	87.5	72.6	250.1	158.4	126.7	49.6	339.0	42.1	65.6

ReservoirExternalInflow (m^3/s) for RES5 in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	25.7	4.8	1.6	4.5	14.1	9.4	15.0	8.5	1.8	13.0	4.2
2	6.3	2.2	1.7	7.7	3.1	4.0	4.0	3.0	10.5	14.4	2.8
3	8.8	17.3	4.7	20.7	28.0	13.2	6.7	33.4	25.5	25.2	6.0
4	31.9	28.7	21.8	41.8	20.4	21.8	33.4	35.1	29.2	48.6	25.0
5	24.8	15.0	29.3	37.8	35.0	26.5	20.2	67.1	30.8	37.5	30.4
6	29.8	9.4	17.4	30.3	13.2	32.9	15.7	18.3	19.7	24.9	31.3
7	40.1	28.1	36.5	31.2	21.6	29.7	27.1	38.6	38.4	33.3	34.8
8	30.8	31.6	36.8	39.0	32.0	67.8	37.6	49.2	49.6	48.4	41.8
9	13.7	16.9	15.9	51.6	21.4	28.1	22.6	33.8	17.0	38.7	37.0
10	31.9	41.7	73.2	35.3	34.2	26.6	22.9	26.7	49.6	26.4	40.2
11	15.8	11.5	24.4	27.2	17.5	30.0	58.5	17.9	54.2	27.1	37.7
12	4.5	12.5	13.3	9.1	52.7	31.4	27.1	5.8	63.3	4.4	7.5

ReservoirExternalInflow (m3/s) for RES6 in the Gibe I-III & Koysha set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	130.3	27.0	17.0	35.6	80.1	63.1	88.1	81.7	23.4	97.6	31.4
2	56.8	12.0	12.2	41.6	23.1	27.7	37.1	37.3	81.6	86.5	21.0
3	36.3	81.1	21.0	98.2	123.4	69.1	39.2	224.7	182.4	91.0	32.6
4	136.6	115.2	101.4	176.4	118.5	140.5	189.2	186.0	163.9	233.9	171.8
5	144.8	77.2	211.9	260.8	166.8	151.2	162.2	463.7	213.2	283.0	264.9
6	138.8	76.0	128.4	231.1	99.7	207.1	103.5	136.6	171.0	208.6	276.2
7	207.9	229.4	268.8	305.3	185.1	253.1	216.8	390.3	390.0	314.3	363.2
8	228.0	221.3	316.0	331.0	296.6	475.2	336.8	463.8	403.8	414.9	445.0
9	93.4	119.8	169.9	346.5	177.0	193.7	234.0	314.2	197.6	397.3	360.5
10	218.5	293.3	467.9	281.4	176.8	146.1	213.4	241.1	390.0	203.5	285.9
11	92.4	72.5	203.4	184.2	86.1	115.0	282.6	141.1	326.1	129.7	390.7
12	27.0	67.5	92.1	76.2	268.9	176.3	136.2	51.8	363.7	44.5	69.1

ReservoirHead (m) for RES1 in the Gibe I-III set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	235.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
2	235.5	239.8	239.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
3	235.4	239.7	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	239.9
4	235.2	239.6	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
5	235.5	239.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
6	235.4	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
7	235.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
8	236.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
9	238.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
10	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
11	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
12	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0

ReservoirHead (m) for RES1 I in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	235.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
2	235.5	239.8	239.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
3	235.4	239.7	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	239.9
4	235.2	239.6	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
5	235.5	239.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
6	235.4	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
7	235.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
8	236.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0

9	238.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
10	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
11	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
12	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0

ReservoirHead (m) for RES1 in the Gibe I-III & Koysha set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	235.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
2	235.5	239.8	239.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
3	235.4	239.7	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	239.9
4	235.2	239.6	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
5	235.5	239.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
6	235.4	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
7	235.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
8	236.8	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
9	238.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
10	239.6	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
11	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
12	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0

ReservoirHead (m) for RES2 in the Gibe I-III set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	500.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
2	500.5	504.8	504.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
3	500.4	504.7	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	504.9
4	500.2	504.6	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
5	500.5	504.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
6	500.4	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
7	500.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
8	501.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
9	503.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
10	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
11	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
12	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0

ReservoirHead (m) for RES2 in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	500.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
2	500.5	504.8	504.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0

3	500.4	504.7	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	504.9
4	500.2	504.6	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
5	500.5	504.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
6	500.4	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
7	500.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
8	501.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
9	503.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
10	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
11	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
12	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0

ReservoirHead (m) for RES2 in the Gibe I-III & Koysha set-up.

SEASON	**Year**										
	1	2	3	4	5	6	7	8	9	10	11
1	500.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
2	500.5	504.8	504.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
3	500.4	504.7	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	504.9
4	500.2	504.6	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
5	500.5	504.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
6	500.4	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
7	500.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
8	501.8	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
9	503.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
10	504.6	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
11	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0
12	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0	505.0

ReservoirHead (m) for RES3 in the Gibe I-III set-up.

SEASON	**Year**										
	1	2	3	4	5	6	7	8	9	10	11
1	230.2	228.0	227.4	226.6	228.7	228.0	227.2	226.8	225.1	226.9	224.6
2	226.2	223.0	221.6	219.7	224.2	223.0	222.8	221.1	217.4	221.7	216.3
3	221.9	218.9	215.9	213.6	220.0	218.5	217.3	216.4	211.4	216.2	207.4
4	217.6	214.5	211.1	208.5	216.8	215.0	213.2	213.0	206.5	212.5	198.6
5	216.0	211.1	209.4	205.5	213.3	212.4	210.3	213.4	202.1	210.8	193.8
6	214.0	209.1	208.0	205.1	211.9	210.2	207.4	213.2	198.8	210.6	192.3
7	216.4	213.0	209.8	209.8	213.4	213.7	207.4	215.0	202.9	212.2	196.9
8	222.9	221.1	217.0	220.1	221.0	220.4	215.7	226.0	213.8	223.3	210.8
9	228.4	226.3	223.6	233.4	231.8	232.4	228.7	236.9	224.8	235.6	227.6
10	234.8	233.6	230.0	237.2	234.2	236.9	234.2	241.3	231.0	242.6	230.4
11	236.4	236.6	234.2	238.2	232.1	233.7	233.5	238.8	231.0	239.3	237.1
12	233.1	232.8	232.2	233.5	229.7	231.7	230.8	233.1	231.0	232.8	232.9

ReservoirHead (m) for RES3 in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	230.2	228.0	227.4	226.6	228.7	228.0	227.2	226.8	225.1	226.9	224.6
2	226.2	223.0	221.6	219.7	224.2	223.0	222.8	221.1	217.4	221.7	216.3
3	221.9	218.9	215.9	213.6	220.0	218.5	217.3	216.4	211.4	216.2	207.4
4	217.6	214.5	211.1	208.5	216.8	215.0	213.2	213.0	206.5	212.5	198.6
5	216.0	211.1	209.4	205.5	213.3	212.4	210.3	213.4	202.1	210.8	193.8
6	214.0	209.1	208.0	205.1	211.9	210.2	207.4	213.2	198.8	210.6	192.3
7	216.4	213.0	209.8	209.8	213.4	213.7	207.4	215.0	202.9	212.2	196.9
8	222.9	221.1	217.0	220.1	221.0	220.4	215.7	226.0	213.8	223.3	210.8
9	228.4	226.3	223.6	233.4	231.8	232.4	228.7	236.9	224.8	235.6	227.6
10	234.8	233.6	230.0	237.2	234.2	236.9	234.2	241.3	231.0	242.6	230.4
11	236.4	236.6	234.2	238.2	232.1	233.7	233.5	238.8	231.0	239.3	237.1
12	233.1	232.8	232.2	233.5	229.7	231.7	230.8	233.1	231.0	232.8	232.9

ReservoirHead (m) for RES3 in the Gibe I-III & Koysha set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	230.2	228.0	227.4	226.6	228.7	228.0	227.2	226.8	225.1	226.9	224.6
2	226.2	223.0	221.6	219.7	224.2	223.0	222.8	221.1	217.4	221.7	216.3
3	221.9	218.9	215.9	213.6	220.0	218.5	217.3	216.4	211.4	216.2	207.4
4	217.6	214.5	211.1	208.5	216.8	215.0	213.2	213.0	206.5	212.5	198.6
5	216.0	211.1	209.4	205.5	213.3	212.4	210.3	213.4	202.1	210.8	193.8
6	214.0	209.1	208.0	205.1	211.9	210.2	207.4	213.2	198.8	210.6	192.3
7	216.4	213.0	209.8	209.8	213.4	213.7	207.4	215.0	202.9	212.2	196.9
8	222.9	221.1	217.0	220.1	221.0	220.4	215.7	226.0	213.8	223.3	210.8
9	228.4	226.3	223.6	233.4	231.8	232.4	228.7	236.9	224.8	235.6	227.6
10	234.8	233.6	230.0	237.2	234.2	236.9	234.2	241.3	231.0	242.6	230.4
11	236.4	236.6	234.2	238.2	232.1	233.7	233.5	238.8	231.0	239.3	237.1
12	233.1	232.8	232.2	233.5	229.7	231.7	230.8	233.1	231.0	232.8	232.9
Year	224.8	222.3	220.0	220.9	223.1	223.0	220.7	224.6	216.3	223.7	214.0

ReservoirHead (m) for RES4 in the Gibe I-IV set-up.

SEASON	Year										
	1	2	3	4	5	6	7	8	9	10	11
1	158.2	156.2	155.2	154.9	156.2	155.6	155.6	154.2	151.3	152.7	149.2
2	157.1	153.5	150.8	150.4	153.2	152.0	153.0	149.9	145.0	149.2	142.9
3	154.9	151.6	145.9	146.3	151.0	148.5	148.8	147.1	141.8	144.3	135.6
4	153.2	151.1	142.2	144.7	150.6	146.0	146.7	145.3	139.1	142.6	130.8
5	154.5	150.5	143.2	146.8	150.6	146.0	148.4	149.7	138.5	144.7	131.5
6	154.6	148.6	141.7	147.2	149.5	146.7	145.9	150.2	135.3	146.1	133.8
7	155.4	149.9	142.6	148.8	148.9	148.1	144.6	150.3	136.9	146.4	137.3
8	158.7	153.7	147.4	152.5	151.8	152.8	148.2	156.8	142.5	153.1	143.0

9	159.2	154.7	149.6	157.9	154.4	159.1	153.6	160.9	144.3	157.6	148.5
10	160.5	157.9	153.6	158.8	155.4	159.0	155.1	163.0	146.6	160.2	150.8
11	160.9	159.6	159.1	161.0	155.0	157.2	155.7	161.1	149.4	158.7	157.2
12	159.0	158.3	158.5	158.9	155.3	158.1	157.0	157.2	154.0	154.7	154.4

ReservoirHead (m) for RES5 in the Gibe I-IV set-up.

SEASON	**Year**										
	1	2	3	4	5	6	7	8	9	10	11
1	541.0	540.2	539.9	539.8	540.2	540.0	540.1	539.7	539.3	539.8	539.6
2	540.6	539.4	538.8	538.6	539.2	538.8	539.4	538.6	537.8	539.1	538.4
3	539.9	538.9	537.5	537.8	538.7	537.8	538.2	538.0	537.0	538.2	537.1
4	539.8	539.4	536.8	538.0	538.8	536.9	537.8	538.2	536.4	538.8	536.5
5	540.2	539.5	537.3	539.1	539.2	537.0	538.3	539.8	536.4	539.6	536.8
6	540.1	538.9	537.0	539.2	538.9	537.3	537.8	540.3	535.8	539.9	537.5
7	540.9	539.0	537.2	538.9	538.3	537.4	537.2	540.2	535.5	539.8	537.7
8	541.8	539.8	538.1	539.5	538.7	538.5	537.9	541.0	536.6	540.8	538.4
9	541.6	539.8	538.2	540.5	538.6	540.0	538.4	542.0	536.4	541.4	539.1
10	541.8	540.6	539.7	541.1	538.9	539.9	538.4	542.2	536.3	541.6	539.8
11	541.8	541.0	540.9	541.7	539.1	539.7	539.0	541.8	537.6	541.7	541.2
12	541.0	540.8	540.7	540.9	539.8	540.7	540.1	540.9	539.6	540.8	540.6

ReservoirHead (m) for RES6 in the Gibe I-III & Koysha set-up.

