Chapter

Integrating Water-Food-Energy Nexus with Climate Services: Modelling and Assessment for a Case Study in Africa

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Abstract

This chapter is based on the work of DAFNE project, a decision analytic framework to explore the water-energy-food (WEF) nexus in complex transboundary water resources of fast developing countries. In particular, we developed three geo- and temporally referenced scenarios under economic growth and climate change in the Zambezi river basin (ZRB), which is the fourth largest river basin in Africa and located in eight different countries.[1] The future scenarios are conceptually driven by the selected combination of the shared socio-economic pathways (SSPs) and the Representative Concentration Pathway (RCP) 4.5. The time horizon of the explored case study in the ZRB shared by eight countries is the period from 2018 to 2060. The aim of this work is to develop a better understanding of the WEF nexus by providing the input to a cost-benefit optimization model aiming to optimally allocate over time and space water-energy-food. The findings show that the water, energy and food requirements are expected to double during the period of interest considering only demographic development, while economic development and international trade will put an additional burden to the supply chain in meeting those goals.

Keywords: modelling tool, integrated assessment, river basin, demographic index, water, electricity and food projections, economic indexes forecast, nexus, Africa

1. Introduction

Developing countries are in front of unprecedented changes, which will determine their paths in economic, environmental and social terms. Climate change, demographic explosion, new international strategies and economic development opportunities constitute some of the competitive drivers of their future pathways.

The Zambezi river basin (ZRB) is the fourth largest basin of Africa with an area of 1.32 million km^2 shared by eight countries (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe) and populated by almost 40 million inhabitants. Currently, the available resource meets the water requirements in the Zambezi basin as a whole. However, possible conflicts between

[1] Zambia, Angola, Zimbabwe, Mozambique, Malawi, Botswana, Tanzania, Namibia.

riparian countries in the ZRB can arise due to the asymmetry between resource availability and population density in addition to the fact that the riparian countries have different river basin shares and investment potential, thus determining a different capability to access and use the available resource.

The first section of this chapter will present the storyline and the assumptions of each of the three future scenarios derived by the integration of the representative concentration pathways (RCPs) into the shared socio-economic pathways (SSPs).

The second and third sections deal with the demographic explosion of the riparian countries as a whole and specifically within the Zambezi area and its implication in future water-energy-food consumption.

The last section presents the economic plans of each riparian country in alignment with their long-term Gross Domestic Value (GDP) growth estimations and how the GDP composition projections impact the water and energy requirements of each economic sector. Lastly, a comparative summary of all scenarios is presented leading to the main conclusions of this chapter.

2. Development of the SSPs

This chapter presents socio-economic scenarios comprised of two core elements: a storyline and the table of descriptors. The scenarios refer to a qualitative narrative describing a potential future in combination with quantitative socio-economic elements and trends. The research adopts the SSPs developed by Kriegler [1]. All of them consider mitigation and adaptation policies regarding climate change in the context of different scenarios, and each scenario is depicted by a storyline of a different future, as explained further below. In order to capture the climate change impacts in the SSPs, RCP 4.5 is selected and integrated in the scenarios of interest (**Table 1**). The main assumption of RCP 4.5 is that the carbon dioxide concentration will reach 650 CO_2 eq.; the radiative forcing is stabilised at approximately 4.5 W/m^2 and both will be stabilised after [2].

As presented by [3], all pathways are followed by a number of assumptions enhancing their storyline. In brief, the SSP1 depicts the sustainability scenario, where the technological change is rapid with the development goals being achieved while a path of sustainability that moves towards a less intensive use of resources is followed including lower carbon energy sources and high productivity of land. On the other side, SSP5 represents a fossil-fuelled economy, where in the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. However, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.

The SSP2 or the business-as-usual pathway follows a consistency with the experience of the last century pattern of action. In particular, it illustrates a world, where social, economic and technological trends do not shift remarkably from historical patterns. Socio-economic progress and per capita income growth proceeds unevenly, with some countries developing rapidly while others fall short of expectations. Although sustainable development goals are a priority for global and national institutions, slow progress is made in achieving them. Environmental systems degrade, although there are some advancements, and overall, the intensity of resource and energy use declines. Global population growth is moderate increasing steadily across the twenty-first century. Income inequality persists or improves only

