Report on the Nexus Humera case study in Ethiopia

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Preface

This report is deliverable D26 of the Dutch Climate Solutions research programme. The programme acts as a platform for the Energy research Centre of the Netherlands (ECN) to support the Netherlands Directorate-General for International Cooperation (DGIS) in the realisation of Dutch policy objectives concerning poverty reduction and sustainable development. Support is delivered through the provision of demand-led, product-driven research and knowledge development. Particular attention is paid to expanding the contribution of Dutch expertise, innovation and technology to international climate assistance.

The main question address within this programme is how to leverage climate and private sector investments for sustainable and climate smart development, for with the consideration of the water-energy-food nexus is key. Accordingly key research questions dealt with are: a) How do we create a sustainable and effective balance in the water, energy and food sectors to achieve the Sustainable Development Goals, in the face of climate change, and b) what is the role and potential of climate finance to bring about transformative change in developing countries?

The program combines mutually reinforcing research and recommendations on the level of multilateral finance architecture, Dutch development aid and the Dutch climate technology sector to propose an integrated approach to support the climate technology sector and explore climate finance mechanisms through which the Dutch water-food-energy sectors can export their Climate Smart Solutions.

The Dutch Climate Solutions programme is funded by the Netherlands Ministry of Foreign Affairs and implemented by a consortium coordinated by the ECN. The consortium comprises the following organisations:

- Energy research Centre of the Netherlands (ECN)
- Deltares
- Stichting DLO, Wageningen UR
- Duisenberg School of Finance (until 1 October 2015).

The Dutch Climate Solutions programme is registered under ECN project number 5.2734.

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Abbreviations

CRGE	Climate Resilient Green Economy
CSA	Central Statistics Agency
ECN	Netherlands Energy Research Centre
GTP	Growth and Transformation Plan
SBN	Sesame Business network
IAIP	Integrated Agro-Industrial Park
LEAP	Long-range Energy Alternatives Planning system
MASL	Metres Above Sea level
Qtl	Quintal (100 kg)
RIBASIM	River Basin Simulation Model
WEF	Water, Energy, Food
WUR	Wageningen University & Research

Summary

The Nexus approach aims to analyse the linkages between the water, energy and food sectors and especially the trade-offs (developing one sector at the expense of the other) and possible synergies (innovative win-wins) between the sectors. The approach aims to break down the walls that so often prompt the relevant ministries and organisations to focus on their mandates and work in isolation from each other. Especially in the light of rapid population growth - as is the case in Ethiopia - and uncertain climate change outcomes is it important to zoom in and interconnect the three fundamental assets of people's livelihoods: water, energy and food.

The approach was applied in Humera woreda in western Tigray in August 2017 to provide insights as to how a nexus approach could work, how possible nexus solutions could be integrated into government programmes and business strategies, and how a contribution could be made to sustainable development of the economy of Humera woreda. The focus of the case study in Humera was the emerging development of a large-scale Agro-industrial Park and its role in potentially boosting sesame production in the area. The latter angle was analysed in close contact with the Sesame Business Network (SBN) project that operates from Humera. A team from Deltares, ECN and Wageningen University joined by SBN staff conducted the case study, and reported its findings in a workshop for stakeholders in Mekelle in December 2017 and to the Royal Dutch Embassy in Addis Ababa.

Applying a nexus approach proved to be very helpful in encouraging sectoral authorities to look beyond their sector boundaries of policy and practice, and think through the implications of the decisions they make. It was acknowledged that these specific sectors of water, energy and food are indeed interrelated. In addition, the case study proved to be a valuable addition to the feasibility study conducted for the Bae'ker Agro-industrial park in which the long term implications of full production on energy, water and food consumption were not included. Different scenarios for 2030 and 2050 were designed and evaluated.

In the case study three different models were applied: the LEAP model for the energy sector, the RIBASIM model for the water sector, and the Water-limited yield model for the agricultural sector. The models were run on the basis of collected data, for different scenarios and based on assumptions that were tested with stakeholders. Generally speaking one can conclude that the planned development of Bae'ker Industrial Park will not jeopardize sustainable development of energy, water and food sectors in Kafta Humera. Resources are also sufficient to allow for the envisaged expansion of the irrigation schemes, and to keep the projected increased population food-secure. Apart from rampant deforestation and the projected depletion of wood resources in

2034 with expected negative implications for water sources, soils and climate, the Nexus analysis did not reveal any other trade-offs to be made between the water, energy and food sectors. The expected shortage of wood (and therefore charcoal) will have to be covered in future by a combination of investments in the forestry sector and related sustainable use of forests, more efficient use of wood and transition to other energy sources such as electricity. This transition is considered to be achievable.

Climate change predictions for Northern Ethiopia show a slight rainfall increase as well as a temperature increase. In addition it is expected that the chances of extreme weather events will increase. This can be extreme rainfall or extreme drought. One of the scenarios simulated therefore was based on 1984 drought conditions. If such conditions reoccur in future, major water shortages can be expected in Kafta Humera. The Tekeze river system is expected to yield too little water to meet all demands from the growing population and industry.

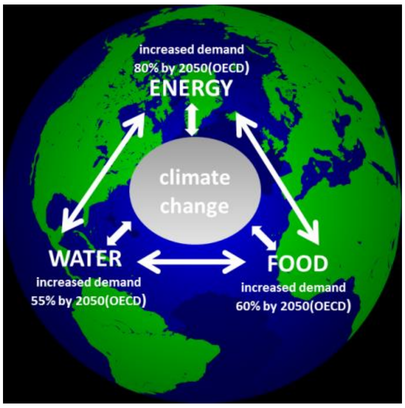
In case of drought like the one of 1984 in which rainfall dropped to 50% of the normal, the agricultural yields would also equally drop 50%. When combined with extreme high temperatures (>40°C) most cereal (food) crops cannot survive. Most likely local food production will not be able to sustain the population and preparation for such extreme events is key. The latter is an important addition. In 1994 Ethiopia was still recovering from turbulent historic events. In 2018, Ethiopia has a stable government and is believed to be capable of managing the impact of droughts.

Overall, the Nexus analysis is good news for the sesame sector that aims to add value to primary production: under average conditions there is sufficient land, water and energy potential in Humera to fully develop a sesame agro-processing industry in the Bae'ker IAIP.

1. Introduction

1.1 Background

According to UN DESA1 the current world population of 7.3 billion is projected to reach 8.5 billion by 2030, 9.7 billion in 2050 and 11.2 billion in 2100. Most of this increase is expected to be concentrated in nine countries: India, Nigeria, Pakistan, the Democratic Republic of Congo, Ethiopia, the United Republic of Tanzania, the United States of America, Indonesia and Uganda. Based on these population trends and on rapid urbanization and rising living standards, it is estimated that by 2050 global energy demand will increase by 80%, water demand by 55% and food demand by 60%2. These trends are placing increasingly competitive demands upon finite natural resources for agriculture, energy and water. The effects of climate change pose an additional challenge, as heavy flooding in coastal areas and severe droughts in more arid regions could further exacerbate this competition and seriously impede economic growth.



So far, energy, food and water challenges have mainly been addressed within the sectors concerned. This has resulted in policies and interventions that focus primarily on individual sectors, rather than considering the broader cross-sectoral impact. This lack of coordination, dialogue and collaboration among sectors can significantly affect the efficiency and effectiveness of policies and may also prevent appropriate measures from being taken. So there is an urgent need to address these challenges simultaneously and develop an integrated approach. Balancing the trade-offs between these sectors will be essential if we are to achieve sustainable development and ensure water, energy and food security by maximising the potential synergies and efficient solutions.

The growing need for integrated resources management thinking is what triggered the development of the Water-Energy-Food (WEF) Nexus concept which stems from system analysis and is centred around the many links that exist between the water, energy and food sectors. Water, for example, is used in agricultural production processes and for cooling the waste heat from power plants; energy is used for irrigation (pumping water), food production processes and

[1] UN DESA: World Population Prospects, the 2015 Revision
[2] OECD Environmental Outlook to 2050: The Consequences of Inaction-Key facts and figures.

power in agricultural machinery and tractors; and palm oil is used for cooking and is a key ingredient in food production, but it is also used to produce biofuel. Taking into account these links while designing policies to ensure long term water-food-energy supply security could result in more development using fewer natural resources.

Nexus and the private sector

The World Economic Forum, a private sector initiative, embraced the concept and argued that there are important links between water, food, energy and climate change. It has since published several books and articles on the issue, with many detailed figures about current and future use of resources and challenges to be faced (see Hoff, 2011). Business drivers for interest in nexus thinking are (Reynolds and Cranston, 2014): business stability (avoid scarcity resources and environmental damage caused by flood, drought, storm etc.), burden of future regulations in the market and reputation. To secure the involvement of the private sector, scale is needed, and investment in natural capital.

Researching the applicability of the Nexus approach in Kafta Humera

To research the usefulness of the Nexus approach one needs a geographical area for testing. The selection of the area was a rather pragmatic process. We needed an area where already contacts existed ('feet on the ground') and where there were possibly issues regarding food, energy and water. Through the BENEFIT programme, Wageningen University and Research has good contacts with ministries and agencies in Ethiopia. One of the components of BENEFIT is the Sesame Business Network (SBN). The staff of the SBN project showed interest in the nexus approach and this study has been conducted jointly. They suggested to focus on the Humera area in Tigray province. The area features extensive sesame production, and an industrial park that will be established to process agricultural products from the area. The establishment of this industrial park is an ambitious project and in combination with a considerable increase of the population in the area, it could have a serious impact on the availability of water, energy and food. This makes the industrial park an interesting focal point for applying a nexus approach.

The case study research has been conducted by institutes from the Netherlands water sector (Deltares), the food sector (Wageningen University and Research) and the Netherlands energy sector (ECN) and is therefore well positioned to investigate the WEF Nexus and to contribute to the debate on long-term water, food and energy supply security challenges. The consortium was joined by the SBN project team to research the Humera case study in August 2017.

1.2 General and specific objectives of the study

General objectives of the case study are:

1. Applying a nexus approach at local or sub-national level by providing insights into how possible nexus solutions can be integrated into government programmes and business strategies.
2. Contribute to the sustainable development and diversification of the economy of the Humera woreda, Ethiopia, by assessing - with stakeholder participation - the trade-offs and synergies between the Agriculture and Food sector at the one hand and the Water and Energy sectors at the other hand in the target area; and propose concrete actions.

Specific objectives are:

1. Assess the sesame value chain and proposals for adding value within Ethiopia, with a focus on the implications for the long-term demand and supply of energy, water and food.
2. Assess future water and energy needs for the urban and rural populations, industrial and agricultural activities.
3. Assess the future food requirements of Humera woreda vis-a-vis the expanding sesame production and required need for water, energy and land.
4. Develop a strategy for sustainable development of the water, energy and food sectors in Humera woreda taken into account the interdependencies between these sectors and the changing weather patterns due to climate change.
5. Propose sustainable options to deliver the needed additional energy and water while securing food for all.

1.3 Description of stakeholders consulted and research methodology

The following groups have been involved in the case study:

- Governmental officials at central level (Addis Ababa)
- Embassy of the Kingdom of the Netherlands in Addis Ababa
- Government at Humera woreda level as well as Tigray State level
- Farmers' organisations and other relevant NGOs
- Research organisations
- Agro-industry in the selected area, if possible Dutch private sector working in selected area
- BENEFIT project and most notably the Sesame Business network (SBN) project staff at national scale and at the level of the selected area
- Projects in the selected area working on water, climate and energy.

Methodology

The work in Ethiopia was executed during three missions to the target area and desk work in the Netherlands:

3. Mission 1: Preparatory mission to the capital of Ethiopia, Addis Ababa, in order to familiarize the Dutch Climate Solution team with the energy, water and food situation in the target area, to collect data and to conduct reconnaissance interviews with representatives of ministries and other stakeholders, including staff of the BENEFIT programme in Ethiopia and The Netherlands;
4. Mission 2: visit to the target area to talk directly to stakeholders and collect relevant information and data.
5. Desk work in the Netherlands to analyse the situation, to identify the trade-offs and possible synergies and to assess possibilities for climate funding of proposed activities. Develop (simplified) business cases to show the benefits and costs and how the solution could be financed.
6. Mission 3: Capacity building and consultation workshop with stakeholders:
    a. Presentation of the results of the first field mission and the desk analysis. A validation and feedback workshop was organised in Mekelle on the 6th of December, 2017. In attendance were staff from Tigray State Government, government departments at Humera Woreda level and from the SBN Project;
    b. Discussion and adaptation of the models that were developed for the three sectors, adapt them to local needs and realities;
    c. Presentation of a simulation game to the stakeholders; and
    d. Discussion of results with the Royal Netherlands Embassy in Addis Ababa.
7. Preparation of final report.

Development of demand and supply scenarios for 2030 and 2050

The Nexus approach aims at analysing the linkages, the trade-offs and possible synergies between the Water, Energy and Food sectors as explained above. For natural resource analysis and policy development it is relevant to do so for today but especially for the future. This section aims to map out the demand and supply of water, energy and food for 2030 and 2050 respectively. Because it is impossible to predict the future we described four different scenarios:

0. The base line situation (current status of WEF use and production) in Kafta Humera
1. The **reference scenario** in 2030 and 2050. This scenario includes the development of Bae'ker Integrated Agro-Industrial Park (IAIP), the projected population growth based on 2007[3] urban and rural population growth percentages, all policies such as the Growth and Transformation Plan II and the Climate Resilient Green Economy implemented as planned, the planned 20.000 ha irrigation schemes in the woreda, and the ongoing deforestation.
2. The "**expanded irrigation scenario**" in 2030/50. This scenario builds upon the reference scenario but includes an additional 200.000 ha of irrigation to boost agricultural production in the region.
3. The "**Nexus policy Strategy**" for 2030/50. For this scenario we have included typical nexus policy measures such as a 100 MW solar power plant at Bae'ker, use of efficient cook stoves, afforestation, solar powered irrigation, biofuel production, the construction of a multi-purpose[4] water reservoir in the Tekeze River. These options are ideas that are not yet part of existing policies. A possible strategy is presented in section 3.5.
4. An "**Extreme drought scenario**", analysing extreme climatic impact" (assuming another 1984 drought as part of the above 3 scenarios)[5].

[3] The data from the 2017 population census were not out at the time of writing this report.

[4] Multi-purpose means storing water for generating electricity, for irrigation and drinking water supply.

[5] Research in Ethiopia showed that droughts are likely to occur again, but this time it will probably not lead to a famine as in 1984. Ethiopia has been very active on matters such as reforestation and soil and water conservation. The land is now much less vulnerable for the occurrence of droughts. Source: Sil Lanckriet, Amaury Frankl, Enyew Adgo, Piet Termonia, and Jan Nyssen. Droughts related to quasi-global oscillations: a diagnostic teleconnection analysis in North Ethiopia. International Journal of Climatology, 2014.

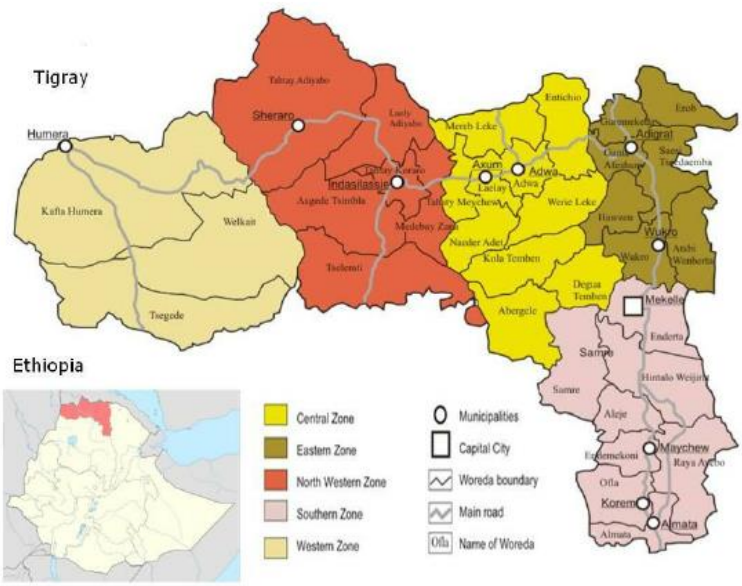
2. Description of the case study area

2.1 Brief physical and social description of Humera woreda

Location, climate and population data

Kafta Humera (district or woreda) is located in north-western Ethiopia, in the western part of Tigray Regional State, 991 km away from Addis Ababa. Kafta Humera borders the woredas Tsegede and Wolkayte in the south (together they form Tigray western Zone) and with Sudan in the west (see map). In the north, the Tekeze River (a tributary of the Nile) separates the district from Eritrea. The district administrative centre is Humera town (Setit). The altitude range is 560-1849 m.a.s.l. The district covers an area of around 7000 Km2. The area is part of a semi-arid agro-climatic zone. The geological classifications of the district are mainly early tertiary volcanic and Pre-Cambrian rocks. The dominant soil types are Chromic Eutric and Calcic Combisols; Chromic and Orthic Luvisols and Chromic and Pellic Vertisols (EMA, 1988). The vegetation communities in the districts include Acacia-Commiphora, Combretum-Terminalia and dry evergreen woodlands (Eshete et al., 2011).

Figure 1 Map of Kafta Humera in Tigray State



Rainfall in the study area is generally characterized by low inter annual and seasonal variability. The mean of rainfall is 540.6 and varies from 357.8mm and 650mm minimum and maximum respectively. The median rainfall of the study area is 549.5mm annually and the coefficient of variation of the annual rainfall was low (16.7 %) implying limited variability of rainfall. On average the main rainy season (June –September) contributes 85% to the annual rainfall totals.

These figures are contradicted by other reports. The June 2015 "Agronomy Feasibility Report of Tekeze Humera pump irrigation" report (page 4) for example states that data from the metrological station located in Humera town show sixteen years (1996-2011) of annual rainfall with an average of 1052.04mm. The SBN project estimates rainfall figures between 600 (min.) and 1000 mm (max) per annum. The mean minimum temperature ranges between 17.5^{0}C and 22.2^{0}C, while, the mean maximum temperature varies between 33 and 41.7 ^{0} Celsius. Mean monthly evapotranspiration rate of the study area ranged between 141.6 in December and 200.7 mm/month in April. Source: Awetahegn Niguse et al (2015, page 24 – 26).

Population in the district has increased from 48,690 in 1994 to 92,144 in 2007 meaning a population growth rate of 3.6% per year. According to CSA (1994, 2007), the majority of the people (about 67%) are living in rural areas while about 33% are urban inhabitants. With these 2007 census figures the population density of the district is 14.56/km^2, which is less than the zone average of 28.9 and the national average 77.72. A total of 23,449 households were counted in this district and the average household size was estimated to be 3.93 persons. The "food security and vulnerability study in selected towns in Tigray (WFP, 2009) found an average household size to be 4.5. Tessema (p. 28) measured the average household size in Humera in 2007 as 4.2. Nega et al (2010) measured an average household size for Humera (rural) of 4.72; and 4.98 for Humera Town. For the analysis in this report it is proposed to stick to an average household size of 4.5. Population growth was partly caused by natural growth but especially the result of resettlement programmes over the past 30 years by government offering land to farmers originating from the highlands.

Current population figures are not available (2017). The last population census is from 2007; the 2017 census has been conducted but confirmed figures will only be available in mid-2018. We therefore estimate population figures for 2017, 2030 and 2050 by extrapolating the figures from the 2007 census. The numbers are in the table 1a and table 1b below. The population numbers in Humera woreda are expected to triple between 2017 and 2050.

Table 1a Estimated population increase Humera in 2030 and 2050 using geometric method (Sources: CSA 2007 Population census; Federal Democratic Republic of Ethiopia (August 2013))

	2017			2030			2050		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Kafta Humera	68,574	50,321	118,895	71,112	91,049	162,161	75,202	226,711	301,913
Humera Town		36,074	36,074		65,271	65,271		162,524	162,524
Total			154,969			227,433			464,437

Table 1b Tigray population growth rate percentage based on CSA population projections 2008-2037

Urban	4.667
Rural	0.28

Land use and farming systems in Humera
The land use system is characterized by a mixed farming system dominated by arable farming; and this includes cereals (31.24%), pulses (5.94%), oilseeds, predominantly sesame (60.87%) and vegetables (1.95%). The economy of the district is centred on the production of sesame, cotton and sorghum. Many farmers (69%) are practicing a mix of cereal-livestock farming, while 28% cultivates annual crops and 3% livestock rearing. Regarding land ownership and land distribution/holding about 75% of farmers possesses own land (meaning state leasehold), 25% is renting (CSA, 2007).