SEASON	**Year**										
	1	2	3	4	5	6	7	8	9	10	11
1	173.2	171.8	170.9	170.5	171.8	171.2	171.2	169.9	167.1	168.8	165.1
2	172.3	169.4	166.6	166.1	169.1	167.8	168.8	165.6	161.0	165.2	159.2
3	170.5	167.4	161.8	162.1	166.7	164.2	164.5	162.8	157.9	160.5	152.5
4	168.9	167.0	158.5	160.6	166.3	161.7	162.4	161.1	155.5	159.0	147.8
5	170.1	166.3	159.3	162.5	166.2	161.7	164.0	165.3	154.8	160.9	148.4
6	170.2	164.4	157.9	162.9	165.1	162.3	161.7	166.0	151.7	162.1	150.5
7	171.0	165.6	158.6	164.2	164.4	163.5	160.5	165.9	153.0	162.4	153.7
8	173.8	169.5	162.9	168.1	167.3	168.1	163.7	172.1	158.2	168.9	158.9
9	174.2	170.4	165.0	173.0	170.0	174.1	169.2	176.0	159.8	173.0	164.1
10	175.5	173.1	169.1	173.9	170.8	173.9	170.5	178.0	161.8	175.3	166.5
11	175.9	174.7	174.2	176.0	170.5	172.4	171.0	176.2	164.7	174.0	172.7
12	174.2	173.5	173.7	174.1	170.9	173.3	172.4	172.7	169.8	170.6	170.4

Appendix G – Topkapi-ETH data

Averaged values of inflow to Gibe I & II from Topkapi-ETH model.

Q_{in} (m^3/s)	Year										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	3.1	3.3	3.3	5.4	12.9	10.4	8.0	8.7	5.4	15.1	6.0
Feb	2.9	2.1	2.4	4.4	4.4	5.2	5.3	4.0	6.2	10.3	4.0
Mar	3.4	4.6	2.8	8.7	7.5	7.1	5.4	12.7	12.8	8.6	4.5
Apr	5.1	4.4	8.9	8.7	8.3	10.3	9.6	10.4	12.0	24.8	8.1
May	6.6	8.7	10.2	20.5	10.4	6.4	8.5	65.4	23.9	49.5	19.6
Jun	6.2	10.2	12.3	29.3	16.6	19.0	13.8	20.1	31.5	56.2	32.4
Jul	10.5	25.6	27.5	88.4	32.7	45.0	30.1	135.2	114.7	126.7	90.3
Aug	21.5	30.8	52.3	124.4	91.4	99.3	87.6	197.8	166.7	163.1	194.2
Sep	15.3	24.2	49.7	109.0	63.9	80.0	94.7	98.7	114.3	198.7	145.0
Oct	25.3	53.6	91.2	82.7	31.4	29.7	91.5	85.3	111.3	50.0	45.4
Nov	10.4	13.3	32.7	37.8	10.3	12.5	26.1	25.8	70.0	11.6	125.3
Dec	4.8	7.1	15.5	11.2	41.8	27.2	30.1	9.3	64.3	8.7	11.9
Year	9.6	15.8	25.9	44.5	27.9	29.5	34.4	56.7	61.6	60.5	57.3

Averaged values of volume of Gibe I & II from Topkapi-ETH model.

V (Mm^3)	Year										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	710.0	837.7	837.8	838.8	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Feb	704.8	832.6	832.9	838.0	838.4	838.5	838.6	838.1	838.7	838.9	837.9
Mar	702.2	830.4	826.4	838.3	838.8	838.8	837.6	838.4	838.8	838.8	835.3
Apr	697.7	826.6	827.9	838.8	838.8	838.8	838.9	838.8	838.9	838.9	838.0
May	704.1	832.7	838.5	838.9	838.9	838.8	838.8	838.9	838.9	838.9	838.9
Jun	703.1	838.6	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Jul	715.0	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Aug	745.0	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Sep	781.0	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Oct	826.6	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Nov	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Dec	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9	838.9
Year	747.5	836.0	836.3	838.8	838.8	838.8	838.7	838.8	838.9	838.9	838.4

Averaged values of external inflow to Gibe I & II from Topkapi-ETH model.

Q_{ext} (m^3/s)	Year										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	3.1	3.3	3.3	5.4	12.9	10.4	8.0	8.7	5.4	15.1	6.0
Feb	2.9	2.1	2.4	4.4	4.4	5.2	5.3	4.0	6.2	10.3	4.0
Mar	3.4	4.6	2.8	8.7	7.5	7.1	5.4	12.7	12.8	8.6	4.5
Apr	5.1	4.4	8.9	8.7	8.3	10.3	9.6	10.4	12.0	24.8	8.1
May	6.6	8.7	10.2	20.5	10.4	6.4	8.5	65.4	23.9	49.5	19.6
Jun	6.2	10.2	12.3	29.3	16.6	19.0	13.8	20.1	31.5	56.2	32.4
Jul	10.5	25.6	27.5	88.4	32.7	45.0	30.1	135.2	114.7	126.7	90.3

Aug	21.5	30.8	52.3	124.4	91.4	99.3	87.6	197.8	166.7	163.1	194.2
Sep	15.3	24.2	49.7	109.0	63.9	80.0	94.7	98.7	114.3	198.7	145.0
Oct	25.3	53.6	91.2	82.7	31.4	29.7	91.5	85.3	111.3	50.0	45.4
Nov	10.4	13.3	32.7	37.8	10.3	12.5	26.1	25.8	70.0	11.6	125.3
Dec	4.8	7.1	15.5	11.2	41.8	27.2	30.1	9.3	64.3	8.7	11.9
Year	9.6	15.8	25.9	44.5	27.9	29.5	34.4	56.7	61.6	60.5	57.3

Averaged values of water level of Gibe I & II from Topkapi-ETH model.

Level (m)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	1670.6	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Feb	1670.5	1674.8	1674.8	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Mar	1670.4	1674.7	1674.6	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1674.9
Apr	1670.2	1674.6	1674.6	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
May	1670.4	1674.8	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Jun	1670.4	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Jul	1670.8	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Aug	1671.8	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Sep	1673.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Oct	1674.6	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Nov	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Dec	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0
Year	1671.9	1674.9	1674.9	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0	1675.0

Averaged values of inflow to Gibe III from Topkapi-ETH model.

Q_{in} (m^3/s)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	235.5	74.7	64.3	87.0	190.1	149.5	147.9	157.1	58.8	180.8	77.0
Feb	67.3	43.0	42.7	63.8	62.9	75.5	101.9	68.7	91.8	146.2	43.3
Mar	84.3	109.6	40.6	180.1	142.7	121.2	84.0	280.8	250.3	160.3	45.8
Apr	125.0	91.5	189.6	179.0	161.9	242.2	230.1	234.2	231.5	282.2	159.1
May	263.3	198.1	316.8	413.0	199.7	151.5	203.8	609.8	316.4	431.4	396.9
Jun	278.4	349.8	331.5	515.7	342.6	382.9	313.7	334.0	429.6	417.2	561.8
Jul	638.6	727.2	660.8	996.5	614.9	741.4	613.9	840.2	1046.7	835.1	1009.0
Aug	738.7	787.4	815.3	1118.8	1006.9	914.4	1075.0	1223.2	1185.0	1105.9	1538.3
Sep	500.7	493.8	677.9	966.6	684.4	890.7	822.9	724.7	938.0	1156.2	1199.2
Oct	687.9	824.4	781.2	603.6	307.8	328.0	643.9	535.7	705.4	444.5	438.8
Nov	243.9	204.0	380.8	348.6	183.4	175.5	224.4	205.8	478.0	142.5	916.5
Dec	97.3	117.3	193.2	153.0	356.4	268.4	260.6	98.2	433.7	90.2	152.2
Year	332.7	338.0	376.1	471.8	357.0	371.9	395.1	446.5	517.2	451.3	545.8

Averaged values of volume to Gibe III from Topkapi-ETH model.

V (Mm^3)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	11688.6	11398.1	11315.9	11198.3	11488.9	11389.7	11288.1	11233.6	10982.5	11248.8	10914.2
Feb	11157.2	10688.1	10471.6	10171.6	10869.1	10691.4	10649.0	10394.4	9820.9	10486.0	9655.2
Mar	10515.9	10054.5	9591.9	9235.2	10219.4	10000.6	9808.7	9673.9	8914.2	9633.4	8334.2
Apr	9854.4	9375.2	8861.9	8488.8	9724.5	9448.0	9175.5	9141.2	8215.0	9078.9	7159.4
May	9608.1	8868.9	8622.5	8061.7	9197.1	9059.2	8755.9	9201.5	7620.0	8825.3	6538.3
Jun	9293.7	8586.2	8428.9	8006.3	8973.0	8737.8	8329.9	9182.2	7182.6	8792.4	6331.9
Jul	9672.9	9152.9	8685.4	8682.2	9216.2	9250.2	8331.5	9459.2	7730.0	9033.2	6934.1
Aug	10666.6	10390.4	9760.1	10241.1	10366.8	10288.8	9562.8	11098.7	9281.5	10718.9	8840.1
Sep	11442.8	11173.0	10780.7	12118.6	11894.3	11980.6	11482.7	12586.0	10955.4	12426.8	11332.6
Oct	12301.9	12139.4	11657.6	12616.5	12221.0	12578.2	12215.1	13237.1	11799.2	13478.4	11718.7
Nov	12510.3	12537.1	12221.0	12760.1	11940.9	12152.9	12121.4	12845.5	11797.4	12923.4	12613.4
Dec	12072.1	12033.7	11960.7	12122.2	11614.9	11889.5	11765.7	12074.1	11798.3	12038.1	12048.7
Year	10897.9	10533.1	10196.4	10309.3	10642.1	10622.1	10288.7	10846.6	9675.0	10724.7	9366.9

Monthly averaged values of external inflow to Gibe III from Topkapi-ETH model.

Q_{ext} (m^3/s)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	234.2	73.3	62.9	84.5	180.2	142.2	143.0	151.5	56.5	168.8	74.0
Feb	66.0	41.7	41.4	62.5	61.5	73.8	99.6	67.3	89.1	139.3	42.0
Mar	83.0	108.3	39.3	175.5	139.2	117.7	82.7	272.6	241.2	155.4	44.5
Apr	123.7	90.2	188.3	173.8	157.0	235.4	224.1	227.4	223.0	261.0	155.8
May	262.0	196.8	311.7	396.0	193.0	148.6	198.9	548.0	296.0	385.5	380.8
Jun	277.1	343.5	322.5	489.7	329.4	367.3	303.3	317.2	401.3	364.3	532.7
Jul	637.3	704.6	636.3	911.2	585.2	699.4	586.9	708.0	935.0	711.4	921.7
Aug	737.4	759.9	766.2	997.7	918.8	818.4	990.7	1028.7	1021.6	946.1	1347.4
Sep	499.4	472.9	631.6	860.9	623.8	814.0	731.5	629.4	827.1	960.8	1057.5
Oct	681.6	774.1	693.3	524.2	279.8	301.6	555.7	453.7	597.4	397.8	396.6
Nov	236.6	193.9	351.3	314.0	176.3	166.3	201.5	183.1	411.2	134.1	794.3
Dec	95.5	113.2	180.6	144.8	317.7	244.1	233.6	91.8	372.4	84.5	143.3
Year	332.7	338.0	376.1	471.8	357.0	371.9	395.1	446.5	517.2	451.3	545.8

Averaged values of water level of Gibe III from Topkapi-ETH model.