Factor	SSP1	SSP2	SSP5
Population growth	Low	Medium	Low
Urbanisation	High	Medium	High
Education level	High	Medium	High
Equity	High	Medium	High
Economic growth	High	Medium, uneven	High
Globalisation	Connected	Semi-open globalised	Strongly globalised
Policy focus	Sustainable development	Weak focus on sustainability	Free markets, human capital
Institutions	Effective	Modest effective	Effective
Technology development	Rapid	Medium, uneven	Rapid
Energy sources	Renewables	Fossil fuels	Fossil fuels
Energy intensity	Low	Uneven	High
Environmental impacts (policy focus)	Low	Continued degradation	Highly engineered
Challenge to mitigation (policy focus)	Low	Medium	High
Challenge to adaptation (policy focus)	Low	Medium	Low
Natural capital (policy focus)	Very high	Medium/low	Medium
Manufactured capital (industry)	High	Medium	High
Financial capital (industry/GDP)	Medium/high	Medium	Very high
Social capital	High	Medium	Very high
Human capital	Medium/high	Medium	Very high

Table 1.
Summary of the main trends in important factors in the SSP.

slowly and challenges to diminishing vulnerability to societal and environmental changes remain.

In this chapter, the SSP2 is explicitly presented through a number of socio-economic indexes projected and analysed, while SSP1 and SSP5 will be discussed qualitatively at the end of each section in comparison with the baseline, i.e. the SSP2. To stay as close as possible to the storyline of the SSPs, the main trends and assumptions have been downscaled for each scenario in **Table 1**. For example, population growth in SSP2 is assumed to be moderated, while in the other two scenarios, it is assumed that the growth rate will be lower, indicating a gentler slope. More details regarding the downscaling of the SSPs are provided within the following sections.

3. Demographic projections within ZRB boundaries

The ZRB is shared by eight riparian countries, each with a different area within ZRB. The biggest part is occupied by Zambia followed by Angola, Zimbabwe and Mozambique (see **Figure 1**). In this section, an estimation of the population within ZRB is demonstrated as developed in [5], considering social factors such as

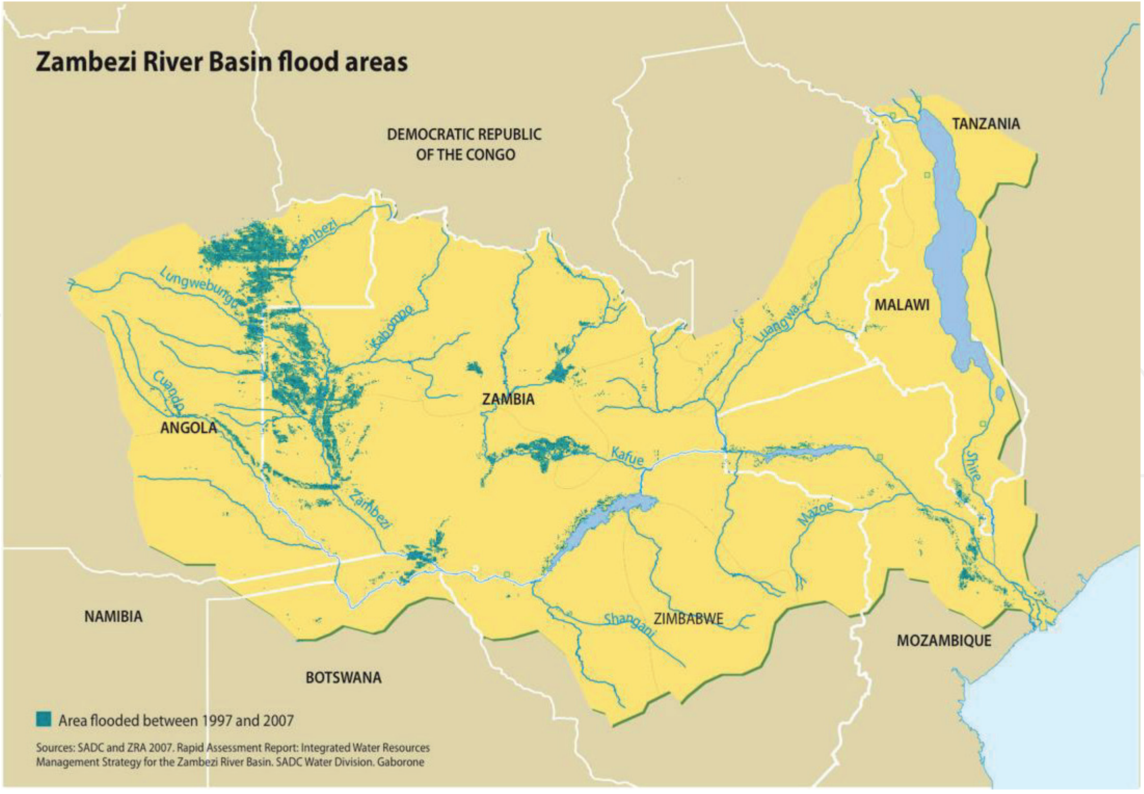

Figure 1.
Zambezi river basin (source: [4]).