"Land ownership" is mixed. One can largely differentiate between "investor farmers" and "small-scale farmers". In Humera over 500 large scale investor farmers cultivate lands over 50 hectares, some even over 600 hectares of sesame, while small scale farmers cultivate up to 3 hectares/household. It is estimated that in the district, investors cultivate 58% of the cultivated land while local farmers use the remaining 42% (KHDLR, 2007).

The average land size per farming household in Humera is 6,23 Tsimad (around 1.5 hectare). The average land size is relatively big for Ethiopian standards because part of western Tigray was used as resettlement area in 2002/2003, and farmers were allocated 2 hectares per household (Abay, 2005; Tessema, 2007). In the whole of Tigray region every household possesses around two plots of land. In Kafta Humera however the average is 1.15 as indicated in the 2011 Tigray Baseline Socioeconomic Survey.

“Big” land sizes, low population density and agricultural potential of the area explain why the three woredas (Kafta-Humera, Welkayte and Tsegede) in western Tigray are (in 2009) the only ones out of 34 in the region that are food secure (WPF/VAM, 2009).

The main land use categories of Kafta Humera, and changes over a 25 year period, are below in table 2 (Binyam, 2012).

Table 2 Areas of Land use and land change of Kafta Humera District for the Years 1985, 1995 and 2010

Land Use and land cover	1985 Area (ha)	(%)	1995 Area (ha)	(%)	2010 Area (ha)	(%)
Agricultural land	148,772.34	23.51	178,640.37	28.23	247,509	39.11
Bare land	27,832.68	4.40	28,433.61	4.49	33,796.62	5.34
Wood land	266,879.88	42.17	225,538.11	35.64	162,973.26	25.75
Shrub land	96,540.03	15.25	108,364.5	17.12	107,579.07	17.00
Grass land	92,158.29	14.56	914,09.94	14.44	80,667.99	12.75
Water body	694.53	0.11	491.22	0.08	351.81	0.06

The most conspicuous trend is that agricultural land has expanded (+15.5% of total Humera land area) while woodland has decreased with 16.4%. Table 3 shows that these trends have increased after 1995.

Table 3 Rate of Changes in land use (1985-2010)

	1985 to 1995		1995 to 2010	
	ha/year	% per year	ha/year	% per year
Agricultural land	2986.80	2.01	4591.24	2.57
Bare land	60.09	0.22	357.53	1.26
Wood land	-4134.18	-1.55	-4170.99	-1.85
Shrub land	1182.45	1.22	-52.36	-0.05
Grass land	-74.84	-0.08	-716.13	-0.78
Water body	-20.33	-2.93	-9.29	-1.89

The current land use is estimated as follows in table 4:

Table 4 The current land use (Source: 2013 baseline survey conducted by the SBN project)

	2013 SBN baseline figures		Kafta Humera
1	Cultivated land	Ha	388,880
2	Forest land	Ha	240,000
3	Grazing land	Ha	36,800
4	Gdmagdmi	Ha	28,142
5	Wasteland	Ha	23,830
	Total	Ha	717,652

The same SBN Project base-line survey estimates the total arable land availability at 396,852 hectares meaning that the future agricultural expansion potential in the woreda is limited.

Deforestation

Northern Ethiopia in general and the Tigray Region in particular, is facing a severe woody biomass shortage. An investigation of the fuel supply and demand behaviour of farm households in rural Tigray showed that biomass fuels, especially woody biomass and dung cover about 96% of the total fuel consumption in the Region. The daily per capita energy consumption was estimated around 2kg in Humera by Tessema, 2007. Zenebe Gebreegziabher (WUR PhD thesis, 2007) calculated the following figures for Tigray:

- For rural households - Wood: 625 kg/yr/hsh and Charcoal: 2 kg/yr/hsh
- For urban households - Wood: 1883 kg/yr/hsh and Charcoal: 542 kg/yr/hsh.

The latter figures are used in the models presented below. Nearly all the households and small business (restaurants, coffee shops, small scale agro-processing) in Humera (Kafta and Setit) use firewood, charcoal or dung as fuel. Converting forest land in agricultural land and sourcing firewood goes hand in hand (Binyam, 2012, p. 77-78).

In Kafta Humera satellite imagery in 2000 (before resettlement) and 2007 (after resettlement) was used to measure the degree of change in land use and cover related to settlement. The results of this analysis showed a decrease in woodland by 25.8% and an increased in arable land by 21.8%, and in 2011 after ten years arable land increased almost by 100%, woody vegetation cover reduced by 42% (Moti et al., 2011).

The figures from the various sources are not completely consistent. However the trend is clear: there is expansion of agricultural land at the expense of woodland. This is summarized in table 5 which shows that in 2013 240,000 ha of woodland was left in Kafta Humera.

Table 5 Summary of Deforestation and annual change in Kafta Humera (Source: Binyam (2012), SBN project Baseline Survey 2013)

	1985	1995	% /year	2010	%/year	2013
Woodland	266879	225538	-1.55	162973	-1.85	
Shrubland	96540	108364	1.22	107579	-0.05	
Total	363419	333902		270552		240000

Livestock production system

Next to crop production also animal rearing is a main income generating system. Cattle population in the study area is currently estimated to be 51,369 heads. Goat population is estimated to be 19,245; sheep population 11,152, and equine (only donkey) 5083 heads. The major feed resource in the area is forage obtained from the rangelands. Almost the total area of the Kafta-Humera woreda excluding the cultivated land by commercial and smallholder farmers is rangeland. It covers about 43% of the total land of the woreda. Crop residues from sesame, sorghum and others are also a good source of animal feed (Kidane, 2011).

Table 6 Summary of Deforestation and annual change in Kafta Humera (Source: Binyam (2012), SBN project Baseline Survey 2013)

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2.2 Projected climate change

This section draws upon two sources: the 2015 MER report on Ethiopia's Climate Change Profile, and the Government of Ethiopia's strategy paper on Climate Resilient Green Economy.

Climate change projections are impossible to generalise for the whole country that consists of very diverse agro-ecological zones. Still, generally speaking the country is expected to face increasingly unpredictable rains, and increased variability of seasons. The lowlands are vulnerable to increased temperatures and prolonged droughts which may affect livestock rearing. The highlands may suffer from more intense and irregular rainfall, leading to erosion, which together with higher temperatures leads to lower total agricultural production. This, combined with an increasing population, may lead to greater food insecurity in some areas.

In Humera the average temperature is expected to increase with 1 degree in 2030 and another degree in 2050; rainfall will increase slightly but especially rainfall variability and seasonal variability are likely to change. This makes rainfall less predictable, and means higher chances of heavy precipitation during the rainy season, and can lead to extreme events (flooding, storms, dry spells) (MER report, page 4). For Humera this could mean that fragile crops such as sesame can be seriously affected, and that extreme rainfall or extreme drought can lead to soil erosion especially after concluding that deforestation in the Humera area is very serious.

Extreme events are estimated to reduce total GDP by 1% to 4%. Soil erosion has been estimated to reduce agricultural GDP by 2% to 3% (around 1% of total GDP) (CRGE, page 5).
The above climate change projections are included in all scenarios that are presented in this study.

2.3 Current water, energy, food/land policy environment

There are a number of policy documents that are relevant for the Humera Nexus case study:

Second Growth and Transformation Plan (GTP II) 2015/16-2019/20
In general, during the period of the second Growth and Transformation Plan on Agriculture, objectives are set to further enhance the benefit of citizens that would receive from the fast and sustained growth, ensure structural transformation within the sector and across the overall economy and build agricultural production capacity. The major agriculture and rural transformation targets of GTP II are broadly set in terms of increasing crop and livestock production and productivity, promoting natural resource conservation and utilization, ensuring food security and disaster prevention and preparedness:

1. Increasing Crop Productivity and Production: the crop subsector constitutes the major share of agricultural GDP. Accordingly, increasing the production and productivity of major crops will continue to be a priority in the next five years so as to maintain the fast and sustained growth achieved during the last decade. In this regard, improving the supply and application of agricultural inputs and effectiveness of agricultural extension services will be given due priority. Establishing effective agricultural marketing systems through forming and strengthening cooperatives will also be an important priority area. The participation of the private sector in this endeavour will be encouraged and supported as well.
2. Increasing Livestock Productivity and Production: The productivity of the livestock sub sector has been at its low during the implementation of the first Growth and Transformation Plan (2010/11-2014/15). Special emphasis will be given to the livestock subsector with the objective of adequately exploiting its potential for growth, export earnings and job creation. The strategies set to realize these objectives are: improving animal health, animal feed and animal breed with targets to increase the productivity of meat, milk, honey and eggs.
3. Natural Resource Conservation and Utilization: During the first Growth and Transformation plan, remarkable achievements have been made in terms of natural resource conservation and utilization. Hence, scaling-up this strategy will be a priority. In this regard, expanding small-scale irrigation in tandem with natural resource conservation to increase agricultural productivity and production would help enhance the economic contribution of natural resources.
4. Food security, disaster prevention and preparedness: The governments is committed to ensuring food security and strengthen the capacity of disaster prevention and preparedness by increasing agricultural productivity and production and implementing other safety net and risk reduction programs.

As part of the *Growth and Transformation Plan (GTP),* the Ministry of Industry and Ministry of Agriculture planned to establish 4 Integrated Agro-Industrial Parks (IAIPs) in the near future. One of them is located in Humera woreda (35 km south of Humera Town), in Bae'ker. The objectives of establishing this park is to boost agricultural business development, to attract private investment in food processing and create jobs and rapid rural economic growth (Federal Democratic Republic of Ethiopia, 2015, page 3). The production area expected to supply the IAIP with raw material covers not only Humera but the entire Western and North-western Tigray sub-regions.

GTP II also promote irrigation to ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

In GTP II efforts will be made to increase **forest contribution** to the economy and ecology, through sustainable forest development and conservation activities. More specifically through initiating the identification, demarcation, registration and protection of forest resources and also undertaking research-based forestry development.

Water in GTP II

With regard to water and sanitation, according to the GTP I standard, it is planned to increase access to clean water from 84% in 2014/15 to 100% at national level during GTP II period. On the other hand, rural water supply coverage (GTP II standard of 25 l/c/d within 1km radius) will increase from 59% in 2014/15 to 85% by 2019/20. Similarly, urban water supply (based on the ranking of the demand: 100, 80, 60 , 50 and 40 litres/person /day from first to fifth level towns, respectively) access to clean water is planned to increase from 51% to 75%.

Accordingly, national water supply coverage is planned to increase from 58% to 83% in the same period. In addition, dysfunctional rural water supply systems will be reduced from 11.2% to 7% and Urban Fault Waters (UFW) is planned to decrease from 39% to 20% in the plan period. Ground water exploration coverage will increase from 13% to 25% during the same period.

The Climate Resilient Green Economy (CRGE)

The CRGE vision is a zero net carbon economy by 2025, and the ambition is to generate all electricity from renewable energy resources with up to 20% wind and solar, 10% geothermal and 70% hydropower.

The *Green Economy (GE) Strategy* sets out the plans for developing a low carbon economy in Ethiopia. Detailed analysis showed that GHG emissions in Ethiopia would rise from 150 MtCO2e per year in 2010 to 400 MtCO_2e in 2030 under a conventional development path ('business as usual' scenario). The GE Strategy identified and prioritised more than 60 initiatives, which together enable the country to achieve the development goals while limiting GHG emissions in 2030 to today's levels. These initiatives would save 250 MtCO_2e per year with around 90% of low-carbon development opportunities coming from the Agriculture and Forestry sectors. For more than 80% of the options, the 'abatement cost' was less than $15 t/$CO_2$e. These options can be seen as 'no and low regrets' offering positive return on investments and therefore directly enhancing economic growth. Continued planning and implementation will make Ethiopia's middle-income economy carbon neutral.

The GE Strategy is built on four pillars, these are:

1. Improving crop and livestock production practices for higher food security and farmer income while reducing emissions (agricultural and land use efficiency measures).
2. Protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks (increased GHG sequestration in forestry).
3. Expanding electricity generation from renewable sources of energy for domestic and regional markets.
4. Leapfrogging to modern and energy-efficient technologies in transport, industry, and buildings (CRGE, page 10).

3. Analysis of the Nexus elements and development of integrated strategies for sustainable development of the region

3.1 The sesame value chain

3.1.1 Sesame production in Kafta Humera

Kafta Humera is a prime sesame production area in Ethiopia[6]. Around 30% of the national production originates from Humera. The cash crop is produced during the rainy season (June-October) and is predominantly (95%) exported in raw form to China, Israel, Turkey and USA.

The main end products in these countries are sesame oil and tahini. Production is done partly by smallholders - around 25.000 households (Hagose, 2017, p.3) - and around 500 investor farmers. The latter own (read: lease from the State at soft terms) land ranging from 50 - >600 hectares. Smallholders typically own less than 3 hectares. Yield levels are relatively low with an average of 559 KG/hectare (see table 7):

[6] Information in this section is obtained from the SBN Project.

Table 7 Sesame production in Kafta Humera 2007-2016 (Source: SBN Project)

Year	Cultivated land (ha)	Total production in qtl.	Productivity per hectare in qtl
2007	203,270.00	998,071.00	4.91
2008	223,918.00	1,403,548.00	6.27
2009	226,788.00	1,428,956.00	6.30
2010	264,657.00	2,143,722,00	8.10
2011	253,099.00	1,792,110.00	7.08
2012	248,068.50	881,553.00	3.55
2013	217,094.25	1,160,038.00	5.34
2014	240,324.00	962,087.00	4.00
2015	180,369.00	667,636.00	3.70
2016	205,113.00	1,355,192.00	6.61
Average	226,270.08	1,279,291.30	5.59

*Note: 1 quintal – qtl = 100 kg

Reasons for low production are manifold:

1. Sesame is a crop sensitive to weather conditions (water logging, droughts, winds during harvesting). Two out of 5 harvests are considered reasonable, mainly due to favourable weather;
2. Poor agronomic practices (little rotation practiced, poor pest&disease control, poor fertilizer regimes);
3. Use of poor seed varieties;
4. Little mechanization, and poor harvesting practice and storage resulting in high post-harvest losses (sometimes 30%);
5. Poor market infrastructure and low market prices for farmers due to a range of reasons such as poor farmer organisation, power of traders and brokers, poor financial position of farmers forcing them to see when prices are low, etc.; and
6. Absence of sesame processing facilities in the region keep prices low and do not provide an incentive for investments in farmers in order to increase production.

The economic loss of low yields is substantial. With a potential to double the yield to 1.2 ton/ha and a price of 40,000 ETB/ton, this loss may amount to 127,929x30,000= 5.1 billion ETB (117 million Euro).

3.1.2 The IAIP in Bae'ker and its consequences for water, sesame and population

As part of the Growth and Transformation Plan (GTP), the Ministry of Industry and Ministry of Agriculture has started with the construction of Bae'ker Integrated Agro-Industrial park (IAIP) 35 kms south of Humera Town. The objectives of establishing this park is to boost agricultural business development, to attract private investment in food processing and create jobs and rapid rural economic growth. The production area expected to supply the IAIP with raw material covers not only Humera but the entire Western and North-western Tigray sub-regions. However, impact will be biggest in Humera: the demand for water; the demand for energy, the influx of labour, and the increased demand for raw material (sesame, sorghum, fruits and vegetables, honey, dairy, meat and other animal products) that necessitates an increase of production as and when the IAIP of 150 hectares big is in full operation in 2026.

Projected water requirements (predominantly from ground water and tapping it from a nearby seasonal stream): 6,777 cum/day. (IAIP Feasibility report, 2015, page 159). Projected power demand: 45.47 MVA (taken from the power station in Humera). (IAIP Feasibility report, 2015, page 166).

The production requirements for the IAIP to become in full operation are substantial especially for sesame, the main crop in the region (IAIP Feasibility report, p. 121). See table 8 which gives figures for Humera woreda and for West Tigray, which contains apart from Humera, two other woredas.

Table 8 Production of main agricultural products in MPTA in Humera woreda and West Tigray (3 woredas) (Source: IAIP Feasibility Report, 2015; production figures from the Agricultural Bureau, Humera)

	2015 Production		2016 Production		Required by IAIP
	Humera	West Tigray	Humera	West Tigray	
Sorghum	451,287	662,988	461,377	659,987	61,602
Sesame	66,763	98,598	135,519	178,132	245,645

* Note: MTPA = Metric Tonnes per Annum

With an average yield level of sesame of 559 kg/ha and an average annual production of 127.929 tons over the past 10 years it means that the amount of land under sesame in western Tigray and most likely in Humera has to double to meet IAIP demand. This does not seem to be a wise option: suitable land is not available anymore; increased sesame production will be at the expense of food production, and deforestation will be enormous with negative impact on soils and climate.

Increased production to meet IAIP demand has to come from improved production technology (such as irrigation, mechanisation, disease control, fertilisation, improve agronomic practices) in the sesame sector resulting in a doubling of yields.

The IAIP is projected to provide employment for 779.000 people (IAIP Feasibility report, 2015, page 343). This staggering amount does not only include people directly employed in the industrial park (109.000) but also those employed in the surrounding rural areas (a radius of 30 km) that produce the raw material (410.000). It is assumed that this number includes the seasonal labour force that annually comes from the highlands to assist in growing sesame. The estimated indirect employment (260.000) is generated in primary, secondary and tertiary sectors including banks, logistics, insurance, trading, brokerage, etc.

Table 9 Projected employment at Bae'ker IAIP in 2026 (Source: Bae'ker IAIP Feasibility study (undated/not published)

	Persons employed	Assumed external origin
Direct employment at IAIP	109,147	54,574
Employment generated at RDC level	4,617	2,309
Additional employment generated in the Agro Commodities Procurement Zone (ACPZ)	405,774	202,887
Total estimated direct employment	519,538	259,769
Estimated indirect employment	259,769	129,885
Total estimated employment	779,307	389,654

* Note: an assumed 25% of projected employment comes from beyond West Tigray – to be added to projected population growth of the zone in 2030 and 2050.

Our assumption is that 50% of these projected employment numbers (400.000) originate from Kafta Humera. 25% (200.000) are assumed to be seasonal labourers who will only marginally affect water and energy consumption. 25% (200.000) of the employees are expected to migrate into Humera and take up residency. This number has added to the projected population growth in 2030 and 2050 which therefore will change as follows:

Table 10 Estimated population increase due to Bae'ker IAIP influx

	2017			2030			2050		
	Rural	Urban	Total	Rural	Urban	Total	Rural	Urban	Total
Kafta Humera	68,574	50,321	118,895	71,112	291,049	362,161	75,202	426,711	501,913
Humera		36,074	36,074		65,271	65,271		162,524	162,524
Total			154,969			427,433			664,437

These figures show that when we include an expected influx of employees to work at Bae'ker IAIP, the population numbers in Humera woreda are expected to quadruple between 2017 and 2050.

3.2 The water sector – the Tezeke river basin in kafta Humera sub catchment

The total annual volume of water flowing from the Tekeze basin is about 7.36 million m^3 with a peak flow rate in July and August. However, due to topographic positions, it has been challenging to use a substantial amount of this volume of water. The streambed is 20 - 100m below the potential arable land; consequently, the river water has been inaccessible unless an expensive water lifting mechanism is introduced.

Additionally, due to seasonal inflow variation from the tributaries of Tekeze, the river has a minimal flow rate during the remaining period of the year (September – June)[7]. Despite these challenges, Tekeze river basin has the potential to provide a sufficient amount of water for different purposes.

The current water demand in Humera is mostly covered by ground water, although the potential has not been thoroughly prospected. This potential is believed to be very limited. To some extent, water for Humera area is drawn from the Tekeze River and distributed in bags on donkeys. However, the water from these surface sources is heavily contaminated with resulting health issues. A supply of clean drinking water for Humera and its nearby farms would do much to improve general health[8].

3.2.1 Assessment of current water demand – the baseline situation

Domestic water supply for Kafta Humera and Humera town is mostly provided from ground water. On the other hand, the irrigation water demand for the 2000ha pilot irrigation area in Kafta Humera is supplied from Tekeze River. Based on the current urban and rural population in Kafta Humera and Humera town, the total water demand is computed and presented in Table 11 and Table 12 respectively. 20 l/cap/day for urban and 16 l/cap/day[9] for rural areas are considered to estimate the total demand[10]. DMI (Domestic Municipal and Industrial) demand incorporates all the demand in the urban setting. Referring to the project report of Humera and nearby towns' water supply detail design main report, other urban demand is also included.