Level (m)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	873.2	871.0	870.4	869.5	871.7	870.9	870.2	869.8	868.0	869.9	867.6
Feb	869.2	866.0	864.6	862.6	867.2	866.0	865.7	864.1	860.3	864.7	859.3
Mar	864.9	861.9	858.8	856.5	862.9	861.5	860.3	859.4	854.4	859.1	850.3
Apr	860.6	857.4	854.0	851.4	859.7	857.9	856.1	855.9	849.5	855.5	841.6
May	859.0	854.1	852.4	848.4	856.3	855.4	853.3	856.3	845.1	853.8	836.8
Jun	856.9	852.1	851.0	848.0	854.8	853.2	850.3	856.2	841.7	853.5	835.2
Jul	859.4	856.0	852.8	852.7	856.4	856.6	850.3	858.0	845.9	855.2	839.8
Aug	865.9	864.0	859.9	863.1	863.9	863.4	858.7	869.0	856.8	866.2	853.7
Sep	871.3	869.3	866.6	876.4	874.7	875.4	871.6	879.9	867.8	878.6	870.6
Oct	877.8	876.5	872.9	880.1	877.2	879.8	877.1	884.2	874.0	885.5	873.4
Nov	879.3	879.5	877.2	881.2	875.1	876.6	876.4	881.8	874.0	882.3	880.1
Dec	876.0	875.8	875.2	876.4	872.6	874.7	873.7	876.1	874.0	875.8	875.9
Year	867.8	865.3	863.0	863.9	866.0	865.9	863.6	867.6	859.3	866.7	857.0

Monthly averaged values of inflow to Gibe IV from Topkapi-ETH model.

Q_{in} (m^3/s)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	457.0	352.6	381.2	496.1	419.8	418.8	469.3	516.7	529.5	527.7	566.4
Feb	374.1	338.0	376.2	500.9	367.7	386.8	418.3	467.8	585.4	522.5	555.0
Mar	355.2	405.1	385.4	553.8	465.5	425.9	421.6	650.2	682.4	527.7	567.3
Apr	451.8	436.8	461.5	627.4	456.5	498.2	568.0	612.3	664.6	660.7	700.7
May	458.5	399.5	569.7	708.5	503.8	502.7	536.8	872.8	710.6	712.6	787.4
Jun	454.5	402.4	490.1	684.2	443.2	558.5	482.9	565.9	674.3	636.0	799.6
Jul	521.5	547.9	623.7	754.0	525.2	605.3	596.2	814.1	879.2	747.8	884.7
Aug	538.8	540.7	667.9	776.5	629.0	807.6	706.3	869.9	890.7	827.1	958.2
Sep	411.5	441.0	531.3	783.2	516.0	541.5	609.0	734.2	698.2	819.3	875.2
Oct	530.5	609.7	807.5	728.5	510.4	496.5	586.1	662.8	875.8	631.6	808.3
Nov	408.3	391.9	552.7	632.2	424.1	471.1	645.2	566.7	803.0	560.1	893.3
Dec	345.9	390.0	452.1	533.1	595.5	518.2	510.3	484.5	845.1	481.5	600.4
Year	443.0	439.0	525.9	649.0	489.4	520.4	546.2	653.3	738.1	638.5	750.0

Monthly averaged values of volume to Gibe IV from Topkapi-ETH model.

V (Mm^3)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	4385.7	4210.5	4122.2	4093.1	4214.3	4155.5	4155.9	4038.0	3784.8	3907.8	3612.1
Feb	4289.8	3972.3	3739.4	3711.7	3952.1	3844.0	3930.6	3666.3	3287.0	3609.9	3124.4
Mar	4100.8	3807.1	3349.6	3385.2	3759.0	3551.5	3578.5	3443.8	3042.0	3233.4	2615.2
Apr	3952.9	3770.0	3076.0	3264.0	3726.5	3358.4	3413.1	3308.6	2847.7	3105.7	2313.4

May	4062.6	3715.4	3152.5	3419.8	3721.3	3361.3	3544.0	3649.7	2804.6	3264.0	2358.3
Jun	4067.9	3556.5	3036.6	3449.9	3633.3	3414.1	3350.1	3693.9	2597.3	3366.3	2500.9
Jul	4144.6	3668.6	3105.4	3572.8	3584.3	3520.0	3258.6	3694.2	2704.7	3390.0	2723.7
Aug	4429.2	3997.5	3463.9	3893.2	3824.6	3918.5	3533.1	4263.8	3094.4	3940.6	3134.1
Sep	4471.0	4084.4	3637.8	4356.6	4056.3	4467.1	3987.3	4640.9	3230.3	4334.8	3551.2
Oct	4604.4	4359.4	3987.7	4439.9	4142.9	4453.2	4116.1	4845.4	3403.8	4567.7	3739.6
Nov	4641.7	4512.0	4462.8	4645.6	4101.8	4299.5	4167.5	4658.0	3619.3	4426.6	4300.8
Dec	4456.2	4391.2	4405.9	4450.1	4132.1	4374.3	4281.9	4298.4	4018.7	4080.7	4055.9
Year	4300.8	4004.2	3628.5	3891.2	3903.9	3893.6	3776.1	4019.0	3203.6	3769.8	3169.4

Monthly averaged values of external inflow to Gibe IV from Topkapi-ETH model.

Q_{ext} (m^3/s)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	136.9	26.0	16.5	35.6	74.4	59.0	85.7	81.9	23.4	88.4	31.5
Feb	53.9	11.5	11.6	40.4	22.3	27.0	34.7	32.9	79.3	83.2	20.1
Mar	35.0	78.6	20.8	93.3	120.0	66.1	38.0	215.3	176.3	88.3	32.5
Apr	131.7	110.2	96.8	167.0	111.1	138.3	184.5	177.5	158.5	221.4	165.8
May	138.3	73.0	205.0	248.1	158.4	142.9	153.2	437.9	204.6	273.3	252.5
Jun	134.3	75.9	125.5	223.8	97.8	198.7	99.4	131.1	168.3	196.7	264.8
Jul	201.3	221.3	259.0	293.5	179.7	245.5	212.6	379.3	373.1	308.4	349.8
Aug	218.7	214.2	303.2	316.0	283.6	447.8	322.8	435.1	384.7	387.8	423.3
Sep	91.4	114.4	166.6	322.8	170.6	181.7	225.4	299.3	192.1	379.9	340.3
Oct	210.3	283.2	442.8	268.0	165.0	136.7	202.6	227.9	369.7	192.2	273.5
Nov	88.1	65.4	188.0	171.7	78.7	111.3	261.7	131.9	297.0	120.8	358.5
Dec	25.8	63.4	87.5	72.6	250.1	158.4	126.7	49.6	339.0	42.1	65.6
Year	122.8	112.5	161.3	188.6	144.0	160.6	162.7	218.5	232.0	199.2	215.2

Averaged values of water level of Gibe IV from Topkapi-ETH model.

Level (m)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	659.2	657.2	656.2	655.9	657.2	656.6	656.6	655.2	652.3	653.7	650.2
Feb	658.1	654.5	651.8	651.4	654.2	653.0	654.0	650.9	646.0	650.2	643.9
Mar	655.9	652.6	646.9	647.3	652.0	649.5	649.8	648.1	642.8	645.3	636.6
Apr	654.2	652.1	643.2	645.7	651.6	647.0	647.7	646.3	640.1	643.6	631.8
May	655.5	651.5	644.2	647.8	651.6	647.0	649.4	650.7	639.5	645.7	632.5
Jun	655.6	649.6	642.7	648.2	650.5	647.7	646.9	651.2	636.3	647.1	634.8
Jul	656.4	650.9	643.6	649.8	649.9	649.1	645.6	651.3	637.9	647.4	638.3
Aug	659.7	654.7	648.4	653.5	652.8	653.8	649.2	657.8	643.5	654.1	644.0
Sep	660.2	655.8	650.6	658.9	655.4	660.1	654.6	661.9	645.3	658.6	649.5
Oct	661.5	658.9	654.6	659.8	656.4	660.0	656.1	664.0	647.6	661.2	651.8

Nov	661.9	660.6	660.1	662.0	656.0	658.2	656.7	662.1	650.4	659.7	658.2
Dec	660.0	659.3	659.5	659.9	656.3	659.1	658.0	658.2	655.0	655.7	655.4
Year	658.2	654.8	650.1	653.4	653.7	653.4	652.1	654.8	644.7	651.9	643.9

Monthly averaged values of inflow to Gibe V from Topkapi-ETH model.

Q_{in} (m^3/s)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	456.1	430.9	514.6	640.8	490.1	516.4	548.1	654.9	727.1	643.9	741.6
Feb	436.7	428.3	514.7	644.0	479.0	511.0	537.1	649.4	735.8	645.3	740.2
Mar	439.2	443.4	517.7	657.1	504.0	520.2	539.9	679.7	750.8	656.1	743.4
Apr	462.3	454.8	534.8	678.1	496.4	528.9	566.5	681.4	754.5	679.5	762.4
May	455.2	441.2	542.3	674.1	511.0	533.6	553.3	713.5	756.1	668.4	767.8
Jun	460.2	435.5	530.4	666.7	489.1	539.9	548.9	664.7	745.0	655.8	768.7
Jul	470.5	454.2	549.5	667.5	497.5	536.8	560.2	685.0	763.7	664.2	772.2
Aug	461.2	457.7	549.8	675.3	508.0	574.8	570.7	695.5	774.9	679.3	779.2
Sep	444.0	443.0	528.9	687.9	497.4	535.1	555.8	680.1	742.3	669.6	774.4
Oct	462.3	467.8	586.2	671.7	510.2	533.6	556.0	673.0	774.9	657.3	777.6
Nov	446.1	437.6	537.4	663.5	493.4	537.0	591.7	664.3	779.5	658.0	775.1
Dec	434.9	438.6	526.3	645.4	528.7	538.4	560.2	652.2	788.6	635.3	744.9
Year	452.5	444.6	536.2	664.4	500.6	534.0	557.4	674.7	758.0	659.4	762.3

Monthly averaged values of volume to Gibe V from Topkapi-ETH model.

V (Mm^3)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	1369.6	1331.2	1317.2	1309.8	1329.2	1321.1	1326.4	1305.2	1290.2	1309.8	1300.5
Feb	1352.5	1292.1	1262.4	1255.9	1284.4	1264.8	1290.9	1254.5	1218.7	1276.1	1246.5
Mar	1314.4	1268.1	1207.5	1215.8	1258.0	1217.8	1237.1	1226.1	1184.0	1234.4	1189.3
Apr	1309.9	1291.2	1179.0	1228.3	1264.8	1182.6	1216.2	1237.5	1159.6	1263.5	1166.6
May	1328.7	1298.4	1199.3	1280.3	1284.9	1185.5	1239.0	1311.8	1160.5	1304.4	1179.1
Jun	1328.2	1269.2	1183.9	1282.9	1267.4	1198.9	1216.0	1337.7	1137.3	1318.7	1203.8
Jul	1365.7	1273.1	1193.4	1267.9	1240.1	1203.5	1194.4	1331.6	1126.7	1312.8	1213.4
Aug	1406.0	1311.3	1231.8	1298.9	1260.0	1252.8	1223.3	1371.0	1170.2	1360.9	1243.9
Sep	1395.9	1311.9	1236.5	1344.3	1255.1	1321.6	1245.4	1417.8	1161.3	1389.1	1277.8
Oct	1405.5	1350.3	1304.9	1373.6	1270.0	1315.5	1243.9	1424.9	1155.9	1400.5	1314.3
Nov	1406.6	1370.0	1367.0	1401.0	1279.6	1306.5	1272.5	1407.2	1210.4	1401.2	1380.3
Dec	1371.2	1357.7	1356.7	1364.3	1310.4	1353.4	1325.6	1362.9	1304.7	1360.9	1350.4
Year	1363.0	1310.5	1253.4	1302.2	1275.3	1260.4	1252.5	1332.8	1190.0	1327.9	1255.5

Monthly averaged values of external inflow to Gibe V from Topkapi-ETH model.

Q_{ext} (m³/s)	Year										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	25.7	4.8	1.6	4.5	14.1	9.4	15.0	8.5	1.8	13.0	4.2
Feb	6.3	2.2	1.7	7.7	3.1	4.0	4.0	3.0	10.5	14.4	2.8
Mar	8.8	17.3	4.7	20.7	28.0	13.2	6.7	33.4	25.5	25.2	6.0
Apr	31.9	28.7	21.8	41.8	20.4	21.8	33.4	35.1	29.2	48.6	25.0
May	24.8	15.0	29.3	37.8	35.0	26.5	20.2	67.1	30.8	37.5	30.4
Jun	29.8	9.4	17.4	30.3	13.2	32.9	15.7	18.3	19.7	24.9	31.3
Jul	40.1	28.1	36.5	31.2	21.6	29.7	27.1	38.6	38.4	33.3	34.8
Aug	30.8	31.6	36.8	39.0	32.0	67.8	37.6	49.2	49.6	48.4	41.8
Sep	13.7	16.9	15.9	51.6	21.4	28.1	22.6	33.8	17.0	38.7	37.0
Oct	31.9	41.7	73.2	35.3	34.2	26.6	22.9	26.7	49.6	26.4	40.2
Nov	15.8	11.5	24.4	27.2	17.5	30.0	58.5	17.9	54.2	27.1	37.7
Dec	4.5	12.5	13.3	9.1	52.7	31.4	27.1	5.8	63.3	4.4	7.5
Year	22.1	18.5	23.2	28.1	24.7	27.0	24.3	28.3	32.7	28.5	24.9

Averaged values of water level of Gibe V from Topkapi-ETH model.

Level (m)	Year										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	541.0	540.2	539.9	539.8	540.2	540.0	540.1	539.7	539.3	539.8	539.6
Feb	540.6	539.4	538.8	538.6	539.2	538.8	539.4	538.6	537.8	539.1	538.4
Mar	539.9	538.9	537.5	537.8	538.7	537.8	538.2	538.0	537.0	538.2	537.1
Apr	539.8	539.4	536.8	538.0	538.8	536.9	537.8	538.2	536.4	538.8	536.5
May	540.2	539.5	537.3	539.1	539.2	537.0	538.3	539.8	536.4	539.6	536.8
Jun	540.1	538.9	537.0	539.2	538.9	537.3	537.8	540.3	535.8	539.9	537.5
Jul	540.9	539.0	537.2	538.9	538.3	537.4	537.2	540.2	535.5	539.8	537.7
Aug	541.8	539.8	538.1	539.5	538.7	538.5	537.9	541.0	536.6	540.8	538.4
Sep	541.6	539.8	538.2	540.5	538.6	540.0	538.4	542.0	536.4	541.4	539.1
Oct	541.8	540.6	539.7	541.1	538.9	539.9	538.4	542.2	536.3	541.6	539.8
Nov	541.8	541.0	540.9	541.7	539.1	539.7	539.0	541.8	537.6	541.7	541.2
Dec	541.0	540.8	540.7	540.9	539.8	540.7	540.1	540.9	539.6	540.8	540.6
Year	540.9	539.8	538.5	539.6	539.0	538.7	538.5	540.2	537.1	540.1	538.6

Monthly averaged values of inflow to Koysha from Topkapi-ETH model.

Q_{in} (m³/s)	Year										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	450.4	353.6	381.7	496.1	425.5	422.9	471.6	516.5	529.4	537.0	566.3
Feb	377.0	338.6	376.8	502.0	368.5	387.5	420.7	472.2	587.6	525.8	555.9
Mar	356.4	407.7	385.7	558.7	468.8	428.9	422.8	659.5	688.5	530.4	567.4
Apr	456.7	441.8	466.1	636.9	463.9	500.3	572.7	620.8	670.0	673.2	706.6
May	464.9	403.7	576.6	721.2	512.2	511.0	545.7	898.6	719.2	722.3	799.7
Jun	459.0	402.5	493.0	691.5	445.1	566.9	487.0	571.4	677.1	647.9	811.1

Jul	528.0	555.9	633.5	765.8	530.5	612.9	600.3	825.1	896.0	753.7	898.1
Aug	548.2	547.9	680.7	791.4	642.0	835.0	720.3	898.6	909.8	854.2	979.9
Sep	413.5	446.4	534.5	807.0	522.4	553.6	617.6	749.1	703.7	836.6	895.4
Oct	538.6	619.8	832.5	741.9	522.2	505.9	597.0	675.9	896.0	642.9	820.7
Nov	412.5	399.0	568.0	644.7	431.5	474.9	666.2	575.9	832.1	569.0	925.5
Dec	347.1	394.1	456.8	536.7	614.3	536.1	519.7	486.7	869.8	483.8	604.0
Year	446.7	443.7	533.2	658.7	497.0	529.2	553.8	664.5	749.9	648.7	761.2

Monthly averaged values of volume to Koysha from Topkapi-ETH model.

V (Mm^3)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	4850.7	4695.7	4602.1	4566.4	4699.9	4638.6	4634.6	4509.9	4251.5	4395.2	4080.4
Feb	4753.5	4448.0	4202.5	4163.6	4424.9	4308.9	4397.4	4116.6	3725.3	4080.9	3566.8
Mar	4559.2	4274.1	3795.6	3818.5	4217.8	3997.2	4028.4	3875.7	3460.1	3684.6	3030.7
Apr	4407.1	4239.0	3506.8	3690.1	4179.8	3786.4	3847.3	3736.0	3248.9	3548.3	2705.8
May	4523.2	4183.6	3579.1	3856.3	4173.6	3783.1	3983.1	4092.1	3194.4	3712.7	2745.6
Jun	4532.3	4015.0	3456.6	3883.5	4079.7	3831.8	3780.7	4150.9	2972.2	3818.5	2892.2
Jul	4614.3	4121.3	3519.6	4000.3	4019.0	3936.2	3677.7	4142.4	3066.5	3840.6	3115.5
Aug	4911.3	4462.9	3888.9	4337.9	4265.5	4350.9	3958.0	4736.0	3479.3	4414.6	3543.2
Sep	4958.3	4554.8	4071.3	4829.4	4505.4	4941.7	4428.6	5144.9	3622.0	4826.6	3986.6
Oct	5092.5	4835.7	4436.5	4923.8	4596.6	4924.9	4559.2	5359.1	3794.0	5072.2	4198.7
Nov	5137.6	5003.8	4950.3	5147.3	4561.4	4768.0	4618.9	5168.3	4041.7	4933.9	4796.5
Dec	4950.0	4881.7	4897.6	4944.0	4599.4	4859.7	4762.2	4794.6	4491.6	4577.3	4550.0
Year	4774.5	4476.8	4075.8	4347.8	4360.0	4344.4	4222.7	4487.8	3612.9	4243.0	3601.2

Monthly averaged values of external inflow to Koysha from Topkapi-ETH model.

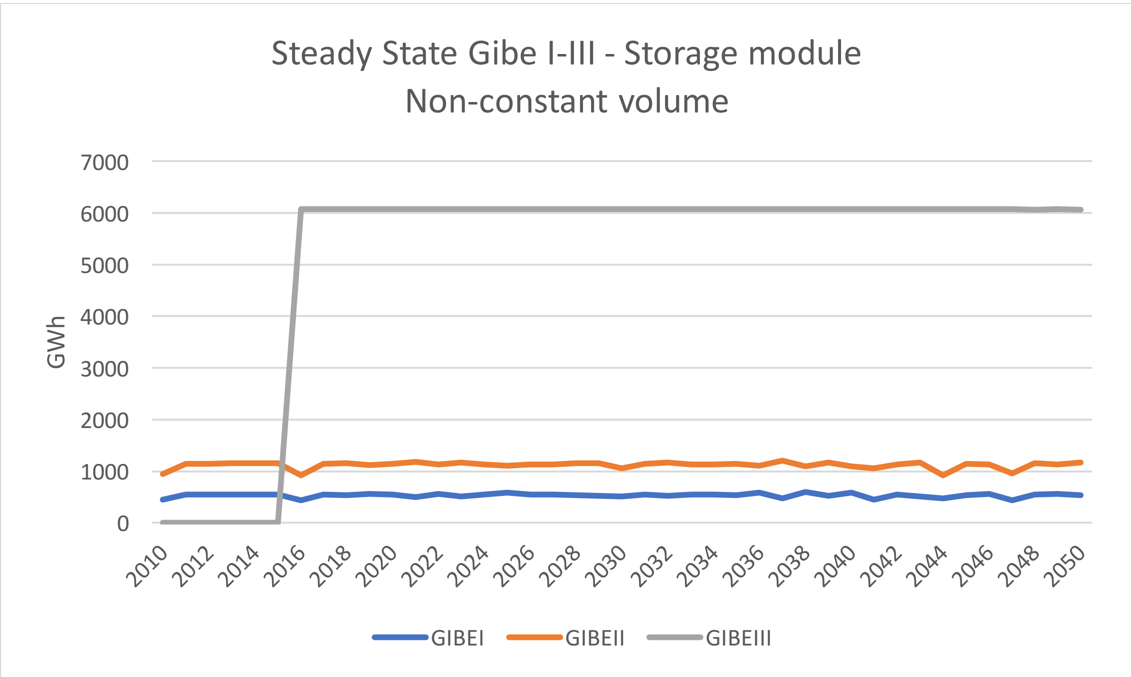
Q_{ext} (m^3/s)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	130.3	27.0	17.0	35.6	80.1	63.1	88.1	81.7	23.4	97.6	31.4
Feb	56.8	12.0	12.2	41.6	23.1	27.7	37.1	37.3	81.6	86.5	21.0
Mar	36.3	81.1	21.0	98.2	123.4	69.1	39.2	224.7	182.4	91.0	32.6
Apr	136.6	115.2	101.4	176.4	118.5	140.5	189.2	186.0	163.9	233.9	171.8
May	144.8	77.2	211.9	260.8	166.8	151.2	162.2	463.7	213.2	283.0	264.9
Jun	138.8	76.0	128.4	231.1	99.7	207.1	103.5	136.6	171.0	208.6	276.2
Jul	207.9	229.4	268.8	305.3	185.1	253.1	216.8	390.3	390.0	314.3	363.2
Aug	228.0	221.3	316.0	331.0	296.6	475.2	336.8	463.8	403.8	414.9	445.0
Sep	93.4	119.8	169.9	346.5	177.0	193.7	234.0	314.2	197.6	397.3	360.5

Oct	218.5	293.3	467.9	281.4	176.8	146.1	213.4	241.1	390.0	203.5	285.9
Nov	92.4	72.5	203.4	184.2	86.1	115.0	282.6	141.1	326.1	129.7	390.7
Dec	27.0	67.5	92.1	76.2	268.9	176.3	136.2	51.8	363.7	44.5	69.1
Year	126.6	117.1	168.5	198.2	151.5	169.4	170.3	229.6	243.8	209.4	226.3

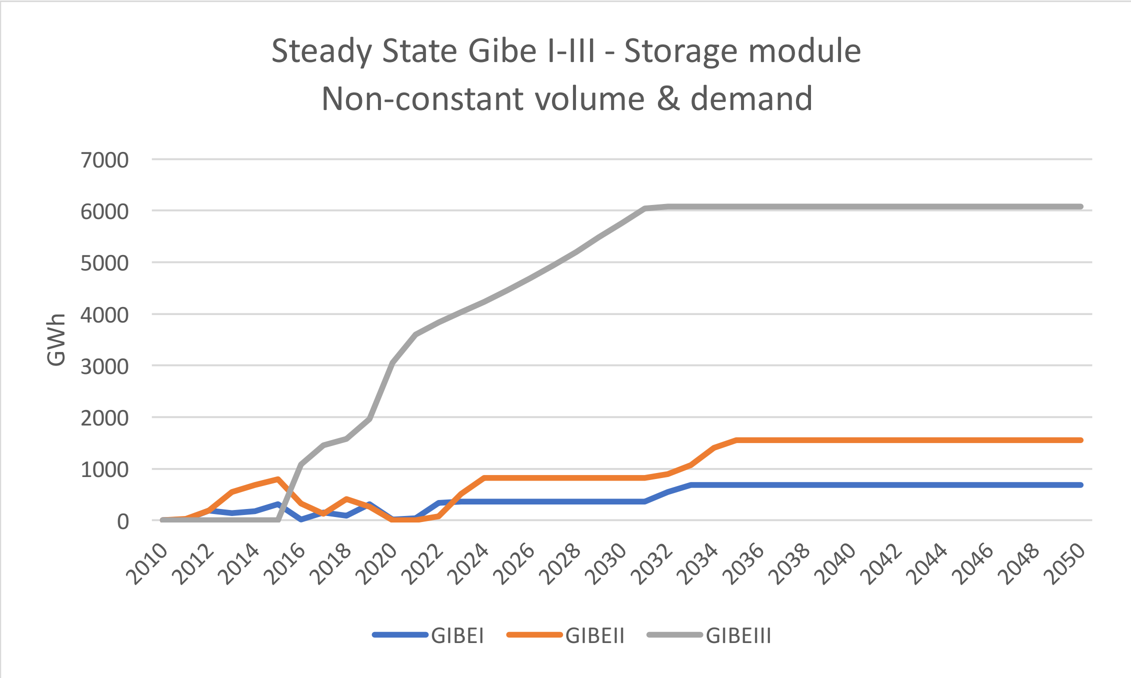
Averaged values of water level of Koysha from Topkapi-ETH model.