Table 11 Kafta Humera current (2017) water demand and supply analysis using RIBASIM

Kafta Humera	2017
Rural Population	68574
Urban Population	50321
Rural demand (m^3/day)	1156
Urban demand (m^3/day)	1007
Total Population demand water supply (m^3/day)	2163
Other Urban demand (m^3/day)	3854
Total demand (m^3/day)	6017
Water supply GW (m^3/day)	6017
Drinking Water Supply Deficit (m3/day)	**0.00**
Irrigation (ha)	2000
Irrigation (m^3/ha)	6000
Irrigation from Tekeze (m^3)	**12,000,000**

7 http://www.iwmi.cgiar.org/assessment/files/pdf/publications/WorkshopPapers/DesignPerformance_Ka-hsay.pdf

8 http://documents.banquemondiale.org/curated/fr/115661468275709895/pdf/multi-page.pdf

9 We note that GTP II mentions a planned 25 litre per person per day but we decided to keep our estimated consumption low.

10 file:///D:/Project/Collaborative%20modelling/120987004/Mission%20doc/Urban%20Water%20Supply%20Universal%20Access%20Plan.pdf

Table 12 Humera Town current (2017) water demand and supply analysis

Humera Town	2017
Urban Population	36074
Urban demand (m^3/day)	721
Other demand (m^3/day)	518
Total demand (m^3/day)	1239
Water supply GW (m^3/day)	**1239**
Deficit (m^3)	**0.00**

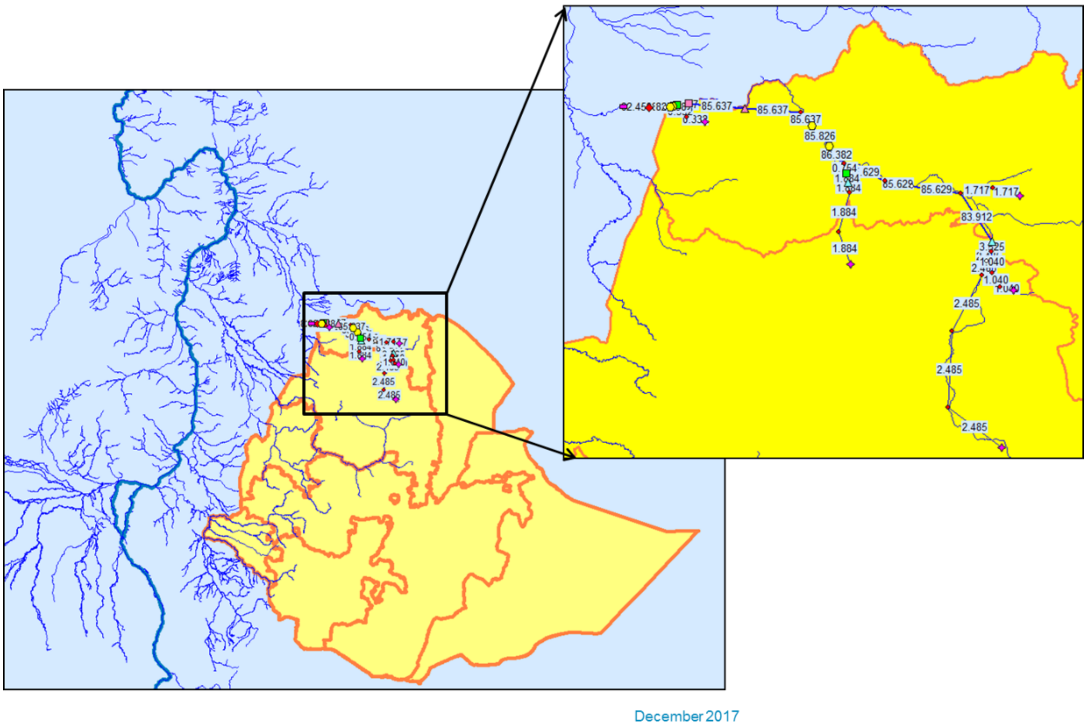
3.2.2 Water demand scenarios for 2030 and 2050

In order to fully analyse and investigate the availability of water in Kafta Humera, various scenarios are considered (see chapter 1): the reference scenario for both 2030 & 2050, the expanded irrigation scenario, the Nexus policy strategy measures and Extreme drought scenario. The reference scenario and expanded irrigation scenario are first investigated by only looking at the available ground water resources in the area. As the results show significant deficits, the Nexus policy measures are applied for each of these scenarios and simulated in the RIBASIM model using the hydrological conditions of Tekeze River Basin. The Tekeze river basin is part of the existing regional model (Nile Basin Model); also this model is built on RIBASIM[11].

All the existing demands and proposed demands are included in the model in Figure 2.

[11] RIBASIM (River Basin Simulation Model) is a generic model package developed by Deltares for analysing the behaviour of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. For more information: https://www.deltares.nl/en/software/ribasim/

Figure 2 RIBASIM model schematization of Tekeze river basin in Western Tigray



The reference scenario

Element 1: A scenario based on the geometric population projections 2030, 20,000 ha irrigated area and including the industrial park permanent 200,000 employee settling in Kafta Humera.

Element 2: A scenario based on the geometric population projections 2050, 20,000 ha irrigated area and including the industrial park permanent 200,000 employee settling in Kafta Humera.

There are three important assumptions made:

1. We assume that the water needs of current population and current developments in Humera are covered by ground water supplies, and that these supplies are recharged annually.
2. We take along the assumption from the Bae'ker Feasibility study that the water demand by Bae'ker IAIP is also covered by ground water.
3. We assume that current ground water extraction is at its maximum. In the absence of ground water studies we cannot assume otherwise. To conduct a ground water study in Humera would be a wise investment considering the planned developments, and expected population growth

The additional demand due to population growth and various developments in 2030 and 2050 will be added to the total demand of the respective year. The demand that exceeds the ground water supply is considered as the deficit. Tables 13, 14 and 15 show the calculated demand, supply and deficit for Kafta Humera, Bae'ker industrial park and Humera Town.

In 2030, the industrial park becomes fully functional, and 20,000ha of irrigation will be used for agricultural production with 600mm of water as crop water requirement in a 3 month of growing season. For Kafta Humera, domestic drinking water and irrigation water demands are included. The resulting demand, supply and deficit is presented in Table 13.

Table 13 Kafta Humera water demand, supply and deficit in 2030 & 2050

Kafta Humera	2030	2050
Rural Population	71112	75202
Urban Population	91049	226711
Rural demand (m^3/day)	1199	1268
Urban demand (m^3/day)	1821	4534
Total Population demand water supply (m^3/day)	3019	5081
Other Urban demand (m^3/day)	7518	17635
Total demand (m^3/day)	10537	40351
Water supply GW (m^3/day)	6017	6017
Drinking Water Supply Deficit (m^3/day)	**4521**	**34334**
irrigation (ha)	20,000	20,000
irrigation (m^3/ha)	6000	6000
Deficit for Irrigation (m^3)	**120,000,000**	**120,000,000**

According to the feasibility study, all demand from the industry (6777 m^3/d) is planned to be fully supplied from ground water source. Assuming there is a sustainable ground water supply, the only water deficit will be the demand that is from the extra 200,000 permanent employees coming outside the region. 20 l/cap/day is used to compute the demand of the permanent employees. The resulting water demand, supply and deficit is presented in Table 14.

Table 14 Bae'ker industrial park water demand, supply and deficit in 2030 & 2050

Bae'ker industrial park	2030	2050
Demand (m^3/day) of the industry	6777	6777
External employees	200000	200000
Demand (m^3/day) from external employees	4000	4000
Total demand (m^3/day)	10777	10777
Water supply GW (m^3/day)	6777	6777
Deficit (m^3/day)	**4000**	**4000**

The total projected urban population in Humera town is used to calculate the total demand of the town. Other demand is also considered for all other demands in the urban setting. The total demand, supply and deficit is presented in Table 15 .

Table 15 Humera town water demand, supply and deficit in 2030 & 2050

Humera Town	2030	2050
Urban Population	65271	162524
Urban demand (m^3/day)	1305	3250
Other demand (m^3/day)	2780	8668
Total demand (m^3/day)	4085	11918
Water supply GW (m^3/day)	1239	1239
Deficit (m^3/day)	**2846**	**10679**

The expanded irrigation scenario

This scenario is the same as the reference scenario element 2 except the total irrigation area is increased from 20,000ha to 200,000ha. The total irrigation water demand is calculated using the 600mm crop water requirement. The total water demand includes the Baker industrial (Table 14) and Humera Town (Table 15) demand. The water demand, supply and deficit of Kafta due to expansion of the irrigation area are presented in Table 16.

Table 16 Water demand, supply and deficit in Kafta Humera expanded irrigation scenario

Kafta Humera	2050
Rural Population	75202
Urban Population	226711
Rural demand (m^3/day)	1268
Urban demand (m^3/day)	4534
Total Population demand water supply (m^3/day)	5081
Other Urban demand (m^3/day)	17635
Total demand (m^3/day)	40351
Water supply GW (m^3/day)	6017
Drinking Water Supply Deficit (m^3/day)	**34334**
Irrigation (ha)	200,000
Irrigation (m^3/ha)	6000
Deficit for Irrigation (m^3)	**1,200,000,000**

Nexus policy measures

The nexus policy measures basically consider Tekeze river basin as a source of water in conjunction with the available ground water. However, the water resources in Tekeze river basin should be developed in order to address increased water requirements for the urban and rural population, the industrial and agricultural sector. The important question is then to identify the most effective strategy to increase water availability to cover all identified deficits for 2030 and 2050. We especially consider efficient irrigation water management and the construction of a multi-purpose reservoir.

Repetitive simulations with the basin water balance model (RIBASIM) were carried out to analyse the availability of water in all scenarios. In the reference scenario case, the deficit is fully supplied from the Tekeze river basin. Due to limited time and budget, various irrigation types and cropping pattern were not considered. Such measures could contribute to a more efficient use of water. Irrigation will be by far the largest water demand in the basin and that will remain so in the future. The water allocation for domestic, irrigation and industrial demand is presented in Table 17, Table 18 & Table 19. The deficit from Bae'ker industrial park and Humera town is added to the Kafta urban water supply demand. Additionally, 30,000 ha irrigation area and Mayday reservoir in Wolkayt are included in the basin water allocation for both 2030 & 2050 elements. For the expanded irrigation scenario, 1.2B cubic meter is allocated to irrigate the 200,000 ha.

Table 17 Water supply from Tekeze River to balance deficit in Kafta Humera for both irrigation and drinking water in 2030/50

Kafta Humera	2030	2050
Drinking Water Supply from Tekeze (m^3/day)	4521	34334
Water Supply from Tekeze river for 20.000 ha irrigation (m^3)	120,000,000	120,000,000

Table 18 Water supply from Tekeze River for Bae'ker industrial water deficit in 2030/50

Bae'ker industrial park	2030	2050
Water supply from Tekeze (m^3/day)	4000	4000

Table 19 Water supply from Tekeze River for Humera town water deficit in 2030/50

Humera Town	2030	2050
Water Supply from Tekeze river (m^3/day)	2846	10679

As the simulation results of both 2030 and 2050 indicate the same result (Zero shortage of water), only the 2030 result is presented here. The 2050 simulation result is presented under Annex A. Simulation results of Element 1 (2030), Kafta urban & rural Water supply is shown in Figure 3a) and Kafta irrigation is presented in 3b). As it is shown in the figures, Tekeze river basin has the potential to provide sufficient amount of water for all demands. It shows zero shortage of water supply for the industry, domestic purpose and irrigation in Kafta Humera.

The scenario on irrigation expansion with 200,000 ha is also simulated and presented under Figure 4.

The deficit from the extra water demand for irrigation can potentially be supplied from Tekeze River. The result shows there is no shortage of water for all demands including for irrigation, industrial and domestic water demand. For detailed supply and demand figures, refer to Annex A for 2030, Annex B for 2050, and Annex C for Irrigation Expansion (2050, with 200,000 ha irrigation).

Figure 3 Zero shortage of water supply (from January to December) for the industry and domestic purpose a) and 20,000ha irrigation in Kafta Humera b) for 2030

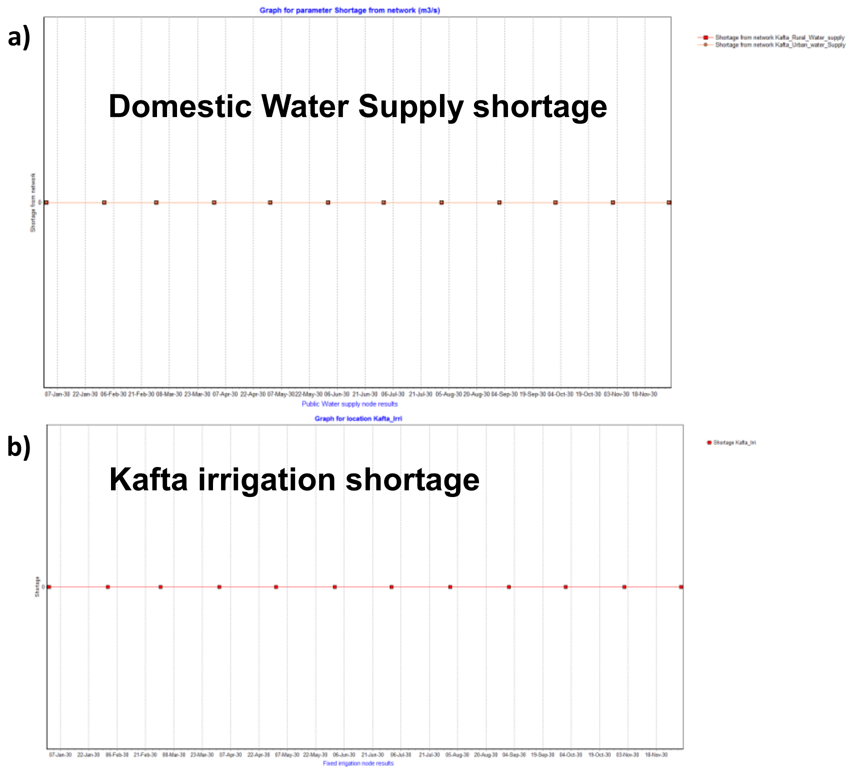
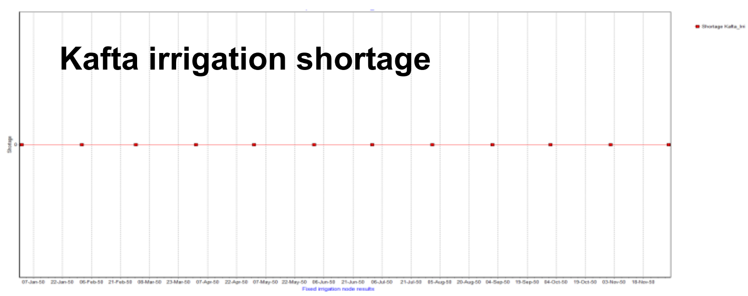


Figure 4 Zero shortage (from January to December) of water for irrigation expansion (200,000ha) in Kafta Humera (2050)

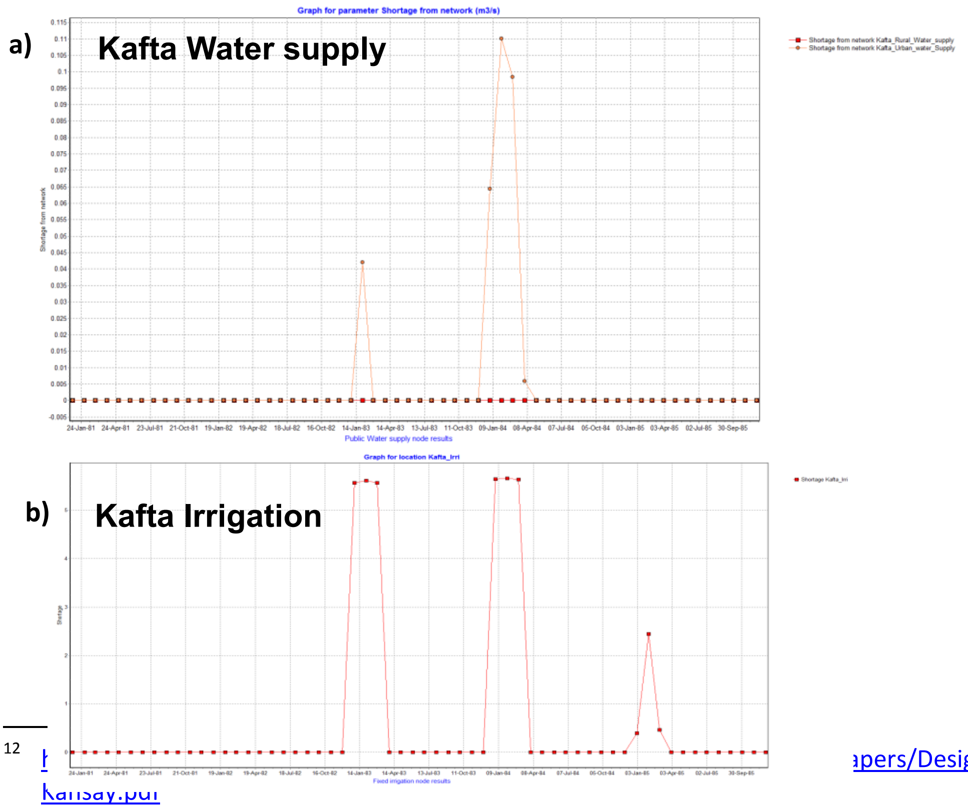


Concluding: simulations for the Tekeze basin indicate that there is enough water available to support the demand in 2030, 2050 and to further substantially increase irrigation intensity if desired. If the changes in the cropping pattern (diversification) were considered in the model, it would even further improve the water availability. However, Tekeze River streambed is 20 - 100m below the potential arable land. Consequently, the river water has been inaccessible unless an expensive water lifting mechanism is introduced[12]. Therefore, reservoirs can be built and the water can be used to meet the required demand in 2030 and 2050.The multi-purpose reservoir could be used to generate hydro-power and provide sufficient water for irrigation and DMI (Domestic, Municipality and Industrial demand).

Extreme drought scenario (the 1984 rainfall)

The reference scenario of 2030 was also simulated with the extreme drought period hydrological conditions that happened in 1984. Figure 5a) and b) shows the resulting shortage of water, for Kafta water supply and 20,000 ha irrigation respectively. The result indicates there will be 74 MCM total water shortage for irrigation and 2.5 MCM for public water supply, if this kind of event happens in the future. During such a drought period, Tekeze River flow has a significant shortage (approximately January-March). To alleviate such shortage, a reservoir could be useful to store enough water during the wet season prior to the drought period. However, this is highly dependent on many factors, for example, the available rainfall, the reservoir volume, evaporation loss, etc. It requires detailed study, planning and preparation to cope with such an extreme drought. For detailed demand and supply figures, refer to Annex D: Extreme drought period.

Figure 5 Shortage of water supply for the industry and domestic purpose a) and irrigation in Kafta Humera b) for 2030 in the extreme drought period



12 h ... apers/DesignPerformance_-Kansay.pdf

3.2.3 Limitations

This study provides an insight in demand and supply of water in Kafta Humera. However, there is still information missing. For example, there is no information on the ground water potential, and therefore the sustainability of the ground water use that is planned for Bae'ker industrial park. To conduct such study is highly recommended. Additionally, during the validation workshop in Mekelle (December 2017), participants indicated that there are developments in the Tekeze river basin that need to be included in the water allocation model. The secondary data that were collected during the first mission need to be updated to incorporate all the water allocation projects in the Tekeze tributaries.

3.3 The energy sector in Kafta Humera

3.3.1 Brief description of the energy sector in Humera woreda

Kafta Humera is one of the 35 rural districts (woreda) in the Tigray region and includes the city of Humera. The total population in 2017 was estimated to amount to nearly 155,000 people, including 36,000 people of the town of Humera. The construction of the Integrated Agro Industrial Park has started near the village of Bae'ker and when fully operational will be a significant agro-processing industrial energy consumer in the region. The analysis of the energy sector presented in this section aims to analyse the feasibility of the Bae'ker industrial park within the broader and longer term Energy-Water-Food security context.