Level (m)	**Year**										
Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan	633.7	632.3	631.4	631.0	632.3	631.7	631.7	630.4	627.6	629.3	625.6
Feb	632.8	629.9	627.1	626.6	629.6	628.3	629.3	626.1	621.5	625.7	619.7
Mar	631.0	627.9	622.3	622.6	627.2	624.7	625.0	623.3	618.4	621.0	613.0
Apr	629.4	627.5	619.0	621.1	626.8	622.2	622.9	621.6	616.0	619.5	608.3
May	630.6	626.8	619.8	623.0	626.7	622.2	624.5	625.8	615.3	621.4	608.9
Jun	630.7	624.9	618.4	623.4	625.6	622.8	622.2	626.5	612.2	622.6	611.0
Jul	631.5	626.1	619.1	624.7	624.9	624.0	621.0	626.4	613.5	622.9	614.2
Aug	634.3	630.0	623.4	628.6	627.8	628.6	624.2	632.6	618.7	629.4	619.4
Sep	634.7	630.9	625.5	633.5	630.5	634.6	629.7	636.5	620.3	633.5	624.6
Oct	636.0	633.6	629.6	634.4	631.3	634.4	631.0	638.5	622.3	635.8	627.0
Nov	636.4	635.2	634.7	636.5	631.0	632.9	631.5	636.7	625.2	634.5	633.2
Dec	634.7	634.0	634.2	634.6	631.4	633.8	632.9	633.2	630.3	631.1	630.9
Year	633.0	629.9	625.4	628.4	628.8	628.4	627.2	629.8	620.1	627.2	619.6

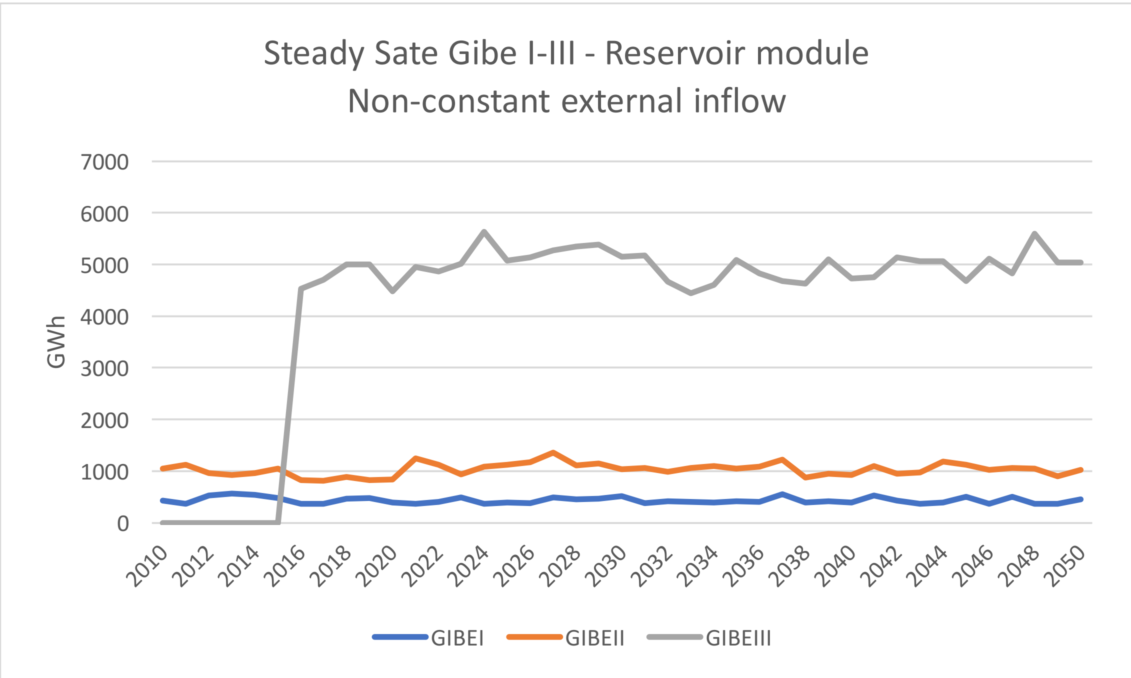
Appendix H – Results



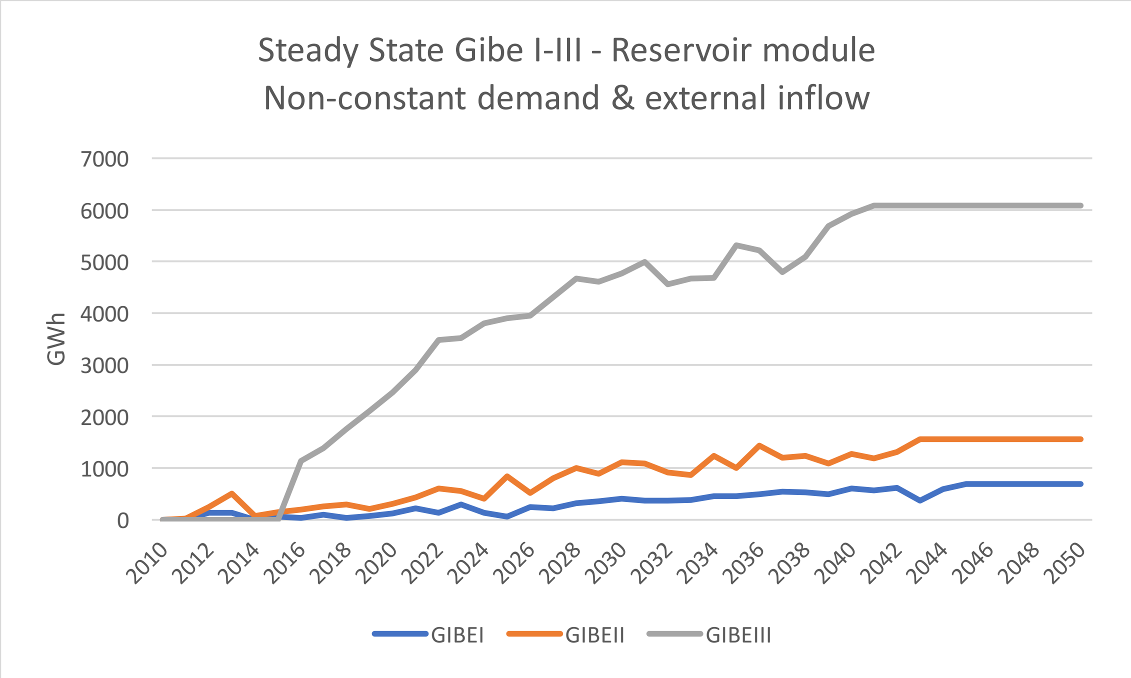
Steady State for Gibe I-III for the Storage module and non-constant volume.



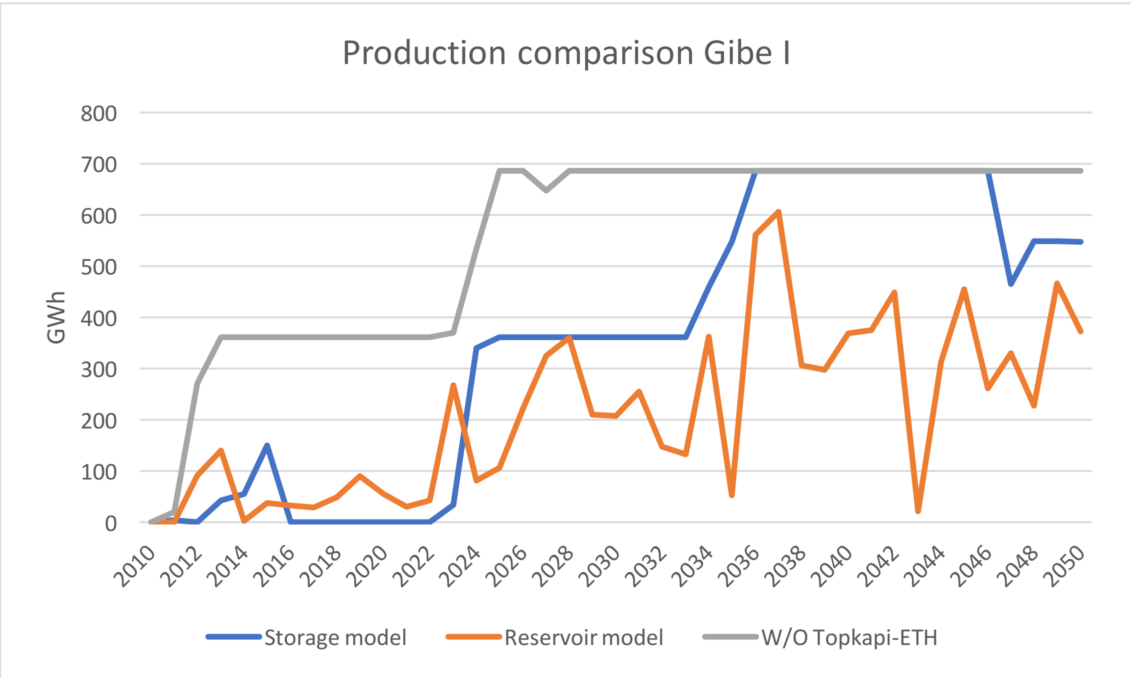
Steady State for Gibe I-III for the Storage module and non-constant volume and demand.