The analysis of the energy sector of Kafta Humera has been conducted using the Long-range Energy Alternatives Planning system (LEAP). LEAP is a very user-friendly simulation model (with some optimalisation possibilities in the power sector) that can be used to track energy consumption, transformation, production and resource extraction in all sectors of an economy. The energy sector of Kafta Humera is structured in LEAP according to the following three components:

Energy consumption:

- Urban and rural households are by far the largest energy consumers in Kafta Humera (domestic energy consumption is the largest in Ethiopia). It accounts for more than 90% of total energy consumption, mainly traditional biomass such as fuelwood, charcoal and animal waste;
- Agro-processing industry: currently of negligible size but the construction of the IAIP will definitely boost this sector;
- Agriculture: energy use for irrigation and other farm activities; and
- Transport: public and private transportation.

Energy transformation (conversion from primary to secondary energy)

- Transmission and distribution of electricity; currently all electricity is imported through a 220 kV transmission line between the hydro plant at Lake Tana and the substation near Humera town;

- Electricity generation: currently no electricity production but a 100 MW solar power plant near Bae'ker park is in an advanced planning stage and potentially a hydro plant in the Tekeze river can be constructed;
- Charcoal production: charcoal is produced within the region; and
- Solar pumping for irrigation: all water pumping is currently diesel-based but potentially a part can be solar-based.

Production and resource extraction

- Wood: forests area in Kafta Humera is 240,000 ha with a assumed wood density of 60m^3 per ha.
- Animal waste: animal waste is used mainly by rural population if wood becomes less easy to access.
- Solar: large solar resources in Kafta Humera with average daily radiation of 5.55kWh/m^2.

The energy demand – supply analysis has been conducted with the LEAP model for the period 2017 – 2050. In this section the energy demand sectors will be described more in detail and energy demand projections are presented for the ´Reference´ and ´Expanded irrigation´ scenarios along with a brief evaluation of how projected energy demand can be met with the currently available energy resources.

3.3.2 Assessment of current and future energy needs in Kafta Humera

This section presents for each of the four energy demand categories the key assumptions used to develop the energy demand scenarios and shows the results for the Reference and expanded Irrigation scenarios. Furthermore, it is briefly explained how this projected future energy demand can be met.

Urban and Rural Households

Information on energy consumption by rural and urban households can only be obtained through surveys. Unfortunately, no energy household survey has been conducted for Kafta Humera and time and budget constraints made it impossible to conduct our own survey. Therefore, for the demand analysis the results of rural household surveys conducted in two other woredas in Tigray (Enderta and Hintalo-Wajirat) and urban households conducted in 350 locations in Tigray (Gebreegziabher, 2007) have been used as a proxy indicator for Kafta Humera. The assumptions about fuel consumption of rural and urban households are presented in the following table.

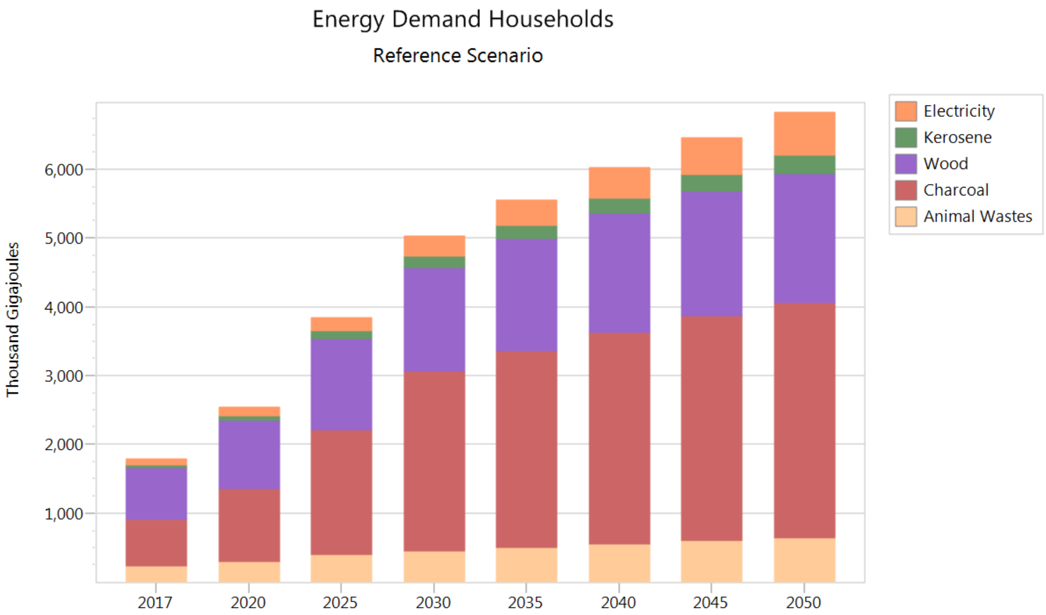
Table 20 Energy consumption of urban and rural households in Kafta Humera (Source: 1) Household Fuel Consumption and resource Use in Rural-Urban Ethiopia; PhD thesis Zenebe Gebreegziabher; 2007; Tables 5.1 & 7 A.1)

Households	Wood/BLT[13] kg/year	Charcoal kg/year	Dung kg/year	Oil products l/year	Electricity kWh/year
Urban	866	1,193	294	55	859
Rural	2,068	40	879	13	150

[13] BLT Branches, Leaves and Twigs

It is further assumed that when income rises households will move up the energy ladder and switch to more convenient (and more expensive) fuels. For Kafta Humera this means that households will switch to electricity and that the amount of electricity used by households will gradually increase from 2025 onwards by 1.5% annually at the expense of wood and charcoal consumption. The total projected household energy consumption for the Reference scenario is depicted in Figure 6.

Figure 6 Projected energy demand of households in Kafta Humera



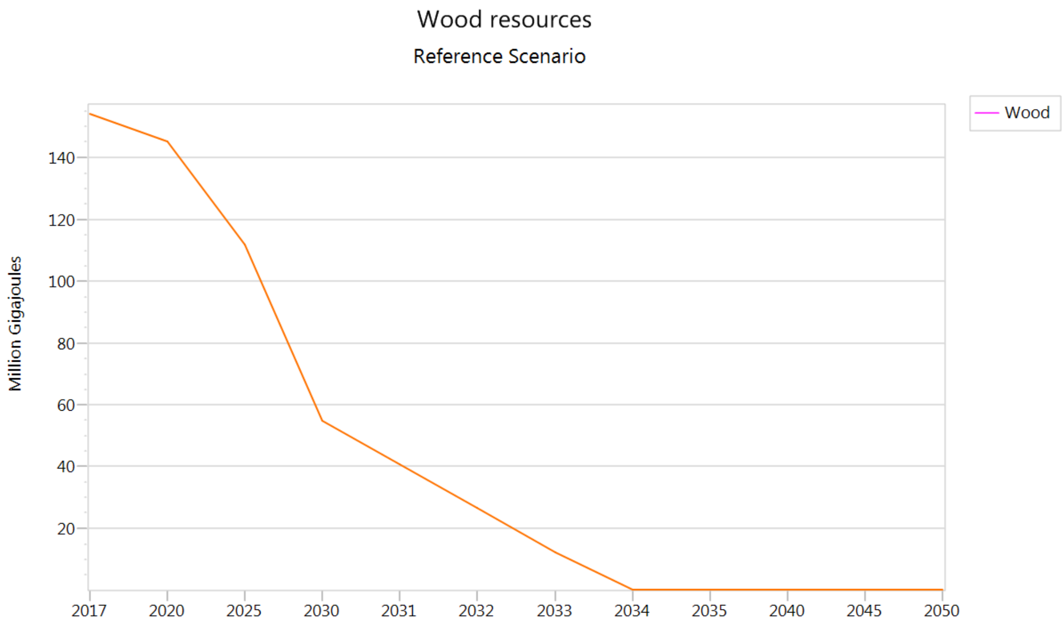
Household energy consumption is projected to increase rapidly during the period up to 2030 as a result of the influx of 200,000 people employed by Bae'ker industrial park who will reside in Humera. After 2030, the growth rate of household energy consumption will decrease.

Traditional biomass, comprising wood and charcoal and animal dung, is the dominant fuel used by households in Kafta Humera. Animal waste (dung) is mainly used by rural households. Use of electricity, kerosene and charcoal is very common in urban areas but most rural areas are also connected to the electricity grid[14].

Currently, the dryland forest area in Kafta Humera amounts to 240,000 ha with an assumed stock density of 60m^3 per ha. The annual sustainable woodfuel yield is taken to be 1 m^3 per ha. The current consumption of wood and charcoal far exceeds sustainable yield and therefore the available wood resources will gradually be depleted if no additional measures are taken. Figure 7 shows that if current trends in wood demand will continue, the forests in Kafta Humera will be depleted by 2034 and from then on wood demand has to be met by imports from other regions.

[14] This statement was made by participants from Humera in the December 2017 validation workshop in Mekelle.

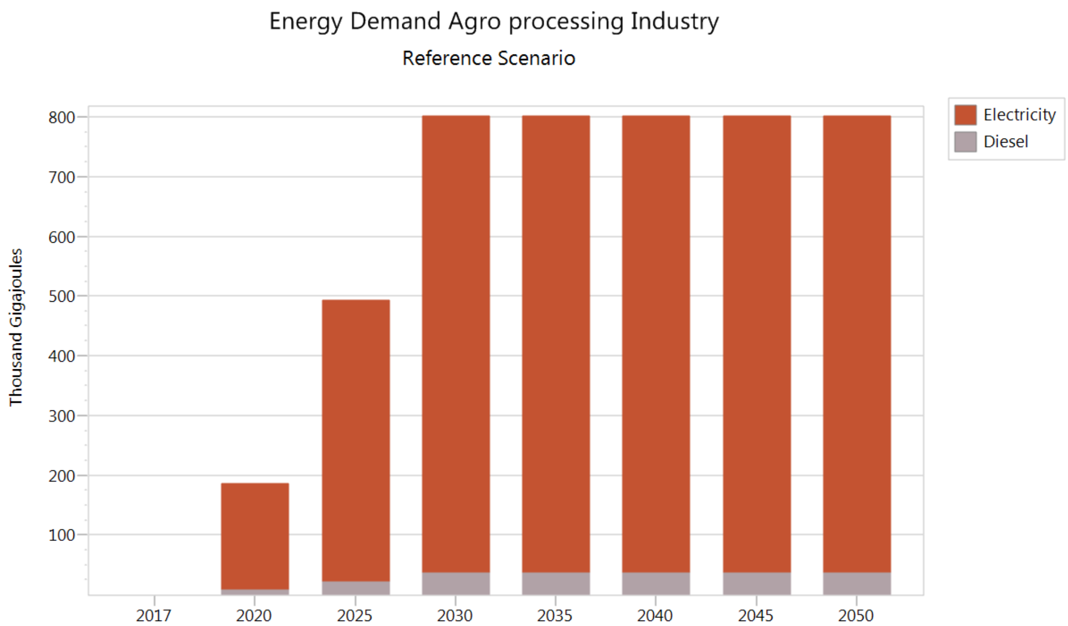
Figure 7 Projected wood resources in Kafta Humera



Agro- processing industry

The industry in Kafta Humera comprises the Bae'ker industrial park which is to become a large electricity consumer (45.5 MW peak demand[15] and 53% capacity factor[16]). The construction of the park has started in 2017 and it is assumed to be in full operation from 2030. Figure 8 shows the projected energy consumption of the park for the Reference scenario.

Figure 8 Projected energy demand of Agro processing industry in Kafta Humera



15 Integrated ACPZ&IAIP Western Tigray; Ministry of Industry, Ministry of Agriculture.

16 Capacity factor is ratio of actual output and potential output if 45.5 MW is supplied throughout the year(8760 hours).

Energy consumption rapidly increases until the industrial park is fully operational in 2030 and from then on remains constant. Electricity is the main fuel used by the Bae'ker park and also small amounts of oil products (diesel) are needed for the machinery. The required electricity for the park will be supplied by the hydro power plant at Lake Tana and will be transported to the existing substation near Humera town by a 220kV transmission line. The capacity of this transmission line is in principle sufficient to meet the electricity demand of the park and the other users.

The transport sector

Energy demand projections for the transport sector in Kafta Humera are developed based on the projected passenger-km travelled and tonne-km of cargo transported per year in Ethiopia are presented in Table 21.

Table 21 Projected passenger-km and tonne-km for Ethiopia (billion km) (Source: 1) Ethiopian Climate-Resilient Green economy, 2025; 2) own extrapolations based on annual growth of 5% between 2030 and 2050

Ethiopia	2017 1)	2020 1)	2030 1)	2040 2)	2050 2)
Passenger-km(billion passenger)	73	95	220	357	582
Tonne-km (billion tonne-km)	55	81	279	508	828

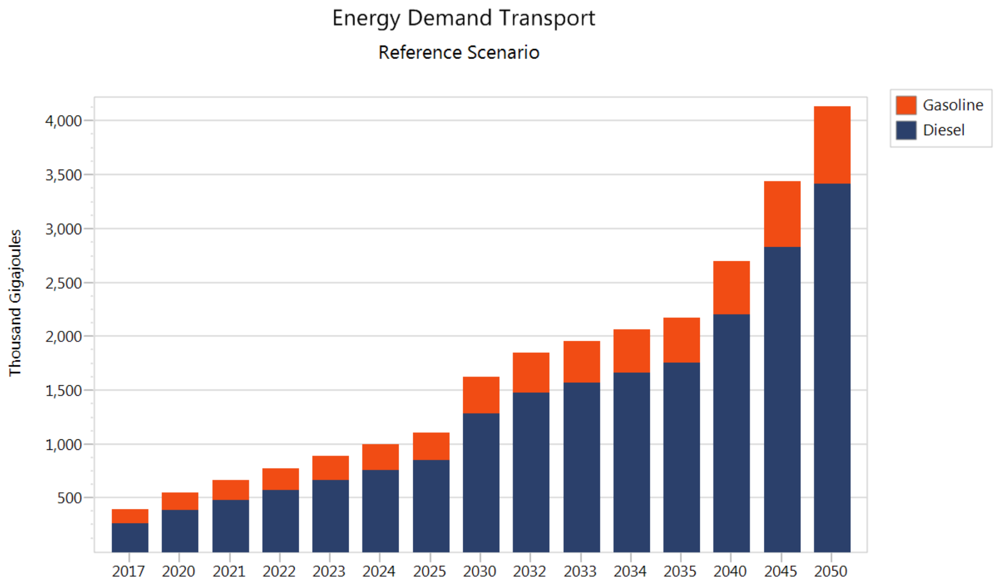
According to the Ethiopian Transport Authority 4.12 % of the total number of vehicles in Ethiopia are registered in Tigray province. Assuming that the number of vehicles in a region is related to the population size and given that the population of Kafta Humera is 3% of the population of Tigray province, the projections for passenger-km and tonne-km in Kafta Humera can be approximated by multiplying the projections for Ethiopia as whole by 0.001236 (0.0412*0.03). The projections for energy consumption in transport sector are presented in Table 22.

Table 22 Projected passenger-km and tonne-km for Kafta Humera (million km) (Source: ETA)

Kafta Humera	2017 1)	2020 1)	2030 1)	2040 2)	2050 2)
Passenger-km(million)	90	116	268	436	710
Tonne-km(million)	68	100	345	620	1,010

The results for the Reference scenario are shown in Figure 9.

Figure 9 Projected energy demand of transport sector in Kafta Humera



Due to high economic growth rates, energy consumption in the transport sector is expected to grow by a factor of 10 in the coming 33 years. In particular, road freight transport is expected to grow rapidly which explains the significant increase of diesel consumption. In the Reference scenario the share of diesel for freight transport is increasing from 64% in 2017 to 83% in 2050.

Although exploration studies have indicated that there are significant proven reserves of oil shale and natural gas in Ethiopia, these fossil fuel resources have not yet been exploited. All oil products therefore have to be imported from outside the country.

Agriculture

Energy demand in agriculture involves the energy needed for pumping water for irrigation. In the Reference scenario it is assumed that 5% of the 388,880 ha cultivated land is irrigated. The remaining area is rain-fed. However, in the Expanded Irrigation scenario it is assumed that gradually 51% of the cultivated land will be irrigated (see section 3.3.3).

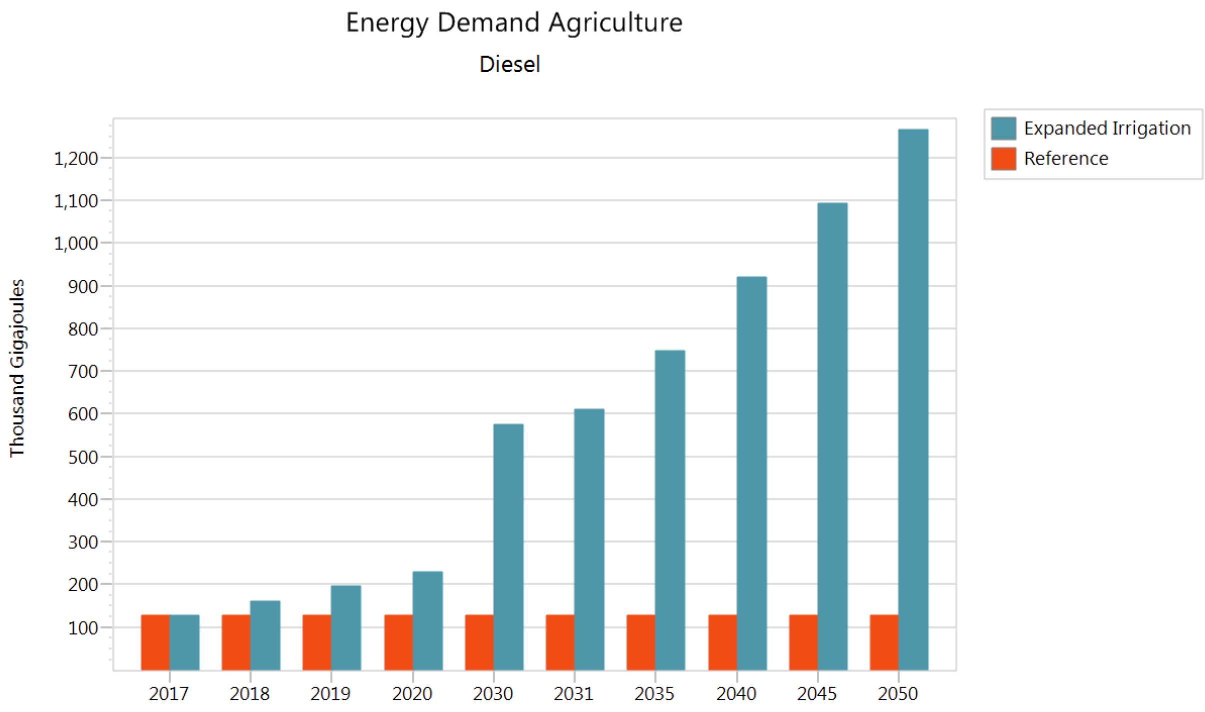
To determine the amount of energy needed for water pumping it is assumed that[17]:

- 0.7 litres of diesel (8kWh) is needed to lift 36,000 litres of water 7 meters per hour
- 67,000 litres of water/ha/day is needed for irrigation
- The total number of irrigation days throughout the year is 90 days.

Combining the above assumptions results in 168 l diesel/ha/year. The projected energy demand of the agricultural sector for the Reference and Expanded irrigation scenarios is shown in figure 10.

[17] Renewable energy for smallholder irrigation, SNV, May 2014

Figure 10 Projected energy demand of agriculture in Kafta Humera



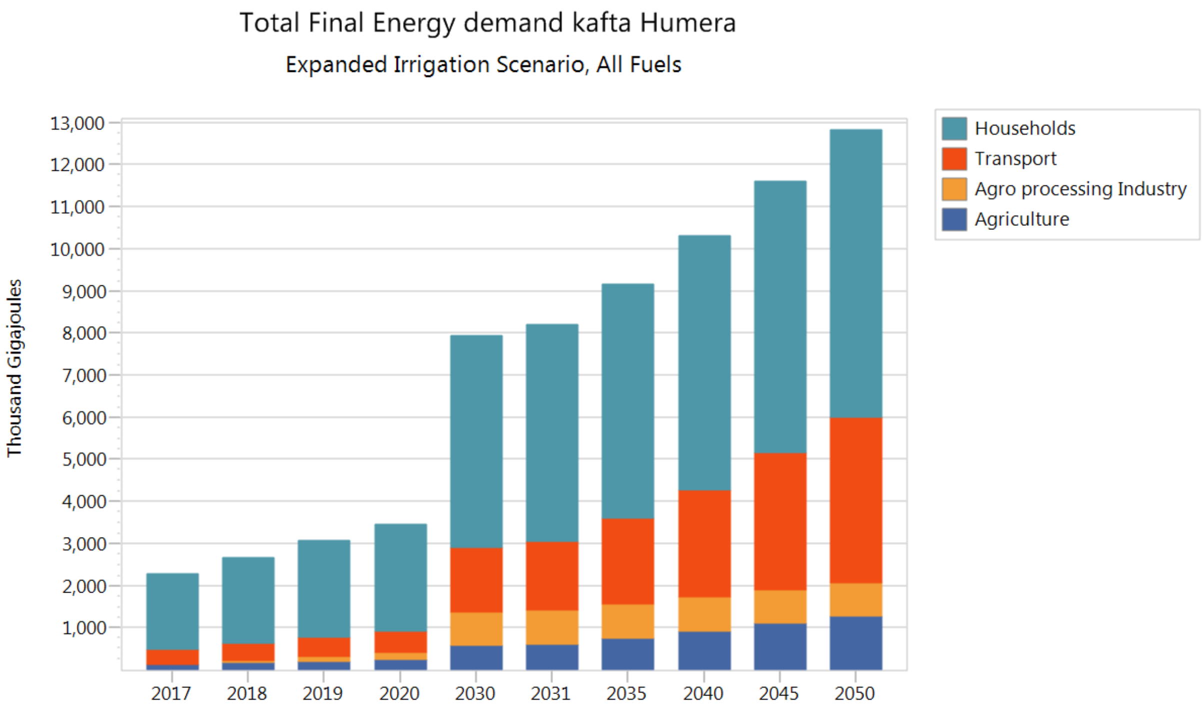
Irrigation is considered to be an important option to increase agricultural yield and the income of farmers and thus to alleviate poverty. It is therefore surprising that despite the ample water resources currently the land under irrigation in Kafta Humera is less than 5% of the region's irrigable land. The purpose of the 'Expanded Irrigation' scenario is to analyse the impact on energy and water consumption of a significant increase in the irrigated land.

Although the cost of electrical power seems not to be a barrier, access to electricity in rural areas is hindered by the frequent power interruptions that make most farmers opt instead for diesel pumps. The Expanded Irrigation scenario shows an increase of diesel consumption by a factor of more than 10. The amount of diesel needed for irrigation cannot be produced locally and has to be imported from outside the region and even from outside Ethiopia.

Total energy demand in Kafta Humera for the expanded Irrigation and Reference scenarios

The total projected final energy demand in Kafta Humera for the Expanded Irrigation scenario is presented in Figure 11.

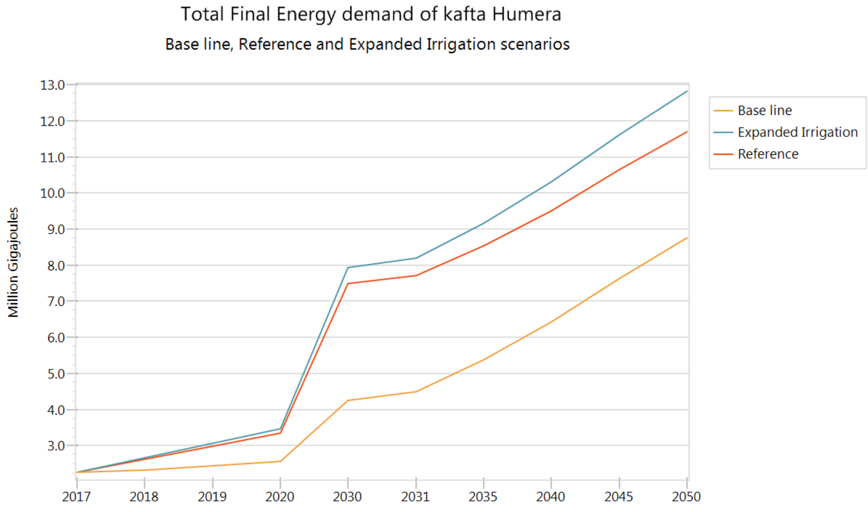
Figure 11 Projected total final energy demand in Kafta Humera for Expanded Irrigation scenario



The total energy demand in Kafta Humera is projected to increase by almost a factor of 5.7 from 2,271 TJ in 2017 to 12,832 TJ in 2050. Households currently are and will remain the largest energy consumers although their share will decrease from 79% in 2017 to 53% in 2050. The rising incomes and, consequently, the shift to modern and more convenient fuels means that the share of traditional biomass (wood, charcoal dung) in total energy consumption is expected to gradually decrease from 79% in 2017 to approximately 46% in 2050.

Figure 12 presents the total projected energy demand for the three scenarios. The base line scenario represents the current situation without the Bae'ker Park. The 'Expanded Irrigation' scenario obviously results in the highest energy consumption.

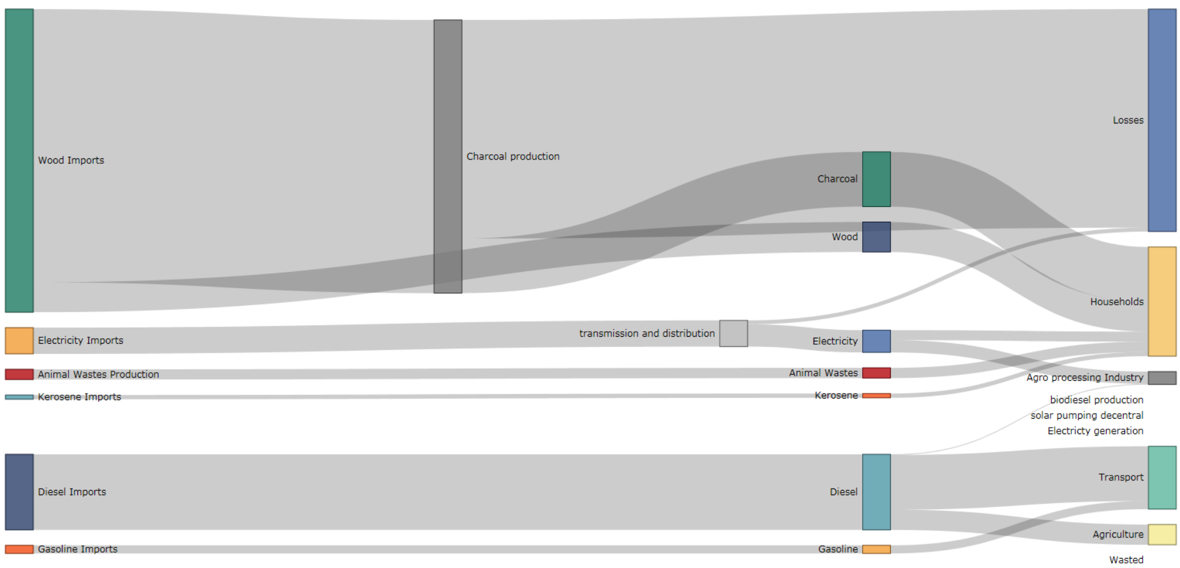
Figure 12 Projected total final energy demand in Kafta Humera for three scenarios



3.3.3 Energy supply in Kafta Humera for the Expanded Irrigation scenario

The Sankey diagram in Figure 13 shows how in the Expanded Irrigation scenario, energy demand in the year 2050 will be met. The diagram presents a visualization of the energy flows from energy production via transformation to the final energy demand categories.

Figure 13 Sankey diagram for the expanded Irrigation scenario in 2050



On the right-hand side of the diagram the four energy demand sectors are represented by bars and the widths of the bars are directly proportional to the amount of energy that is needed in 2050.

- Households: the sandy brown bar
- Agro processing Industry(Bae'ker industrial park): dark grey bar
- Transport: green bar
- Agriculture: white bar.

The dark blue bar represents the energy losses that occur during the transformation process of wood to charcoal and the electricity that is lost during distribution. The total sum of the bars equals the total energy requirements in 2050.

Similarly, on the left-hand side of the diagram the energy supply sectors are represented by bars.

- Wood supply which is fully imported in 2050 because wood resources in Kafta Humera will be depleted in 2034: forest green bar
- Electricity is also imported from outside the region: sandy brown bar
- The oil products diesel, gasoline and kerosene are all fully imported: light blue, pink and dark blue bars
- Animal waste production is the only locally available resource in 2050 in the Expanded Irrigation scenario: red bar.

The total amount of energy produced (imported) equals the total amount of energy demanded by Kafta Humera. The sum of the widths of the bars at the left-hand side is equal to the sum of the widths of the bars at the right-hand side of the diagram.

3.3.4 Energy supply in Kafta Humera during droughts

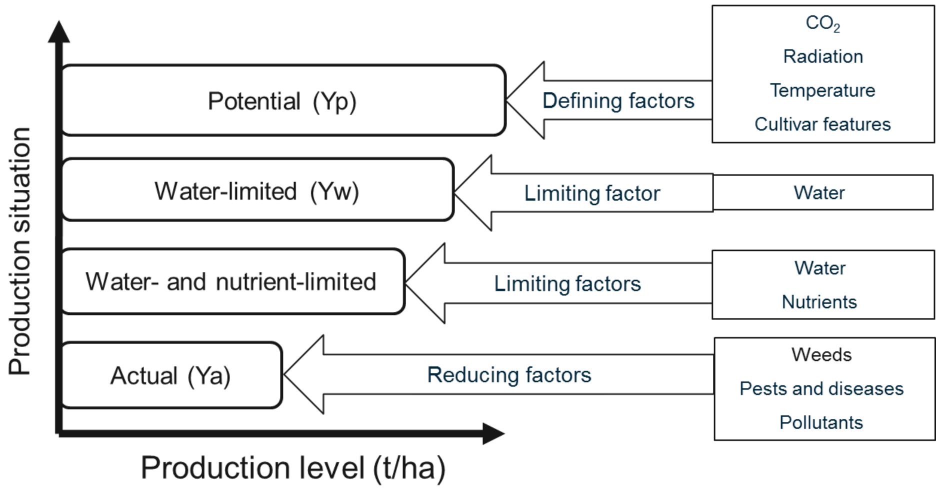
In case of serious droughts as was the case in 1984 it is expected that water reservoirs elsewhere in Ethiopia (such as Lake Tana) are still able to generate electricity. Import of energy into Kafta Humera will therefore not be affected.

3.4 Food security and sesame production potential

3.4.1 Estimates of production levels for selected crops in the region

To get an idea of the order of magnitude of the production levels or yields which can be achieved in the region we use a simple quantitative approach. We opted not to calculate the maximum or potential yield but to estimate the "water-limited yield", which is a more realistic assessment method.

A potential yield is defined as the total dry matter production of a crop that has no limitations related to water or nutrient supply and has no reductions in growth related to pest, diseases and competition with other plants. From the potential yield the water-limited and nutrient limited yields are derived, the reductions by other factors are often derived from field observations and experience. Climate variables radiation (only the photo-synthetically active part), temperature, additional CO_2 levels and the crop or cultivar determine the potential yield:



In this study, we will focus on the yield levels determined by water by using a simple conversion of the amount of water needed to produce dry matter. We assume a water use efficiency (WUE) of 200 kg water per kg dry matter. This WUE of 200 kg/kg is taken to reflect the drought tolerance of the crops cultivated in the region. A typical range for a WUE would be between 150 and 300.

Simple calculation using Water Use Efficiency
From the feasibility study of the industrial park we learn that the mean annual rainfall of the basin is 632.08 mm. The total average amount of rainfall during the rainy season is 590.61 mm. (p. 178, feasibility study). Other sources mention 357.8 mm and 650 mm as minimum and maximum rainfall figures for Humera18. The region has a distinct wet period.

Not all rainwater is used by the crop; part of it will run-off or is transported to the deep ground water. We assume that only 50% of the rainfall of the rainy season is transpired by the crop which is about 300 mm or 3 10^6 kg water per ha. With the given WUE a total of 15000 kg dry matter is produced per hectare. To arrive at the above ground biomass we have to subtract the below ground biomass or roots. We assume 15% of the crop is below ground so the total above ground biomass is 12750 kg dry matter. For the minimum and maximum rainfall for the district the WUE this would be between 7650 kg and 14025 dry matter per ha.

The harvest index (HI) is the ratio of the economic yield (grains) to total aboveground biomass. For sorghum the HI is 0,4 for sesame HI is 0.2 (HI of around 0.15 is reported)[19]. So for Sorghum grain the economic yield based on water availability is then 5100 kg dry matter per ha while for sesame this is 2550 kg per ha. However, rainfall is erratic in Humera. By taking the minimum and maximum rainfall figures the range of yield will change accordingly: the economic yield for sorghum ranges between 3060 and 5610 kg, for sesame this is between 1530 and 2805 kg per ha. Note that the estimates of the

18 We realise that a variety of references use different rainfall figures for Humera.

19 Sources: Ali. S and A. Jan. 2014. Sowing dates and nitrogen level effect on yield and yield attributes of sesame cultivars. Sarhad J. Agric. 30(2): 203- 209; and: Zenawi Gebregergis Gebremichael, 2016, Sesame Sowing Time and Insecticide Application Schedule on Sesame Webworm (Antigastra catalaunalis) Infestation and Yield in Western Tigray, Northern Ethiopia. A Thesis Submitted in Partial Fulfillment of the Requirements for the Masters of Science Degree in Dryland Agronomy College of Dryland Agriculture and Natural Resources, Department of Dryland Crop and Horticulture Science, Mekelle University, Ethiopia.

factors used are difficult to obtain with a high degree of certainty; the outcomes provide a range and order of magnitude.

Current yields

From the IAIP feasibility study (page 45) local yield levels in Western Tigray are given for sorghum and sesame:

Crop	No. of holders	Area in hectare	Production in quintal	Yield (q t / ha)
Sorghum	78,568	44,940.06	1,314,194.77	29.24
Finger millet	37,438	9,888.66	227,037.49	22.96
Pulses	22,646	1,829.42	28,302.60	
Faba beans	11,568	681.97	13,496.87	19.79
Field peas	2,127	*	*	*
Haricot beans	*	*	743.6	*
Oilseeds	82,667	72,812.81	615,982.63	
Neug	10,439	2,191.22	*	*
Linseed	1,889	89.13	*	*
Sesame	76,718	70,515.27	574,432.15	8.15
Vegetables	28,357	297.79	20,196.28	
Red peppers	18,657	216.03	5,865.31	27.15
Fruit Crops	7,690	*	*	
Papayas	3,897	*	*	*
Hops	7,560	96.68	3,344.04	34.59

Source: CSA data for 2013-14

The production levels according the quoted study are 2924 kg per ha for sorghum and 815 kg per ha for sesame. When looking at FAOSTAT the minimum and maximum range for sesame production in Ethiopia for the 2010 – 2014 period is 410 – 850 kg /ha. In comparison, also from FAOSTAT, sesame yields in China and Israel are in the order of 1500 kg/ha.

On page 65 of the feasibility study we find: “In terms of productivity, the average yield of Western Tigray region is the highest in the country even it is above 10 quintal/ha.” Local information from SBN however suggests differently. Information from SBN project over the past 10 years reveals that the average sesame yield in Humera is 559 kg/hectare. The average yield of sorghum in Humera over the past 6 years (according the Humera Agricultural bureau) is 3060 kg/ha.

Demand of sesame by Bae’ker IAIP

The planned IAIP in Bae’ker requires 245,645 MTPA (metric tons per annum). The current average annual production in Humera is 127,929 MTPA (SBN Project). The shortage can be easily covered by increasing yields as shown in the table below.

Table 23 Demand of sesame by the Beaker industrial park

Average # of hectares under sesame (10 year period)	Water-limited minimum rainfall economic yield in tons	Water-limited maximum rainfall economic yield in tons	Israel/China yield levels in tons	Required volumes by Bae’ker IAIP
226,270	226,270x1530kg=346,193	226,270x2805=634,687	226,270x1500=339,405	245,645 ton

Yield increases
With improved crop varieties and improved management, with a strong focus on crop protection and fertilisation, the yields of both sorghum and sesame could be much higher. The water limited yields give an indication of what can be achieved but also given the current yields in other countries a doubling of the sesame and sorghum yields is not outside the current technological scope. The targets for the industrial park seem feasible.

In addition, irrigation would allow for an extra crop in the year so we can double the annual production levels of both crops with current production levels simply by adding an extra season without claiming extra land.

Assuming only sesame is irrigated and in 2050 20,000 ha of irrigated land is available the yields in 2050 would reach (given optimum nutrient and crop protection management) water-limited production levels and provide two harvests per year. The production from the irrigated area in 2050 would be 102000 ton per year (2550 kg/ha * 20,000 ha * 2 harvests per year). If the irrigated area in 2050 would reach 200,000 ha as modelled in the expanded irrigation scenario, the production would reach 1,020,000 ton per year.

3.4.2 Land use based on diets

The diets of rural and urban populations are almost equal with 60% of caloric intake being cereal-based. With a total caloric intake of about 2500 kcal per day, 1500 kcal per day is cereal-based. With 0,651kcal per cup (192 grams this means that 442 gram of cereal per day is needed to arrive at the 1500 kcal per day.

Not all cereal produced reaches the consumer and assuming a waste of 25%, we need 589 gram or about 0.6 kg per day per person. This is converted to 219 kg of grain requirement per person per year. Please note that this includes waste and only 164 kg is consumed.

With a production level of 3 ton per ha (see information above) this means an area of about 0.075 ha per person is needed to provide the necessary grain. For 100,000 persons the area needed would be 7500 ha. Note that grain comprises 60% of the caloric intake. The other 40% consists of meat, dairy, fruits, vegetable, etc. These foods are not included in this equation as these sectors do not compete with arable farming for land in this region. When achieving water limited production levels of 5100 kg/ha the area required per adult person would be 0.04 ha per person (4000 ha for 100,000 adults). The assumption is 1 harvest per year (so no irrigated sorghum).

When using the population info from chapter 2.1 (and we add the anticipated influx of 200.000 people employed by/through the Bae'ker IAIP, see chapter 3.1), we move from a total population in 2017 of 154,969 to 427,433 in 2030 and 664,437 in 2050. These numbers would require at current yield levels: 32,057 hectares in 2030 and 49,832 hectares in 2050. With water limited productions this would be 17.097 and 26,577 ha in 2030 and 2050 respectively. All well within the total average sorghum production area of 129,658 reported by the agricultural office in Humera.

3.4.3 The extreme drought Scenario (1984)

Under stress such as the drought of 1984 in which rainfall dropped to 50% of the normal, the yields would also equally drop 50%. Obviously with irrigation this would be less. When combined with extreme high temperatures (>40°C) sesame could die. Most cereal (food) crops cannot survive such high temperature, so most likely local food production will not be able to sustain the population. The production systems will clearly be stressed. Preparing for extreme events such as a drought is part of building resilience. It is not only linked to production but other aspects such as early signalling and warning, distribution, migration etc. Being prepared and organised helps in dealing with extreme events, this is part of adaptation to climate change.

3.5 Towards a Nexus Policy Strategy for sustainable development

In the previous sections the water, energy and food demand projections for Kafta Humera up to the year 2050 have been presented. The main conclusions were as follows:

- The groundwater resources in Humera woreda are sufficient for the present but assumed to be not sufficient for the expected growth in population, agro-industries and irrigation. To cover that growth the Tekeze river catchment can be tapped (provided a multi-purpose reservoir is constructed).
- To meet future energy demand in the Reference and Expanded irrigation scenarios all fuels - except animal dung - have to be fully imported from other regions in Ethiopia. From an energy policy and strategy perspective this is unsatisfactory because it means that 1) Kafta Humera is fully dependent on other regions for meeting its energy requirements; 2) Kafta Humera is insufficiently tapping its own energy resources; and 3) the energy sector might not be resilient enough to cope with impacts of climate change.
- Extrapolating current firewood and charcoal demand results in a depletion of forest resources by 2034 with accompanying negative effect on soils, water sources and probably food security (since not everybody in the rural area will be able to pay for replacement energy for daily cooking). This calls for a serious overhaul of forest management policy and practice.
- The agricultural potential of the woreda is sufficient to double sesame production (in response to demand by the Bae'ker agro-park), and keep the growing population food secure.

In this section a Nexus Policy Strategy is presented that aims to develop and use local energy and water resources in order to reduce energy imports and to contribute to sustainable development. The strategy comprises several so called 'nexus' policy measures. These measures are designed in such a way that they not only address (future) problems in the energy sector but also take into account the consequences of these measures for the water and food sectors. This integrated approach across the three sectors will improve the efficiency and effectiveness of the proposed interventions. To analyse these measures the project team had at its disposal a unique set of models comprising the LEAP model for energy, RIBASIM model for water and WUR Agriculture model (all presented in previous sections).