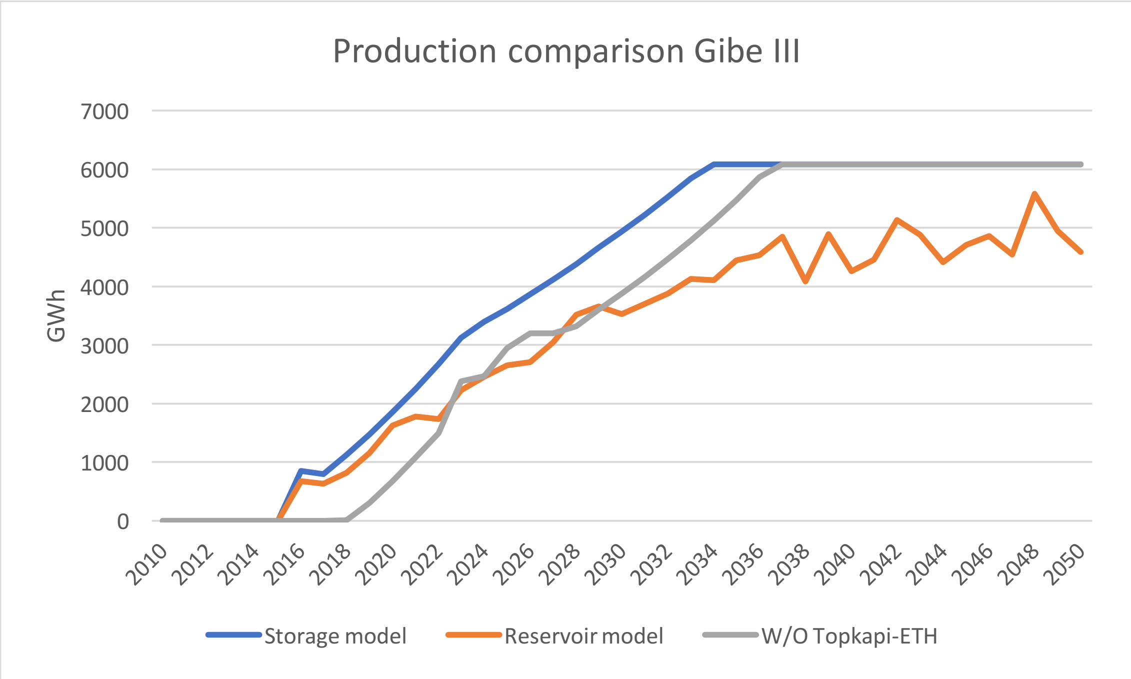
Steady State for Gibe I-III for the Reservoir module and non-constant external inflow.



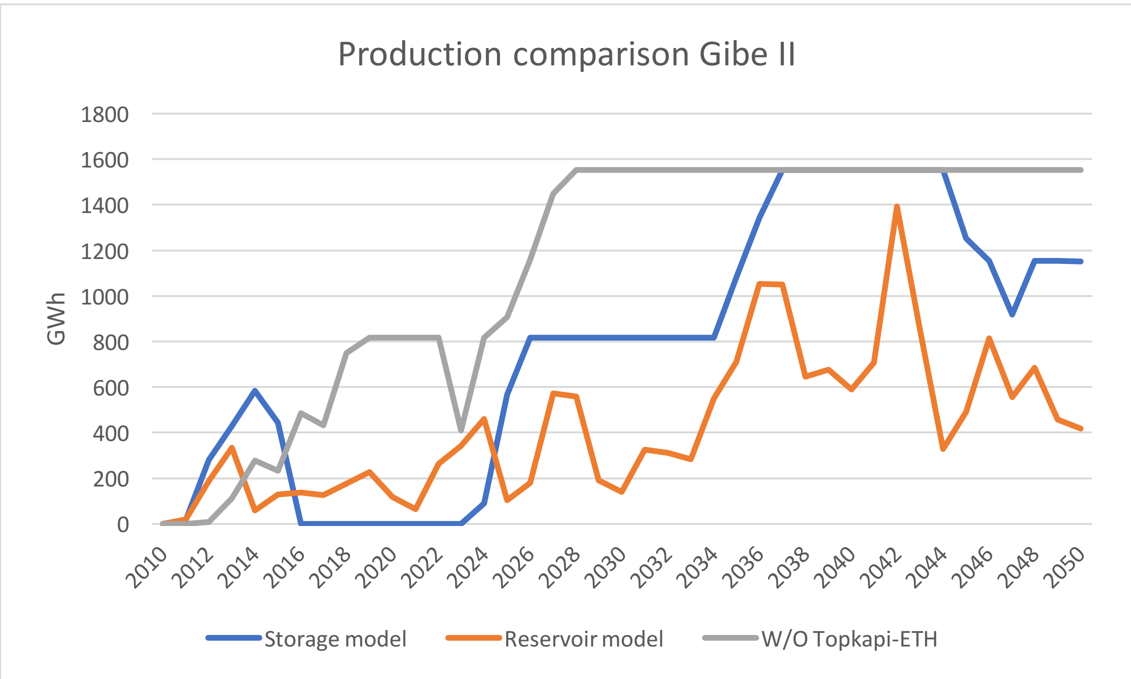
Steady State for Gibe I-III for the Reservoir module and non-constant demand external inflow.



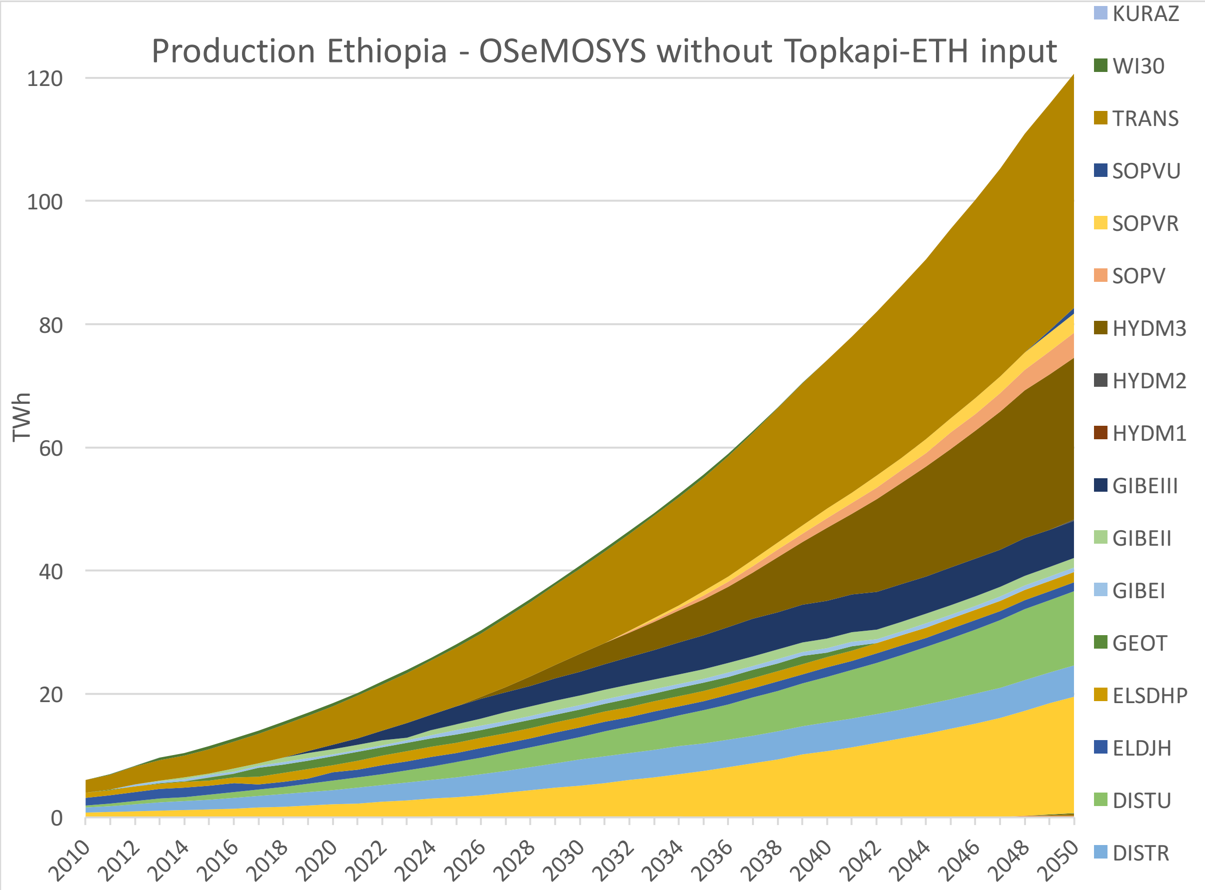
Production in Gibe I for the Storage module, Reservoir module and OSeMOSYS without Topkapi-ETH input.



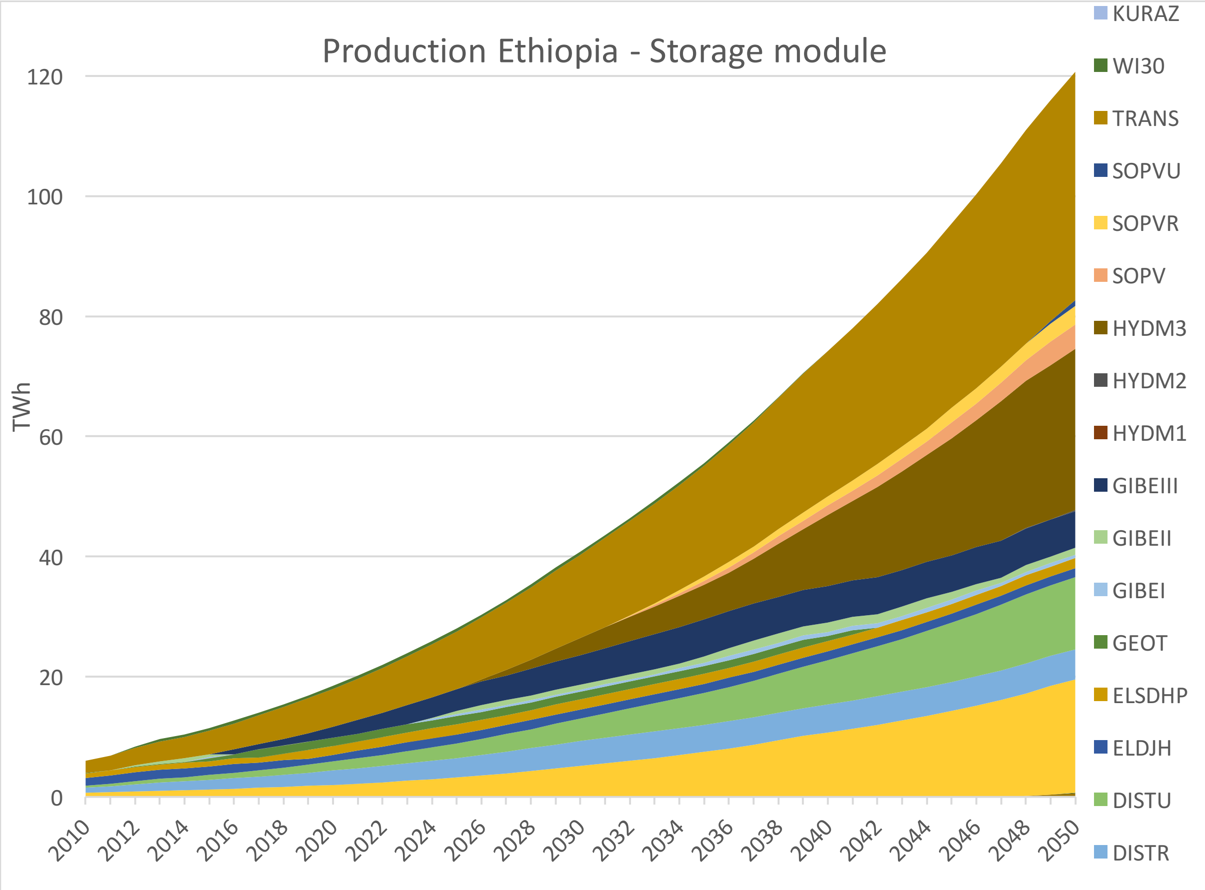
Production in Gibe II for the Storage module, Reservoir module and OSeMOSYS without Topkapi-ETH input.