The Nexus Policy Strategy consists of the following proposed nexus policy measures:

1. Construction of a 100 MW solar power plant near Bae'ker park
2. Introduction of more efficient cook stoves
3. Solar powered irrigation
4. Construction of multi-purpose reservoir to store the water from the Tekeze River

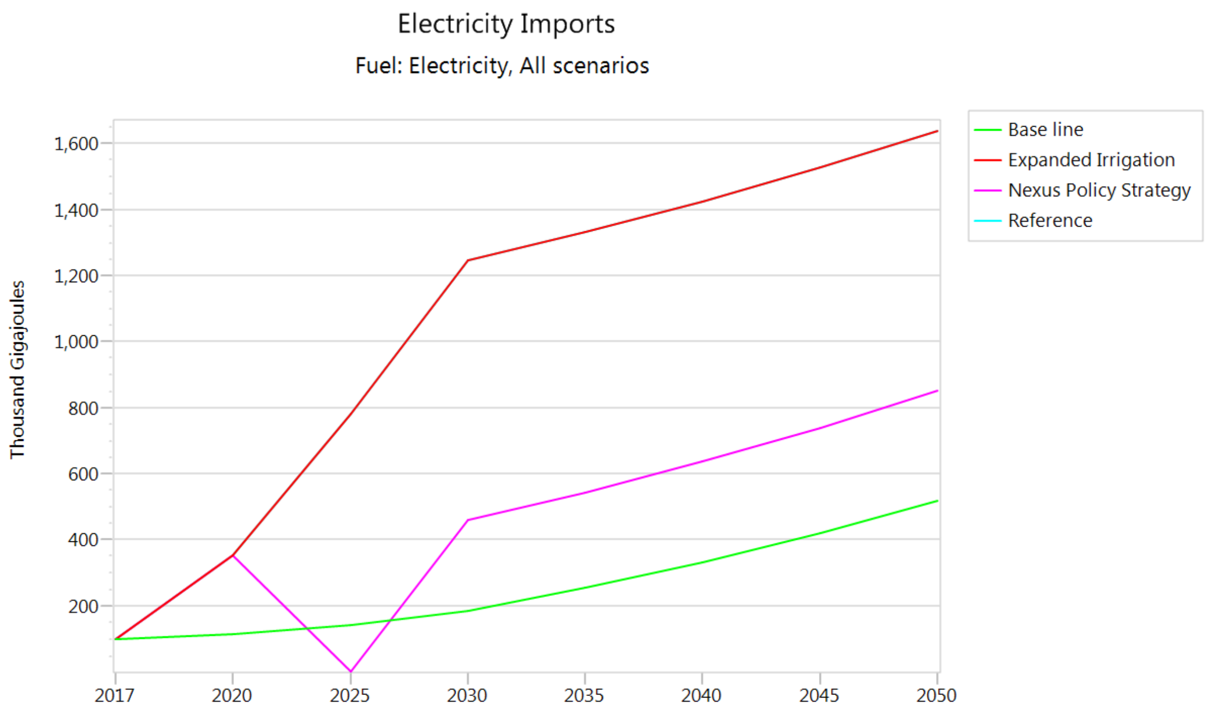
5. Afforestation
6. Land-use for biofuel production.

In this section an analysis is presented of the above nexus measures and the combined impact on the energy sector of the Nexus Policy Strategy on the water, energy and food sectors is analysed.

1. Construction of 100 MW solar energy power plant

Kafta Humera has abundant solar energy resources. The average annual solar irradiation is more than 2400 kWh/m^2 in this woreda. Currently, 20MW of solar energy has already been installed in Ethiopia and the construction of a 100 MW power plant near the Bae'ker industrial park is being considered but has not yet approved. The proposed solar energy plant clearly is a nexus measure because it affects the energy sector (diversification of supply), the food sector (electricity supply for the Bae'ker agro-processing park) and the water sector (increasing water demand for irrigation to supply Bae'ker). For this analysis it is assumed that the power plant will be operational from 2025 onwards and will operate with an average capacity factor of 25%[20]. The total costs for the construction of this plant are estimated to be in the range of USD 120 – 140 million. Figure 14 shows the impact of this plant on electricity imports for the different scenarios.

Figure 14 Electricity imports for three scenarios



For the Reference and Expanded Irrigation scenarios future electricity demand of Kafta Humera will be met by imports from the hydro power plant at Lake Tana. In the Nexus Policy Strategy it is assumed that the solar energy power plant will start producing electricity in 2025. As can been seen in Figure 14 this means that in 2025 no electricity imports are needed anymore. However, this is only for a very short period because due to growing demand the maximum capacity of the

[20] A 100MW plant does not produce 100 MWh electricity throughout the whole year (8760 hours) but only during 25 % (2190 hours) of the year. For example, during the night the production is zero.

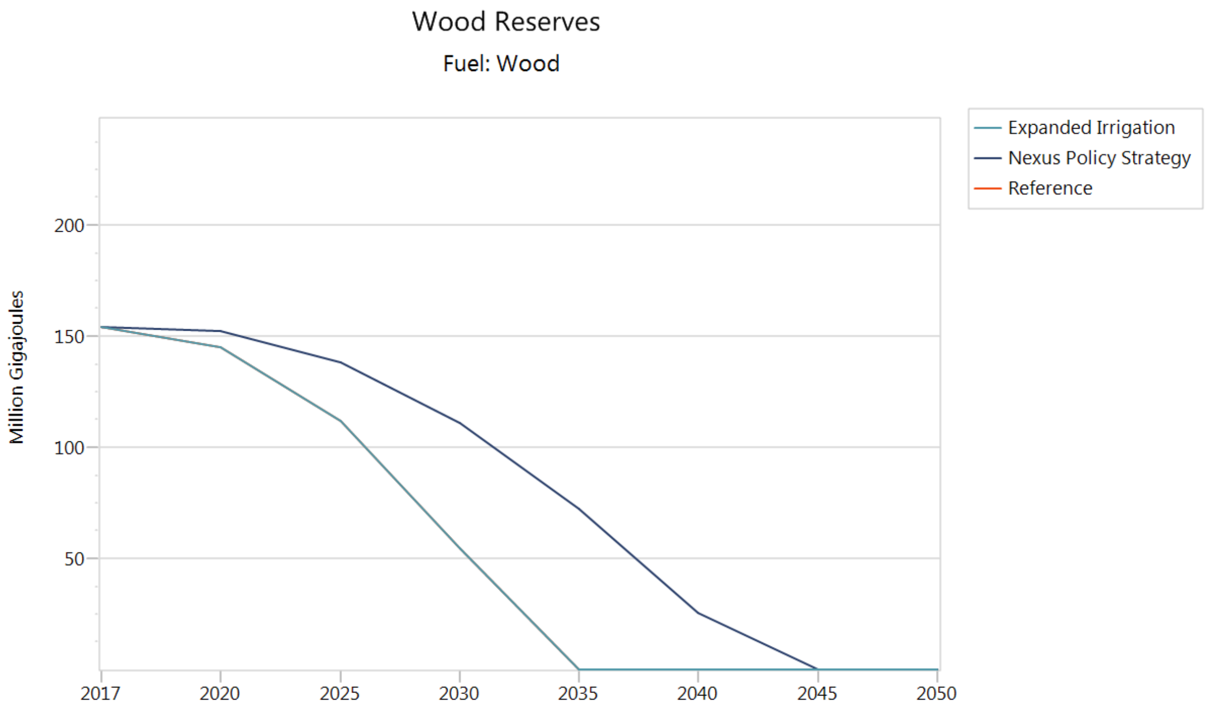
solar plant will be reached in 2026 and then imports are needed again but at a structural lower level than in the Reference and Expanded Irrigation scenarios (both scenarios are overlapping in Figure 14).

2. Introduction of more efficient cook stoves

The Reference scenario showed that current and future wood demand is unsustainable and will result in the disappearance of the forests in Kafta Humera. The introduction and further dissemination of improved cook stoves among especially rural households aims to address this problem by using wood more efficiently. This could reduce deforestation and land degradation but would also positively affect indoor air pollution which causes adverse health effects.

Improved cook stoves (ICS) dissemination programmes have been set-up and implemented by the government of Tigray and several donor organisations (for example, GIZ is currently implementing the Energising Development ICS programme). These new cook stoves could potentially save 30 - 50% of wood compared to the traditional three stone stove. For the Nexus Policy Strategy, it is assumed that ICS stoves will be gradually introduced and that by 2050 all households use an ICS.

Figure 15 Wood resources for three scenarios



By switching to ICS stoves less wood is needed for cooking which slows down the deforestation rate. In the Nexus Policy Strategy it will take 10 more years to fully deplete the forests in Kafta Humera. The wood reserves are the same for Expanded Irrigation and Reference scenario so the graphs overlap each other.

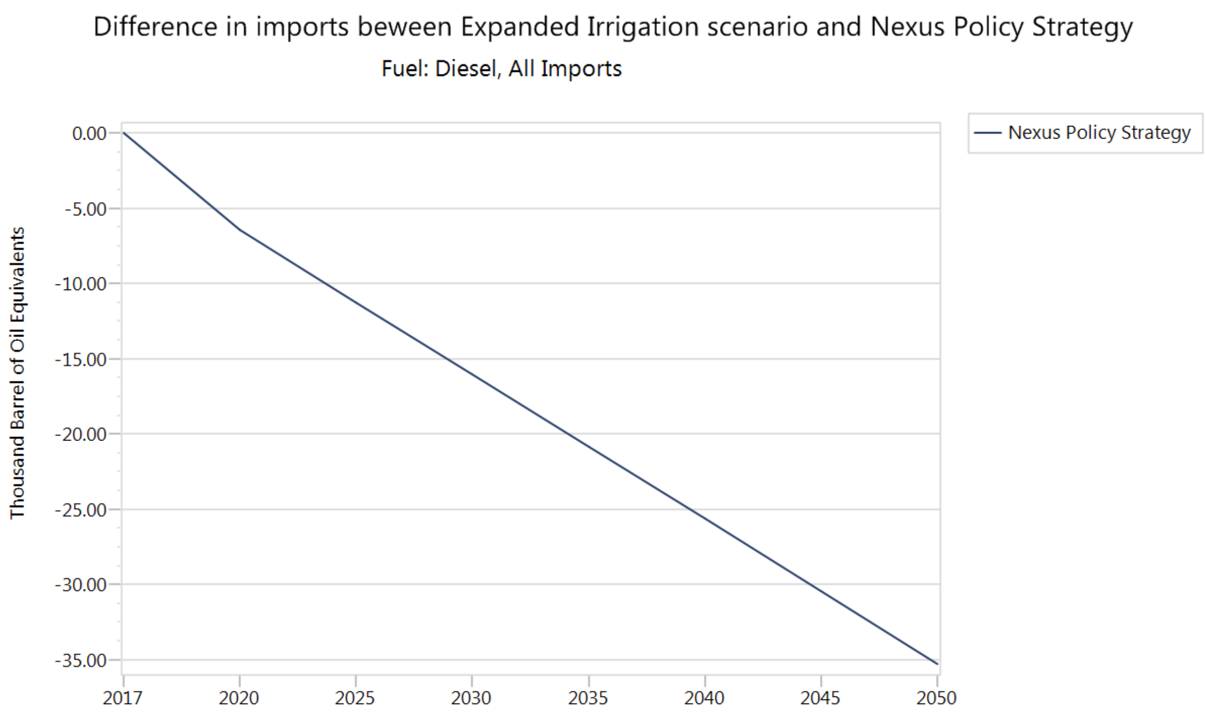
3. Solar powered irrigation

Irrigation is among the measures that can improve agricultural yields and is considered as a basic strategy to alleviate poverty and improve food security. Irrigation is needed mostly during the dry seasons where there is a shortage of rainfall. However, especially for sesame also during the rainy season irrigation might be needed when it has not rained during 2-3 consecutive days. Currently, the sesame harvest in Kafta Humera varies much because of insufficient rainfall during the rainy season (see table 6).

In the previous century the most commonly used type of irrigation was surface irrigation through the use of gravity forces. Nowadays, modern irrigation systems are based on diesel or electric driven water pumping systems. Solar powered water pumping is becoming increasingly interesting because the sharp decline in costs of solar PV[21]. Solar pumping affects energy use, but there are clearly cross sectoral aspects related to cop yields, water consumption, energy expenses and environmental impacts.

In the Nexus Policy strategy it is assumed that 51% of the irrigated land (200,000 ha in 2050) will use solar energy to pump water. Figure 16 shows how this affects diesel demand.

Figure 16 Difference in diesel imports of solar powered water pumping



In the Expanded Irrigation scenario the irrigated land area in Kafta Humera is assumed to gradually increase to 200,000 ha in 2050 and for water pumping diesel powered pump sets are used. In the Nexus Policy Scenario the assumption is that 40% of the 200,000 ha will be irrigated by solar based water pumping systems. Figure 16 shows the difference in diesel use (imports) between the two scenarios.

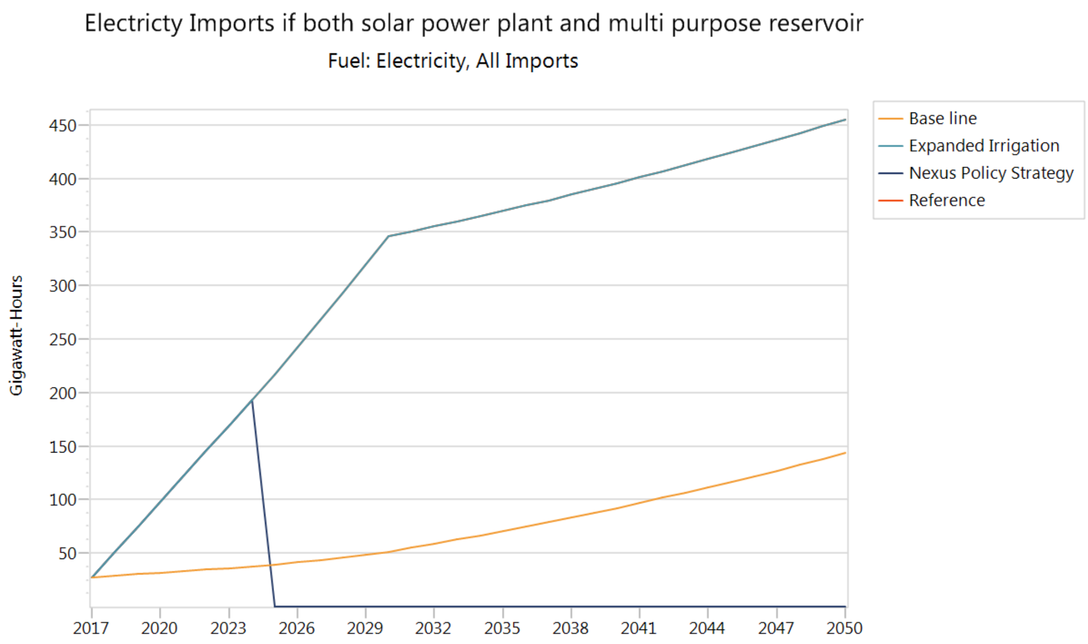
[21] The cost of 10 HP solar pumping system and 9,000 Wp (discharge of 70,000 l/day) is approximately USD 22,000.

The consumption (import) of diesel will decline if more solar based water pumping sets are used. This could save up to 35,000 barrels of oil equivalent in 2050 which corresponds to 5.3 million litres of diesel annually.

4. Construction of multi-purpose reservoir in Tekeze river

The construction of a multi-purpose reservoir in the Tekeze River has already been studied but no policy decision has yet been taken on the construction of the reservoir. The reservoir can provide water for irrigation and drinking water and the turbines in the dam can produce electricity. For the Nexus Policy Strategy, a 50 MW hydro plant is assumed with 80% availability and it starts producing electricity in 2025. If this hydro plant is included in addition to the solar energy power plant no electricity imports are needed anymore as shown in Figure 17. In fact, total electricity production exceeds demand and an amount of 110 gigawatt hours can be exported.

Figure 17 Electricity imports for the four scenarios



5. Afforestation

During the past decades Ethiopia has experienced high levels of deforestation due to agricultural expansion and wood & charcoal consumption. This has resulted in a dramatic decline in forests area from 40% of total land area at the turn of the 19th century[22] to less than 5 % in 2015. To combat the high deforestation rate the Ethiopian government has - in addition to the introduction of efficient cook stoves - developed and implemented afforestation and reforestation policies. These policies involve farm land and community tree planting programmes and rehabilitation and creation of productive forest land that aim to improve local livelihoods, to reduce total water consumption through evapotranspiration and to increase fuelwood availability.

22 Restoring Ethiopia's forestland at a historic pace; Sara Shibeshi, 2015.

The total forest area in Kafta Humera in 2017 is approximately 240,000 ha. Although Humera is relatively well endowed with forests compared to the rest of Tigray province, the current levels of wood and charcoal consumption are highly unsustainable. If this trend continues the forests in this woreda will be depleted by 2034 as shown in the previous section. This calls for immediate policy action that could involve several options ranging from decreasing wood demand by higher efficiency cook stoves and switching to other fuels (electricity) to measures that aim to increase the available wood resources.

As explained earlier, wood consumption in Kafta Humera is expected to increase rapidly, especially after the influx of 200,000 people who will be employed by the Bae'ker industrial park in 2025.

Table 24 presents the wood demand-supply balance based on the LEAP analysis and the following assumptions:

- 1 GJ = 64.5 kg of wood
- 1 m^3 of wood = 710 kg
- The annual sustainable wood yield is 1m^3 per ha
- The forest area in Kafta Humera is 240,000 ha.

Table 24 Wood and charcoal demand and sustainable wood supply in Kafta Humera

	2017	2030	2050
Sustainable wood supply(mln kg)	170.4	170.4	170.4
Wood demand from hsh (mln kg)	48.1	61.4	71.6
Wood used for charcoal production (mln kg)	219.0	445.4	733.0
Total wood demand (mln kg)	267.1	506.8	804.6
Deficit (mln kg)	96.7	336.4	634.2
Area needed to fill wood deficit(ha)	136,189	473,861	893,292

The annual sustainable wood yield from the currently available wood resources is estimated to amount to 170 million kg. This is not enough to meet current wood demand of 267 million kg, let alone estimated future demand of 804 million kg. An additional forest area of some 136,000 ha is needed in 2017 to be able to meet wood demand in a sustainable way. This does not seem possible and means that afforestation can only cater to a limited extent for the energy needed for cooking by households in Kafta Humera. Other measures such as a significant switch to electricity (to replace charcoal consumption) and the adoption of more efficient cook stoves are also needed to achieve sustainable supply of cooking energy for households and a sustainable use of wood resources. For this study it is assumed that during the period 2020 to 2030 10,000 ha of new forests will be planted in Kafta Humera (see figure 18), increasing the sustainable wood yield by some 7.1 million kg annually.

6. Land use for biofuel production

Ethiopia has to import all its oil requirements which account for more than 80% of its export earnings. The country has high potential for biofuel production. To reduce the financial burden on the national budget and create employment and income the government is pursuing a biofuel development strategy focused on the production of ethanol from sugar beet and sugar cane and the production of biodiesel from Jatropha and castor bean plants. Despite its high potential, currently the biofuel sector is still underdeveloped. This is mainly due to lack of a conducive regulatory framework and high production costs. However, the growing concerns about climate change and the rapidly increasing global energy demand lead to renewed interest in biofuels that are derived from renewable sources. Furthermore, the expected increase in global biofuel prices will make the production of biofuels more financially viable.

Biofuels comprise of bioethanol which can be blended with petrol, and biodiesel which can be blended with petroleum diesel[23]. Bioethanol is produced from molasses which is a by-product from the sugar production. There are two ethanol producing sugar factories in Ethiopia but none in Kafta Humera. Biodiesel production is still in an early stage of development in Ethiopia. Some 300,000 hectares have been allocated for Jatropha/castor bean based biodiesel production but so far only very limited amounts of biodiesel have been produced because of high costs of feedstock and low global oil price[24].

The possible (water-limited) yields under both minimal rainfall and maximum rainfall conditions mentioned in an earlier section suggest that both sorghum and sesame yield levels can be dramatically increased, especially under irrigated conditions. The yield increases potentially free up land for biofuel production and 10.000 hectares of reforestation to cushion the predicted forest depletion. Both forms of production do not have to be at expense of food production. Marginal lands are available in the woreda. Assuming an annual oil yield from Jatropha of 1,458 litres per ha[25], approximately 39,290 ha will be needed to produce the amount of diesel consumed by the transport and agriculture sectors in Kafta Humera in 2050.

Energy demand and supply in Kafta Humera for the Nexus Policy Strategy scenario

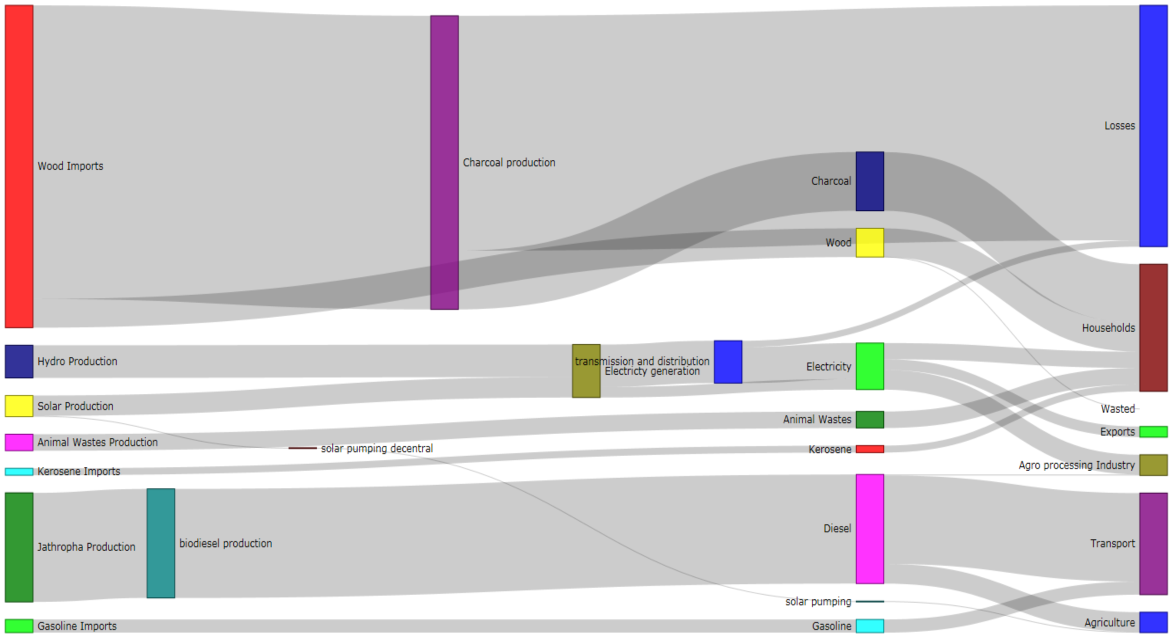
The above six nexus policy measures have been combined into the Nexus Policy Strategy. The energy demand and supply in 2050 in Kafta Humera for the Nexus Policy Strategy is shown in Figure 18.

[23] Ethiopia has set targets for blending of bioethanol with petrol(10%) and blending of biodiesel with petroleum diesel(5%); Climate Resilient Green Economy.

[24] Also, literature on biofuel production is generally not very positive about the potential of Jatropha for this purpose.

[25] A review on potential and status of biofuel production in Ethiopia; Abadi Birhanu, Shimels Ayalew; Mada Walabu University & Dire-Dawa University, Ethiopia.

Figure 18 Sankey diagram for the Nexus Policy Strategy in 2050



The following conclusions can be drawn from a comparison of the Nexus Policy Strategy with the Expanded Irrigation scenario in the year 2050:

- In the Nexus Policy Strategy sufficient electricity is produced in Kafta Humera from hydro(deep blue bar) and solar (yellow bar) to meet the demand. No electricity imports are needed, even a small amount of electricity can be exported (light green bar at the right-hand side of the diagram);
- The electricity needed for the Bae'ker industrial park(dark green bar on the right hand side) is supplied by the solar power plant (yellow bar on the left hand side);
- In the Nexus policy Strategy biodiesel is produced from Jatropha in Humera woreda (dark green bar) which is used to meet diesel demand from for transport and agriculture sectors. Therefore, no diesel imports are needed;
- To meet the demand for wood and charcoal, in both scenarios all the wood has to be imported from outside the region but in the Nexus Policy Strategy at a significant lower level (26%) compared to the Expanded Irrigation scenario because of the adoption of improved cook stoves and afforestation;
- Apart from diesel, in both scenarios all other petroleum products have to be imported; and
- In 2050, Kafta Humera dependency on energy imports is forecasted to decrease from more than 97 % of gross energy consumption in the Expanded Irrigation scenario to 67% in the Nexus Policy Strategy.

4. Concluding

4.1 Conclusions

Generally speaking one can conclude that the planned development of Bae'ker IAIP will not jeopardize sustainable development of the energy, water and food sectors in Kafta Humera. Resources are also sufficient to allow for the envisaged expansion of the irrigation schemes, and to keep the projected population increase food-secure as to the staple food sorghum. It should be noted that this study is not about economic but "physical" feasibility.

Apart from rampant deforestation and the projected depletion of wood resources in 2034 with expected negative implications for water sources, soils and micro-climate, and with likely negative impact for poor groups to get fuel for cooking at a reasonable price, the Nexus analysis did not reveal any other trade-offs to be made between the water, energy and food sectors. The expected shortage of wood (and therefore charcoal) will have to be covered in future by a combination of investments in the forestry sector and related sustainable use of forests (e.g. improved woodstoves), and transition to other energy sources such as electricity. This transition is considered to be achievable.

This is good news for the sesame sector that aims to add value to primary production: under average conditions there is sufficient land, water and energy potential in Humera to fully develop an agro-processing industry in the Bae'ker IAIP.

More specifically for the water sector:

1. For the reference scenario (2030 & 2050): considering only ground water supply as is currently the case this will lead to a water supply deficit to meet all demands in both 2030 and 2050. The 2030 scenario shows a deficit of 11,367 m^3/day and in 2050 there will be 49013 m^3/day deficit of public water supply. In both years, the total irrigation water deficit is estimated to be 120MCM. However, the Tekeze river basin can supply sufficient volumes of water to meet all these demands. In all cases it is important to conduct a groundwater study to determine sustainable use levels of this resource.
2. For the irrigation expansion scenario: the envisaged expansion of irrigation area to 200,000ha will require 1.2B m^3 water. With limited ground water potential this volume of water has to be drawn from the Tekeze River. The RIBASIM model shows this is feasible in terms of available river water volumes.
3. The Nexus policy measures: it can be concluded that Tekeze river basin in conjunction with ground water is capable of meeting all the demand in 2030 & 2050. Even though it has been

challenging to use a significant amount of this Tekeze River due to topography and seasonal variability of flow, the river water can be accessed with various mechanisms. For example by constructing a multi-purpose reservoir along the basin. Because of the topography, the multi-purpose dam can serve to produce hydropower energy while it releases enough water for irrigation and domestic purposes.

4. Extreme drought scenario (assuming the 1984 rainfall): if this kind of drought period returns, there will be unmet demand for both irrigation and public water. In the 2030 scenario simulation result case, there will be 74 MCM total water shortage for irrigation and 2.5 MCM for public water supply. Alternative measures have to be applied to balance the shortage of supply in such crisis years, for example in the form of the above-mentioned multi-purpose reservoir.

More specifically for the energy sector:

1. If the Bae'ker industrial park will materialize as planned, energy demand in Kafta Humera is projected to grow by a factor of almost 6 over the period 2017 – 2050.
2. Households account for the largest share of total energy consumption but their share is expected to decrease from 81% in 2017 to 50% in 2050.
3. There is no one single measure that can be used to address the dwindling wood resources in Kafta Humera. A combination of energy demand management, options to increase the sustainable wood supply and apply other sources of energy is necessary to significantly reduce the current deforestation rate and the risk of especially poor groups not getting access to energy for cooking in the future.
4. The transport sector is the fastest growing energy demand sector in Humera woreda.
5. If no additional policy measures are taken Humera woreda will become almost completely dependent on energy imports in 2050. However, if locally abundantly available solar, hydro and Jatropha resources are developed, the woreda could become self-sufficient in meeting its electricity and diesel demands.
6. The establishment of the Bae'ker industrial park seems feasible and sustainable from an energy sector point of view but the high influx of new workers in Humera will further increase the pressure on wood resources.
7. The impact of climate change on energy demand and supply in Humera woreda is negligible. In case of drought in the woreda it is expected that energy/electricity supply (from elsewhere in Ethiopia) remains constant.

More specifically for the food sector:

1. The agricultural potential of Humera and the IAIP production zones to supply Bae'ker with required inputs seems sufficient. The current production is not sufficient. With regard to sesame in Humera little additional suitable agricultural land can be added to the current production area. It is therefore necessary to double the yield levels. The current yield levels, given current rainfall levels and available land, provide enough room to increase production levels of sesame and sorghum to the levels needed to fulfil the demand related to the Agro Industrial Park.
2. With the introduction of irrigation, the goals needed for the Agro Industrial Park would be even easier to reach. Adding an extra growing season would already double the current land productivity.
3. Water-limited production levels provide enough room for improvement; also indicating that the main restrictions on production levels are related to factors such as lack of nutrients, occurrence of pests and diseases, and institutional factors.
4. When aiming to increase yield levels the investments could best focus on obtaining the required inputs (seeds, fertiliser, water/irrigation, and pest control), farmer skills and

mechanisation of agriculture. It is noted that the current SBN project and other components of the Benefit Project are dealing with these issues.

5. Population growth in Humera because of natural growth and in-migration due to the development of the IAIP is substantial. The urban and rural population of the district is expected to quadruple between today and 2050. Still, the (potential) production of food is considered sufficient to keep the district food secure.
6. Deforestation rates in Western Tigray in general and Humera in particular have been alarming over the past 25 years. Causes are forest conversion to agricultural land, and demand for firewood. If deforestation continues at the current rates there will be no forest areas left in 2034 with negative effect on CO^2 sequestration, soil fertility due to erosion, river flow due to sedimentation, recharge of ground water levels and the risk of especially poor groups not getting access to energy for cooking.
7. Under stress such as during the drought of 1984 in which rainfall dropped to 50% of the normal, the yield would also equally drop 50%. When combined with extreme high temperatures (>40°C) most cereal (food) crop cannot survive. Most likely local food production will not be able to sustain the population and preparation for such extreme events is key.

4.2 The Nexus approach – what have we learnt in Humera woreda?

The following lessons were drawn:

1. Applying a Nexus approach encourages sector ministries to look beyond their boundaries of jurisdiction,
2. and think through the implications of policies and practice on relevant sectors. This was confirmed by
3. stakeholders in the Mekelle 6th of December 2017 workshop.
4. Nexus thinking encourages representatives from the water, energy and food sector to jointly arrive at
5. "smart innovations" that deal with identified trade-offs. This is likely to make related decisions more realistic and implementable.
6. The nexus approach proved to be a valuable addition to the detailed feasibility study for Bae'ker IAIP in the sense that future implications of Bae'ker operations on water, energy and food security were analysed, and feasibility from that perspective was confirmed.
7. The Nexus approach that we applied took into account in its models the climate change that is foreseen for the studied region (i.e more extreme events such as dry spells). It prompts representatives from all three sector to jointly think about climate change implications and mitigation measures across sectors, making these measures more realistic in implementation.
8. The LEAP-RIBASIM-Agriculture modelling combination allowed a detailed analysis of cross sectoral impacts of different policy choices. This enables policy makers to design a more efficient and effective policy strategy to achieve the objectives of the WEF sectors simultaneously.
9. The applied approach was based on data that were not always complete or completely reliable. For example: we missed data on sustainable groundwater yields, we made assumptions about the growth rate of woodlands and the kilograms of wood in 1 m^3 and we used data from case studies conducted in other regions of Ethiopia. We made best guesses and in that way we could obtain a picture that is not 100% reliable but still gives a fair impression of the occurring trends in the different scenarios.
10. Time and budget constraints prevented the project team to analyse the costs and environmental implications of the proposed nexus policy measures in more detail. It is recommended to examine these aspects more thoroughly in follow-up activities because they can be decisive in formulating the most efficient WEF nexus policy strategy.

11. In the December 2017 workshop with stakeholders in Mekelle a collaborative modelling game was presented. There were not enough funds available to develop the game for the three sectors; only water was covered. Stakeholders in the workshop had to allocate a limited amount of investment to different water management options. It was an exercise to increase the awareness of the stakeholders about different trade-offs in the water sector. It could still be useful to further develop the game so that it covers all three sectors. Generally, the session was very productive and helped the participants to understand how important it is to work together while dealing with a problem that affects many stakeholders.

4.3 Nexus and climate finance

One of the main outcomes of the 2009 climate change summit in Copenhagen was the commitment of industrialised countries to give USD 100 billion a year in additional climate finance from 2020 onwards. While there is no internationally agreed definition of the term 'climate finance', it here refers to the financial flows from developed to developing countries and emerging economies that are needed to help them develop and implement policies that aim to combat the effects of climate change.

According to the OECD, the aggregate of public and private climate finance mobilised by developed countries for developing countries reached USD 61.8 billion in 2014 (USD 45.1 bn public finance and 16.6 bn private finance)[26]. Although these flows are substantial, they fall short of the estimated USD 350 billion that developing countries need annually to implement their UN climate pledges given in the Paris Agreement. It is therefore expected that climate finance flows will increase rapidly in the coming decades and that this will create growing opportunities for companies that can offer climate technologies or expertise to benefit from this emerging 'climate market'. The water-energy-food nexus offers special opportunities because nexus solutions typically pursue low carbon climate resilient development and therefore qualify for climate finance.

The international architecture of climate finance comprises a wide range of actors including national, bilateral and multilateral climate funds. The climate finance landscape is still under development, with new financial institutions and instruments being set up regularly. The four main multilateral climate funds (MCFs) are the Green Climate Fund (GCF); the Adaptation Fund(AF); the Climate Investment Funds (CIF); and the Global Environment Facility (GEF). Some valuable insight for (Dutch) companies about the landscape of multilateral climate funds and the possibilities to get involved through the projects and programmes these MCFs finance can be found in the 'SME Guide to Multilateral Climate Funds'[27]

Climate change is now high on the political agenda in Ethiopia. The government has developed the 2011 Climate Resilient Green Economy (CRGE) strategy which aims to achieve simultaneously the objectives of developing a green economy and building greater resilience to climate change. The priority sectors mentioned in the CRGE are hydropower development, rural cooking technologies, the livestock value chain and forestry development. These sectors are very relevant also for Kafta Humera and the Nexus Policy Strategy developed to achieve sustainable development for this woreda includes these sectors.

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[26] Climate Finance in 2013-2014 and the USD 100 billion goal; A report by the OECD in collaboration with Climate Policy Initiative

[27] SME Guide to Multilateral Climate Funds; Dutch Climate Solutions Research program 2014-2017;ECN, Wageningen UR, Deltares; June 2017.

In order to achieve the CRGE's objectives, Ethiopia is actively seeking access to international climate finance. The main achievements in this respect are:

- Climate Investment Funds - PREP programme is currently implementing a USD 50 million wind and geothermal development programme in Ethiopia
- Climate Investment Funds - PPCR programme is developing a Multi-Sector Investment Plan for Climate Resilient Agriculture and Forest Development 2017-2030 focussing, amongst others, on better resource management, affordable access to climate smart energy and low carbon electricity production. Expected start of the programme is mid-2018.
- In March 2016 the Ethiopian Ministry of Finance and Economic Cooperation became the national accredited entity of the Green Climate Fund. In October 2017 the GCF's 18th Board meeting has approved the Ethiopian Government's $50m climate resilience proposal focusing on sustained provision of water for potable and productive use, including the use of solar energy to power the water pumps, and improved land use management to increase ground water recharge and soil nutrient content. This is Africa's largest GCF direct access proposal.

At the national level Ethiopia established in 2012 the Ethiopian Climate Resilient Green Economy Facility. This is a financial mechanism that can provide concessional loans, grants, performance based payments, risk mitigation instruments and capital assistance to support the implementation of the CRGE, including nexus policy measures. The facility will be primarily accessed by Government institutions at federal, regional, local level and by communities. Funding sources include global climate finance and domestic public funding.

The above implies that in principle it should be possible to find funding for the proposed nexus policy measures elaborated under section 3.5 if these can be proposed in a politically and economically feasible way.

Literature cited

Awetahegn Niguse et al (2015). Agro Climatic Characterization of the Western Zone of Tigray Region, Humera. In: Journal of Environment and Earth Science, Vol.5, No.17, 2015, page 24 - 26.

Berhe, Amare & Kefyalew, A & Zeleke, M. (2012). Typical features, characterization and breeding objectives of Begait sheep in Ethiopia. Animal Genetic Resources/Ressources génétiques animales/Recursos genéticos animales. 51. . 10.1017/S2078633612000379.

Binyam, Alemu Yosef (2012) Carbon stock potentials of woodlands and land use and land cover changes in north western lowlands of Ethiopia. MSc. Thesis

CSA – Central Statistics Agency population reports 1994 and 2007.

EMA (Ethiopian Mapping Authority), 1988. National Atlas of Ethiopia. EMA, Addis Ababa, Ethiopia. 76 pp.

Eshete, A. Sterck, F. and Bongers, F., 2011. Diversity and production of Ethiopian dry woodlands explained by climate and soil stress gradients. Forest Ecology and Management 261: 1499-1509.

Federal Democratic Republic of Ethiopia (2015). Integrated ACPZ & IAIP - western Tigray. Feasibility report.

Federal Democratic Republic of Ethiopia (Undated). Ethiopia's Climate Resilient Green Economy - Climate resilience strategy, agriculture and forestry.

Federal Democratic Republic of Ethiopia/national Planning Commission (2015). GTP II.

Fredu Nega et al (2011). Baseline Socioeconomic Survey Report of Tigray. Mekelle University & Bureau of Planning and Finance.

Gebrehaweria Kidane (2011). Pastoralists' perception, vegetation diversity and condition assessment in rangelands of Kafta Humera woreda, Tigray regional state, Ethiopia. MSc Thesis.

Gebreegziabher, Z. (2007); Household Fuel Consumption and resource Use in Rural-Urban Ethiopia; PhD thesis. Wageningen University.

Hagose, L.W. (2017). Strategic analysis of Sesame (Sesamum indicum L.) market chain in Ethiopia, a case of Humera District. In: International Journal of Plant and Soil Science, 15(4): 1-10, 2017.

Haile Fesseha Tessema (2007). Land degradation assessment at Idris resettlement scheme, Kafta Humera woreda, western zone of Tigray, Ethiopia. MSc Thesis.

Hoff, H. , 2011. Understanding the Nexus. Background paper for the Bonn 2011 Conference: The Water, energy and Food Security Nexus. Stockholm Environmental Institute, Stockholm.

Kafta Humera District Livelihood Report (KHDLR), 2007. Disaster Prevention and Preparedness Agency, Ethiopia.

Kidane, G. (2011). Pastoralists'perception, vegetation diversity and codition assessment in rangelands of Kafta Humera, Tigray regioal State, Ethiopia. MSc. Thesis.

MER (2016). Climate change profile: Ethiopia. MER Report. http://api.commissiemer.nl/docs/os/i71/i7196/climate_change_profile_ethiopia_2016_reduced_size.pdf

Moti J, Mekonnen Y, Adugna T, Mitiku H, Ansha Y, Kindeya G, Kelemework T, Yemane G, Mekonnen T, Nigatu R, Mulugeta T, Abiye A and Kiros M (2011). Impact of Resettlement on the Livelihood, Food Security and Natural Resource Utilization in Ethiopia.

Nega, F., Mathijs, E., Deckers, J., Haile, M., Nyssen, J., and Tollens, E. (2010). Rural Poverty Dynamics and impact of Intervention Programs upon Chronic and Transitory Poverty in Northern Ethiopia, African Development Review, 2(1), 92-114.

Reynolds, J. and G. Cranston, 2014. Nexus thinking: can it slow the Great Acceleration?. Nexus Network think piece. http://www.cisl.cam.ac.uk/publications/latest-publications/nexus-thinking-can-it-slow-the-great-acceleration

WFP-Ethiopia Vulnerability Assessment and Mapping (VAM) (2009). Food security and vulnerability in selected towns of Tigray region, Ethiopia.