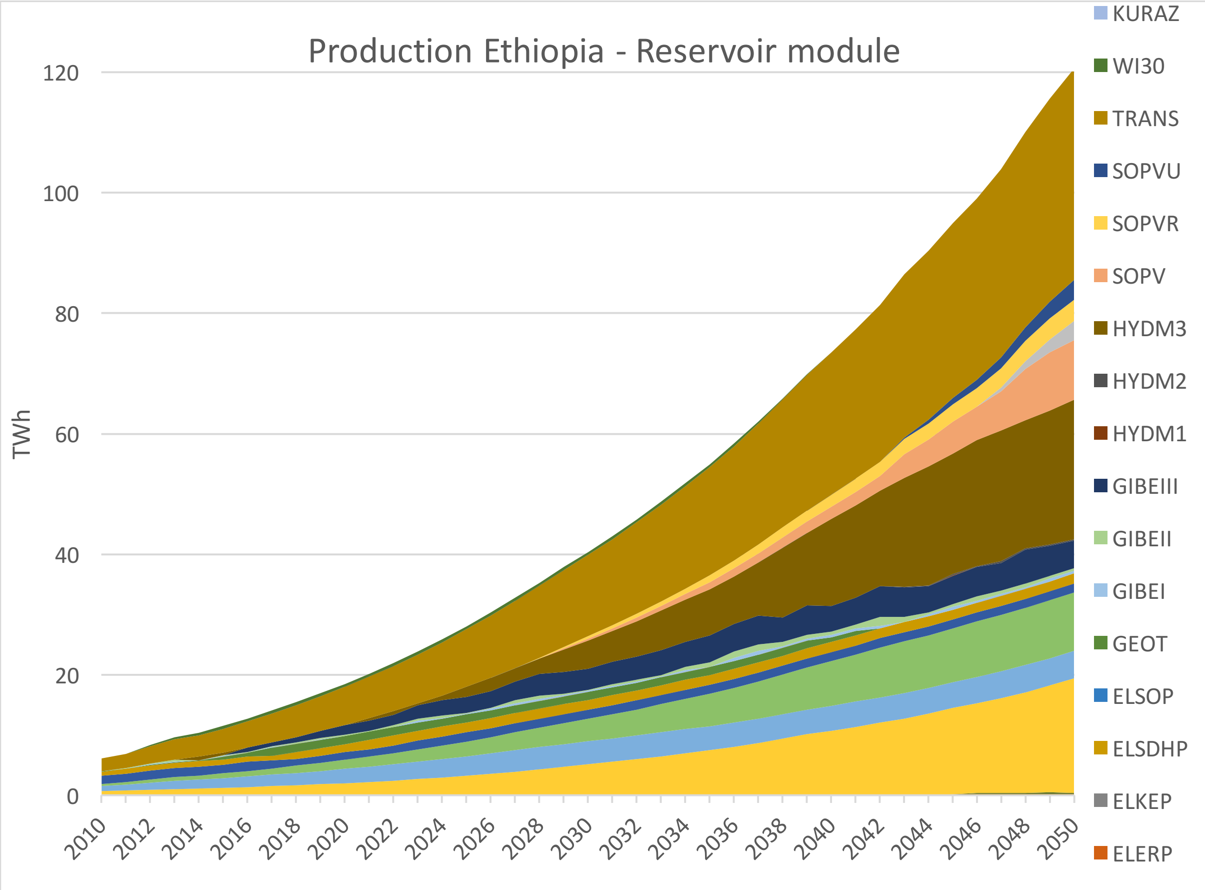
Production in Gibe III for the Storage module, Reservoir module and OSeMOSYS without Topkapi-ETH input.



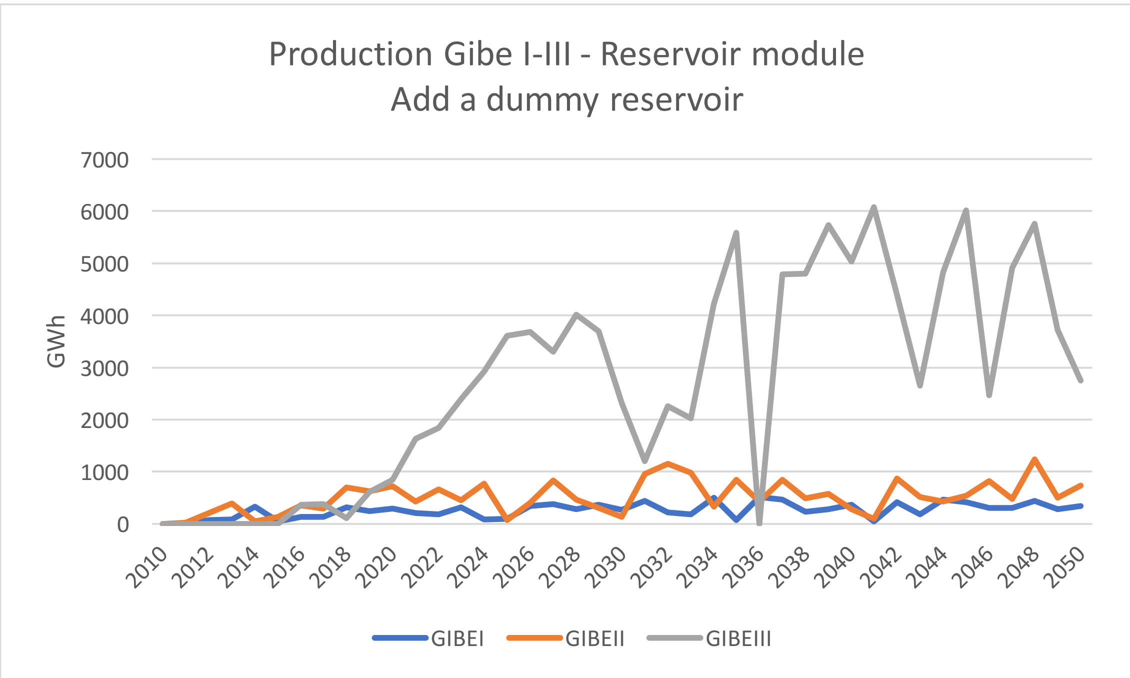
Production in Ethiopia in the OSeMOSYS model without Topkapi-ETH input.



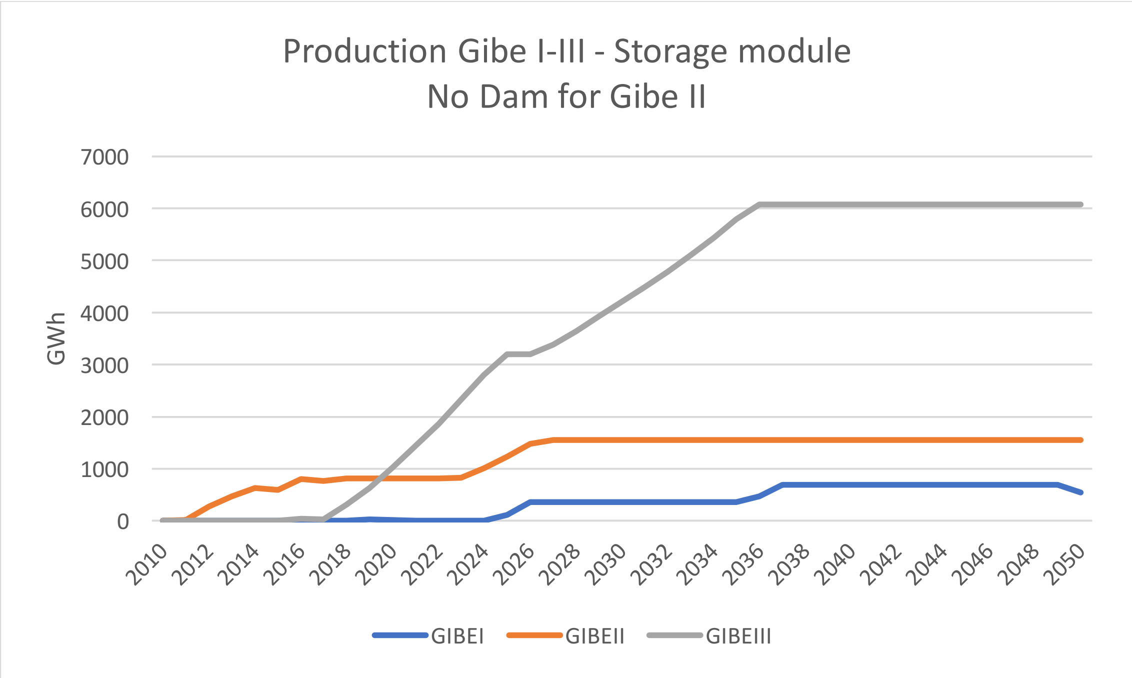
Production in Ethiopia for the Storage module.



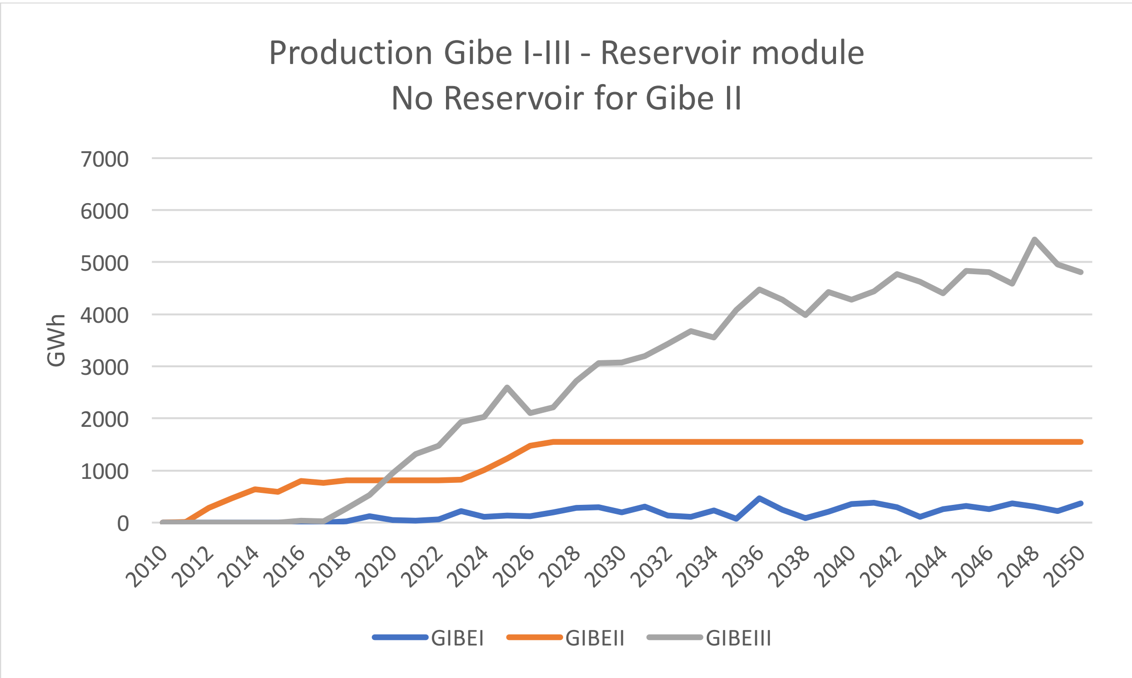
Production in Ethiopia for the Reservoir module.



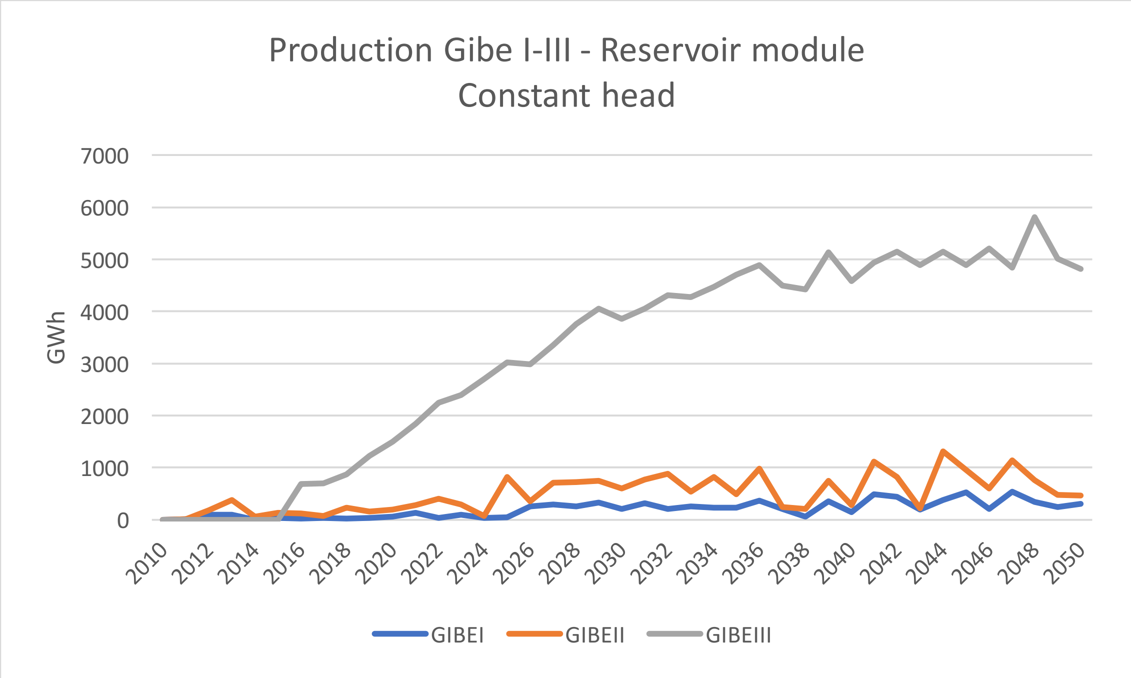
Production in Gibe I-III in the Reservoir module when one adds a dummy reservoir after the reservoir of Gibe III.



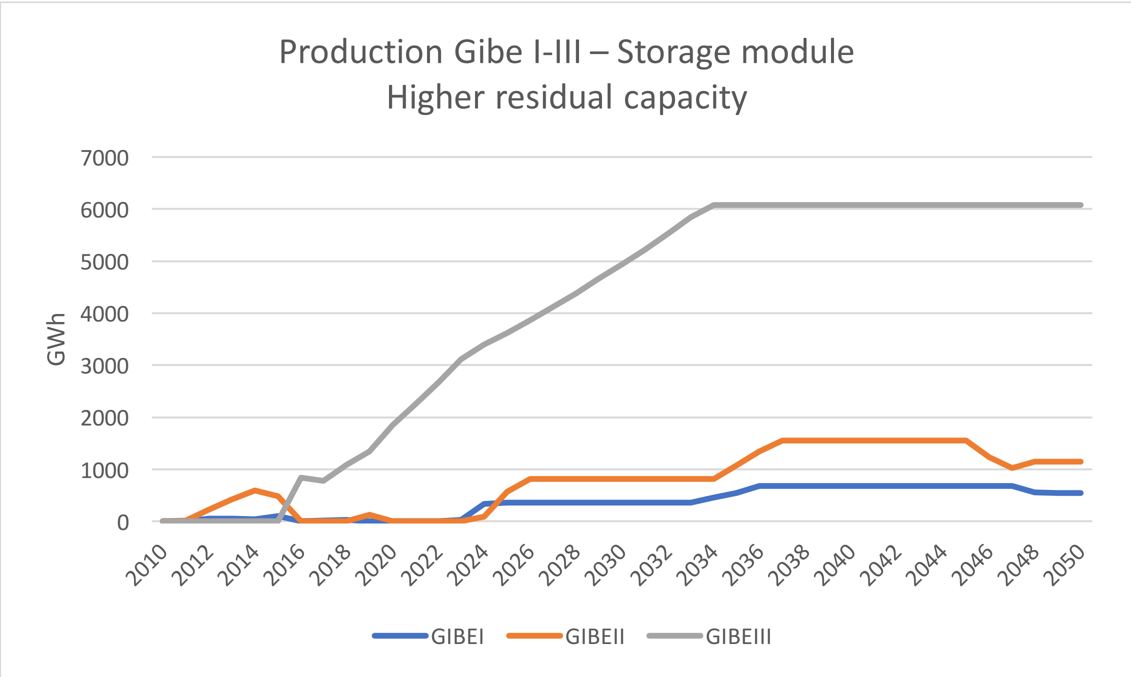
Production in Gibe I-III in the Storage module when one removes the dam for Gibe II, treating it in theory as a run-of-river.



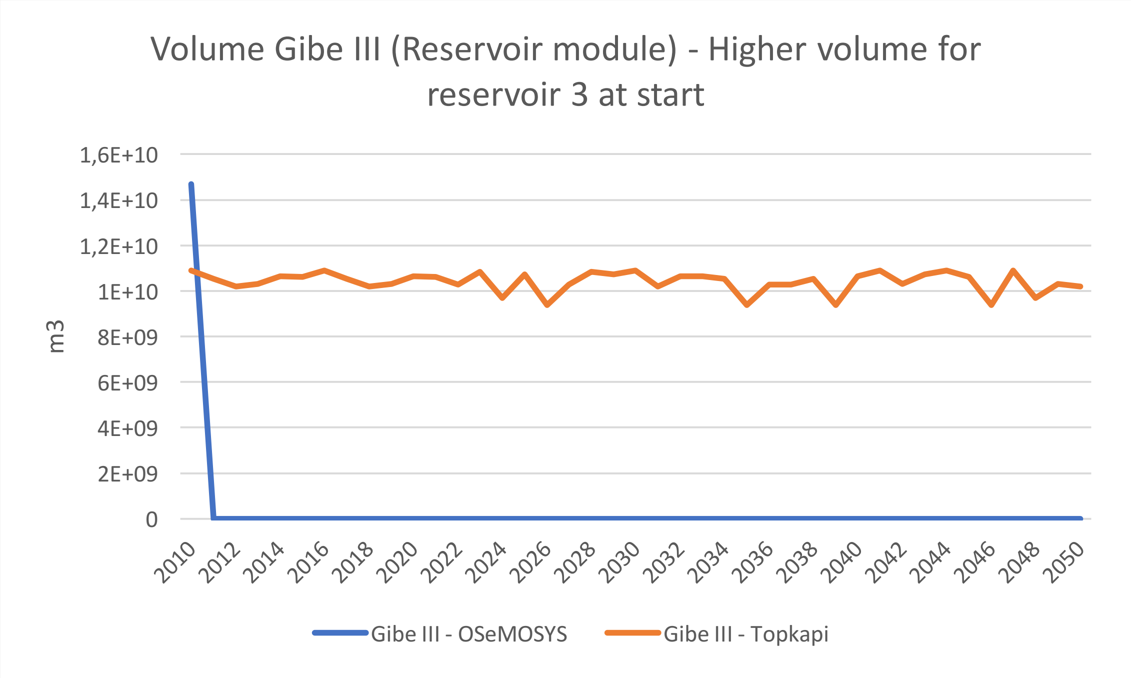
Production in Gibe I-III in the Reservoir module when one removes the reservoir for Gibe II, treating it in theory as a run-of-river.



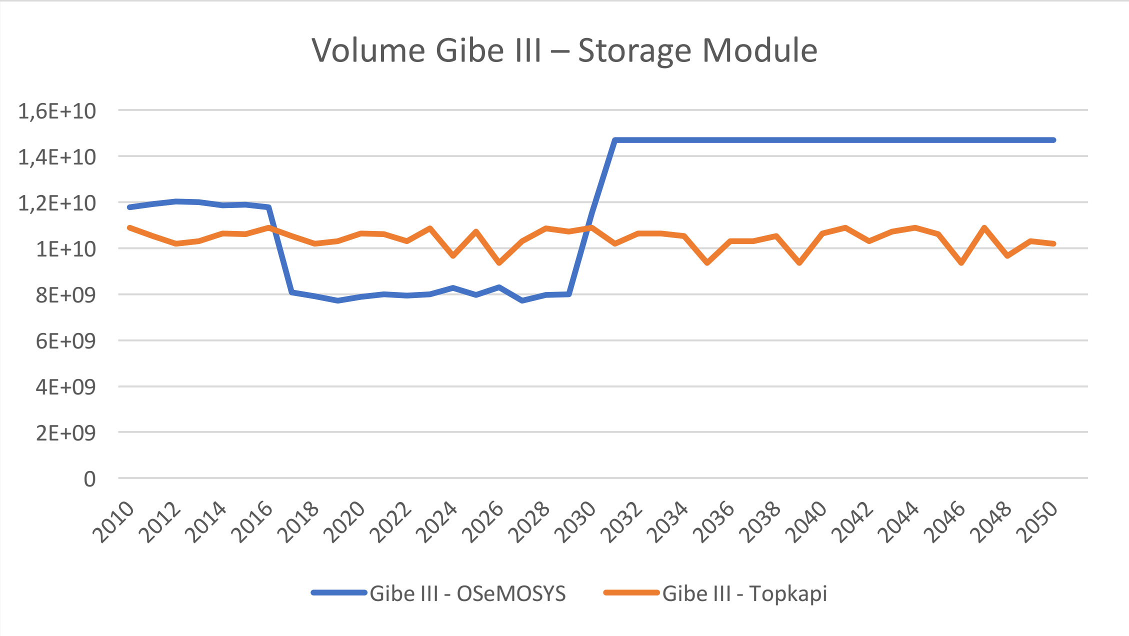
Production in Gibe I-III in the Reservoir module when modelling with a constant head.



Production in Gibe I-III in the Storage module when increasing the residual capacity of the dam and storage, i.e. the forcing of storage availability.

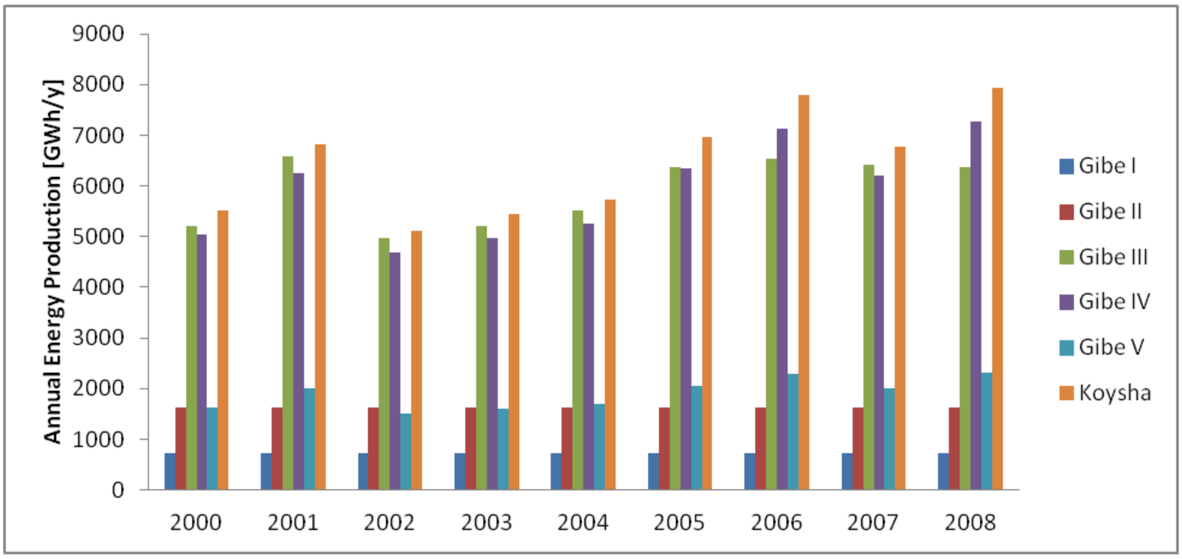


Volume in the reservoir of Gibe III when setting the volume to the maximum possible from start in the Reservoir module.



Volume in the reservoir of Gibe III in the Storage module.

Appendix I – Results from Boulos (2017)



Histogram of computed annual energy production by Boulos (2017) for different power plants. In Boulos study, this is for the no artificial release policy.

Average annual production for different cascade set-ups in Omo River Basin.

Dam cascade set-up	Gibe I-III	Gibe I-V	Gibe I-III & Koysha
Average production [GWH/y]	8,259	16,063	14,715
Average production [PJ/y]	29.73	57.83	52.97

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