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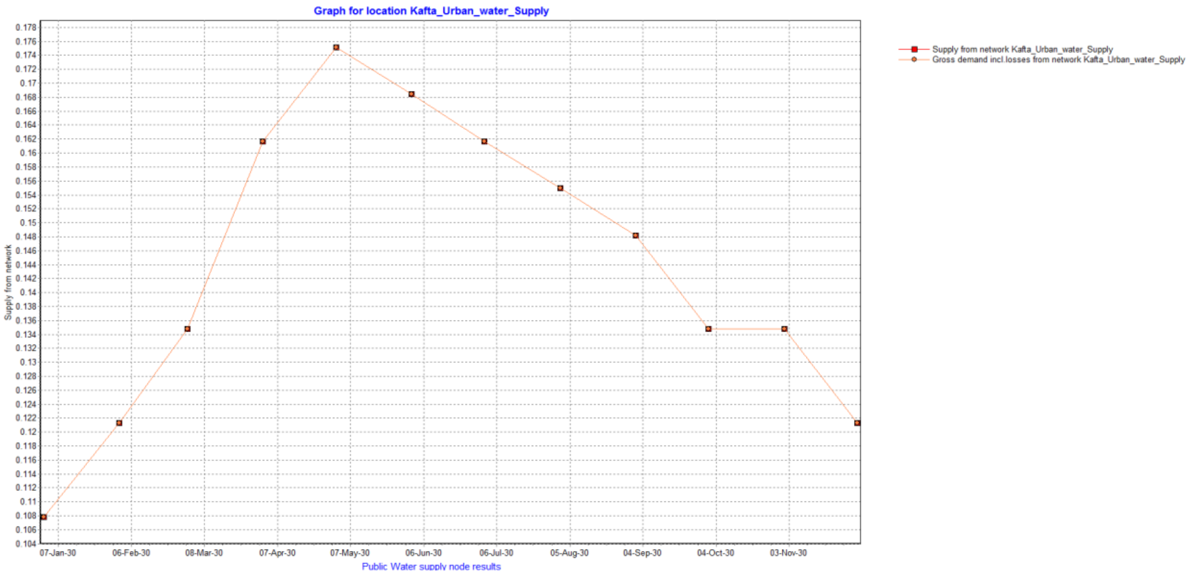
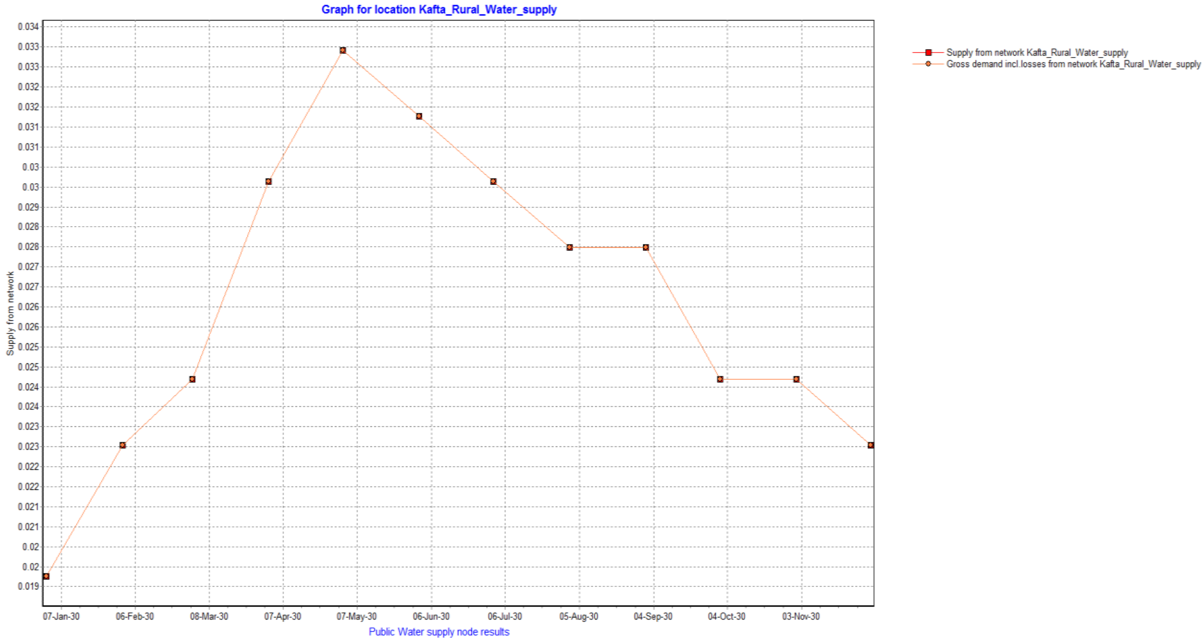
Annexes

Annex A: Reference scenario, Element 1: 2030

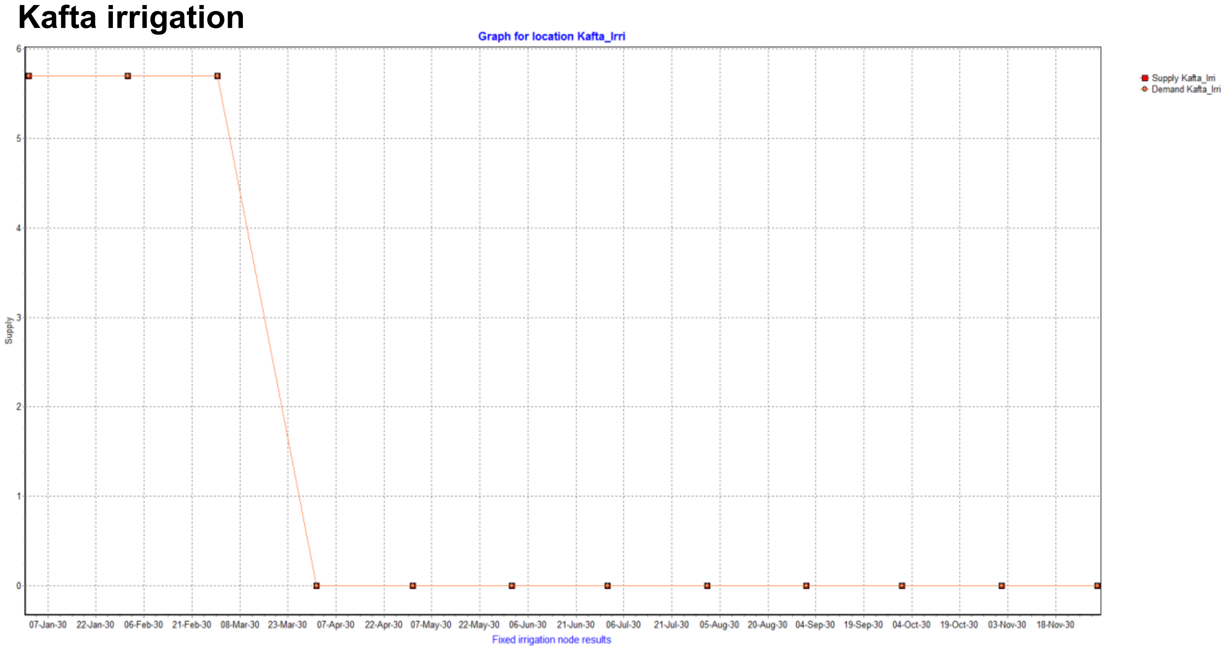
Kafta urban water supply



Kafta rural water supply

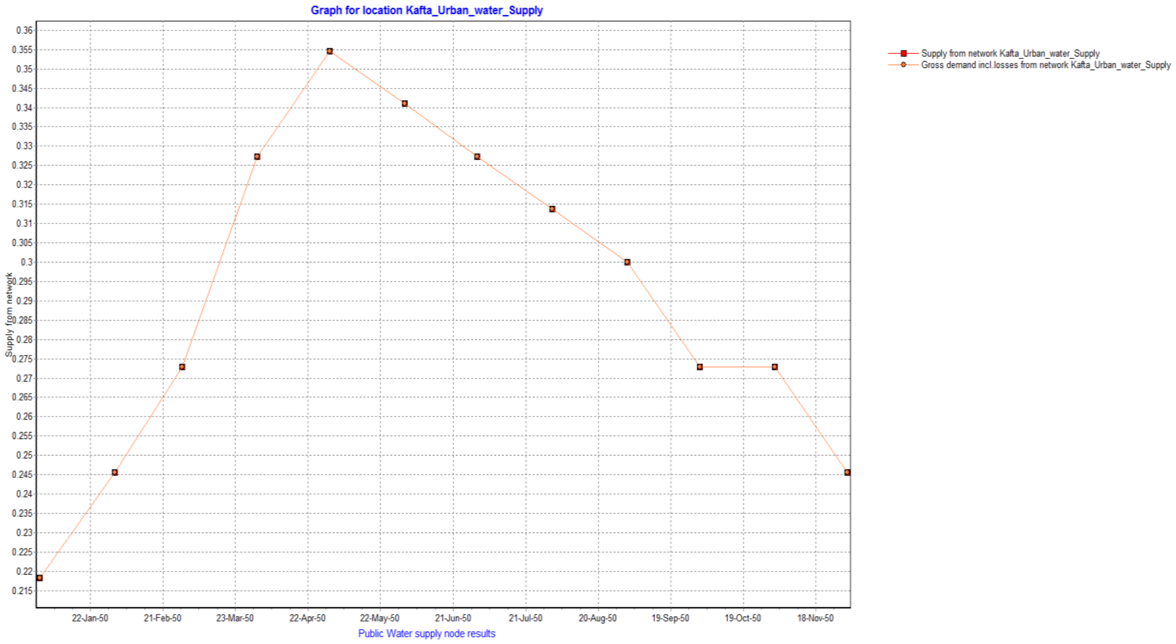


Kafta irrigation

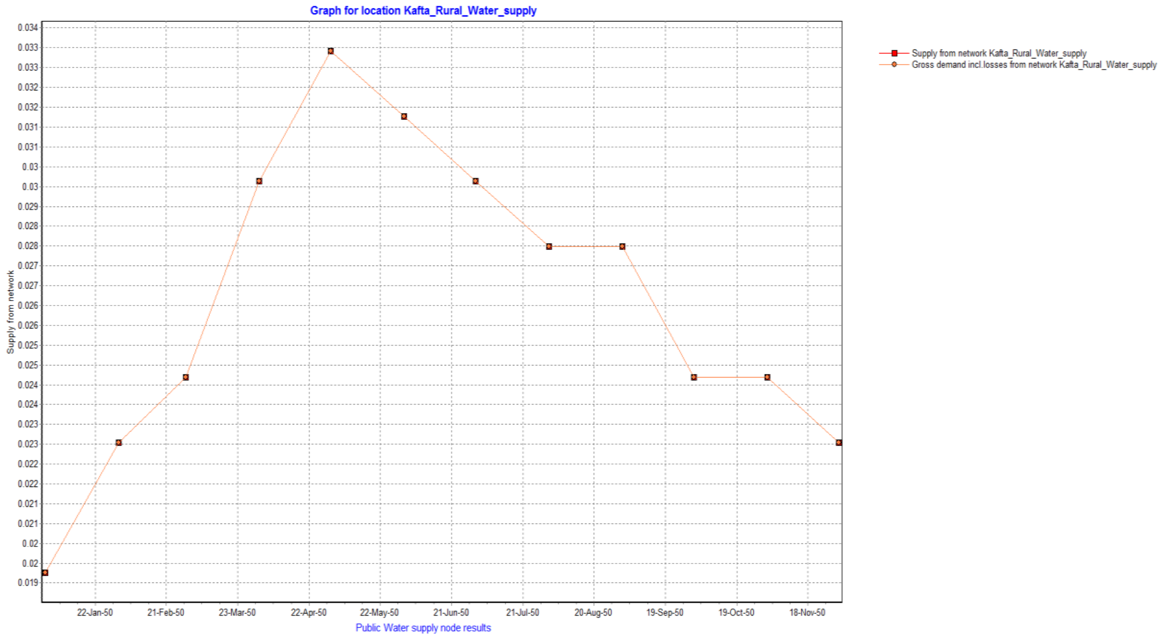


Annex B: Reference, Element 2: 2030

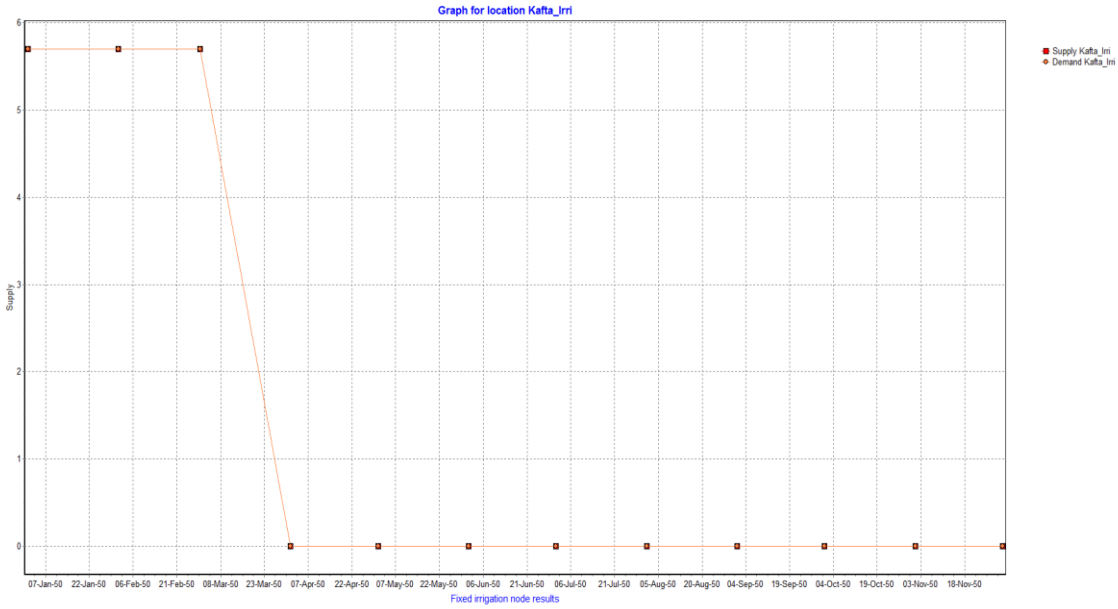
Kafta urban water supply



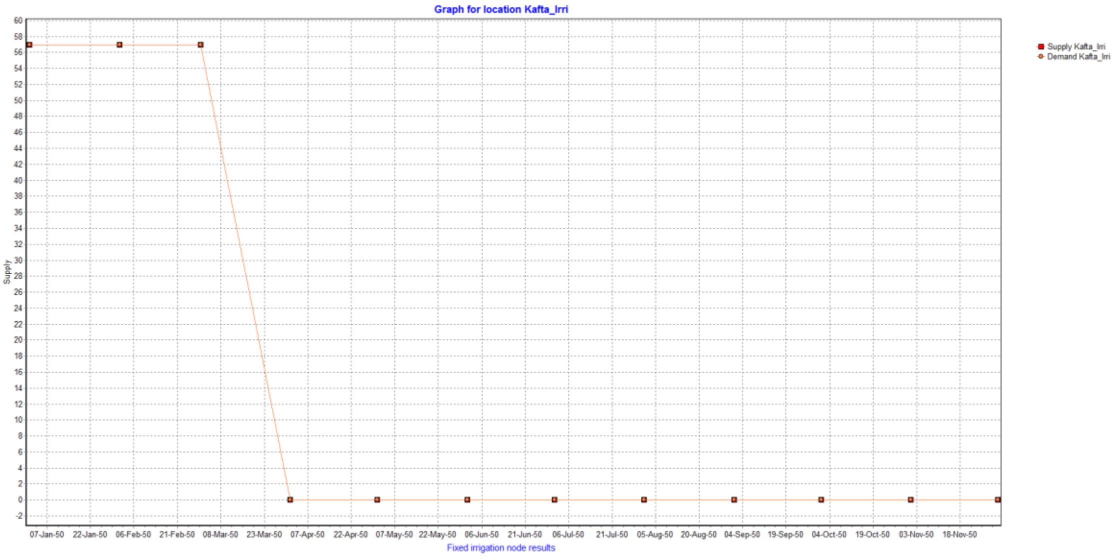
Kafta rural water supply



Kafta irrigation

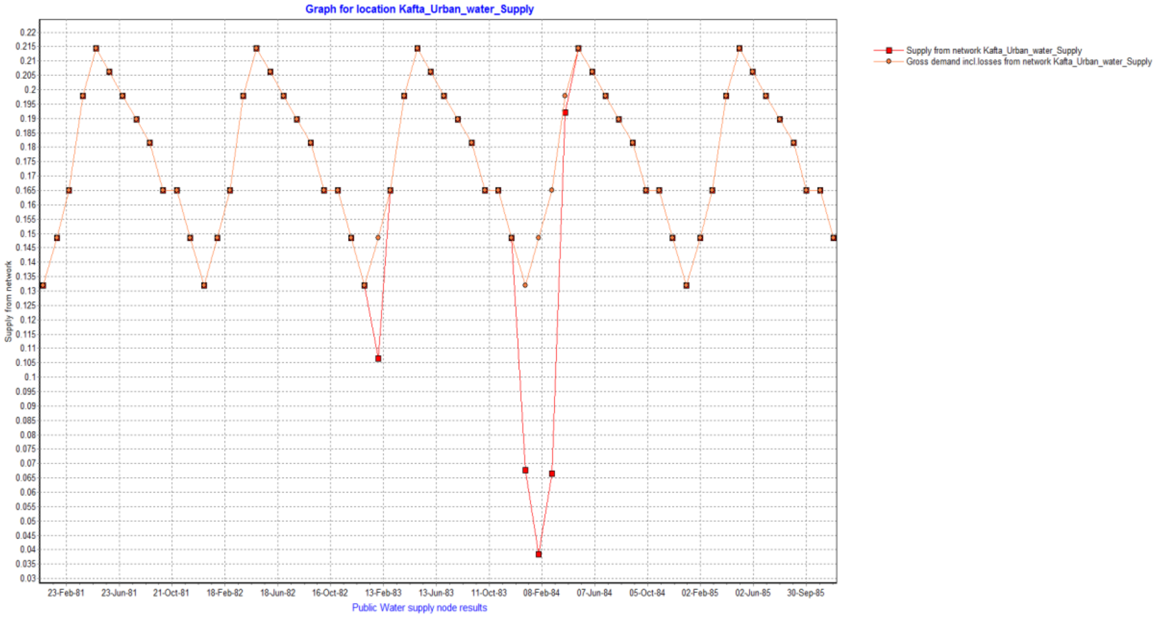


Annex C: Irrigation Expansion (2050, with 200,000 ha irrigation)

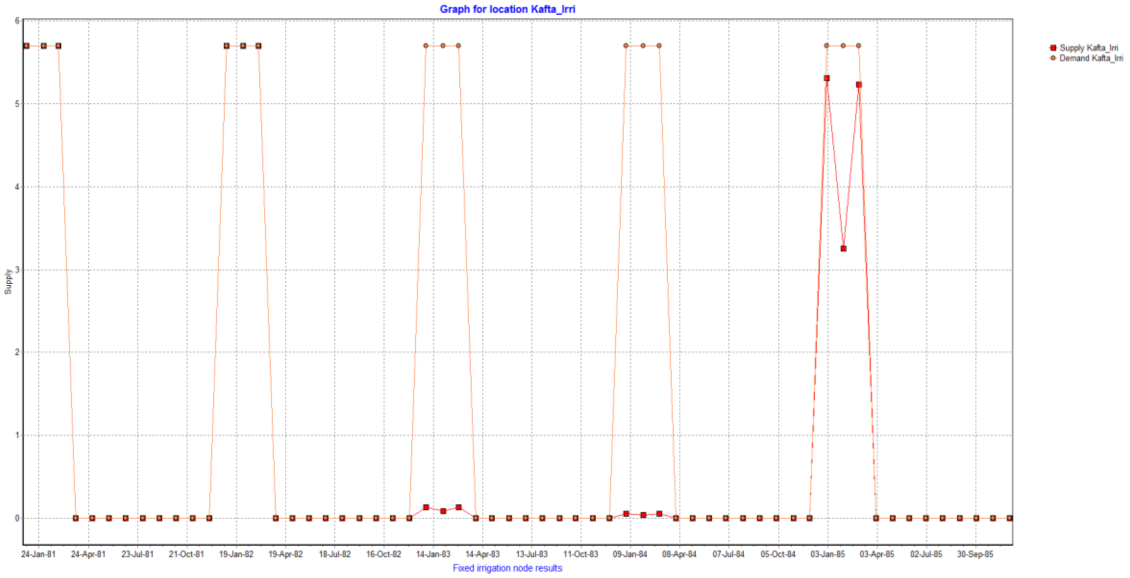


Annex D: Extreme drought period 2030

Kafta urban water supply



Kafta irrigation



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