mortality, fertility, international migration and urbanisation for the period from 2018 to 2060. The analysis below is based on the SSP2 scenario, which illustrates the middle of the road scenario, assuming that population fertility and the urbanisation level are both medium levels. SSP1 and SSP5 are examined as a comparison to the SSP2 at the end of the section.

3.1 Population growth per country

Population growth by country is estimated and presented in **Figure 2**. In order to calculate those trends, a simple model with one lag considering the values of the previous year and the annual population growth rates per country is run. A comprehensive and transparent selection of the growth rates was an important stage of this exercise, due to its impact on the future trends. After comparing a number of resources, population growth rates provided by [6] seem to have the most transparent and analytical approach. A crucial benefit of this report is not only the 100-year

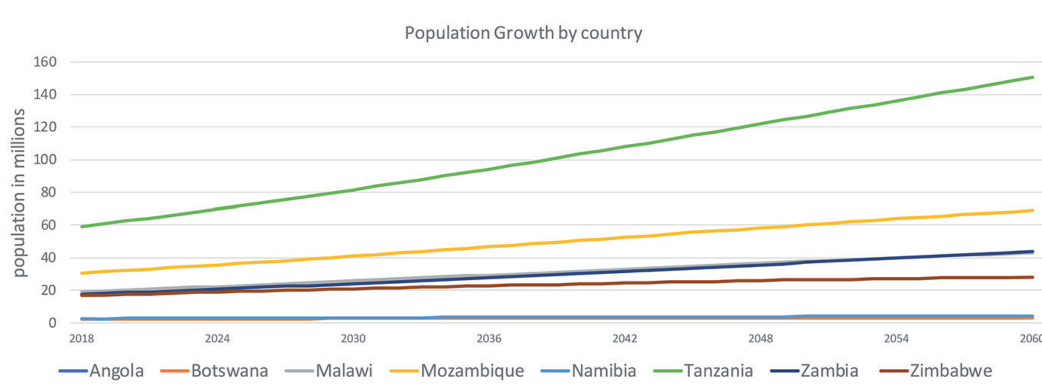

Figure 2.
Population growth by country.

forward looking but also the time slice of the predictions to 5-year periods, which enables projections to be comparatively more accurate. In order to be in alignment with SSP2 pathway, a population growth rate with constant mortality, normal international migration and median fertility assumptions is selected among the 10 indices provided in [6].

In Tanzania, population is proceeding apace in the next 40 years and it is expected to more than double, reaching almost 150 million people, which is of exceptional importance. However, such an enormous population increase would be accompanied by high concentration in major urban cities. Although only one urban city of Tanzania (as urban centres are considered cities with a population greater than 100,000 inhabitants), Katumba, located at the borders of Malawi, is identified within ZRB area, intra-urban agglomeration effects may be noticed increasing so the intensions over the water use of the river. Moreover, Malawi and Zambia, which together have as many inhabitants within ZRB as the rest of the countries jointly, seem to follow similar growth trends starting from 20 million to 18.6 million correspondingly and exceeding 43 million people each by 2060. Hence, the increased needs for water from half of the ZRB population are increasing, but not rapidly in the following 30 years enabling so, factors such as innovation and precautions to play a considerable role.

3.2 Population growth per major urban centre

Major urban centres are outlined by large populations, intensive economic activity and infrastructural development, which inevitably impose a significant strain on natural resources and especially water. Out of the 56 major urban centres with population greater than 100,000 identified for all riparian countries, 19 are geographically located within the boundaries of the ZRB. This chapter presents the population increase of these 19 major cities and the transition of smaller cities into major urban centres within ZRB boundaries during the period of interest.

The estimation of the demographic development for each riparian city is based on the data derived by [7] regarding their population levels in 2018 and by annual population and urbanisation growth rates provided by [6, 8]. **Figure 3** illustrates the population projections by major cities within ZRB, with Lusaka (Zambia) and Harare (Zimbabwe) reaching 3.2 million and 2.6 million people by 2060. The most

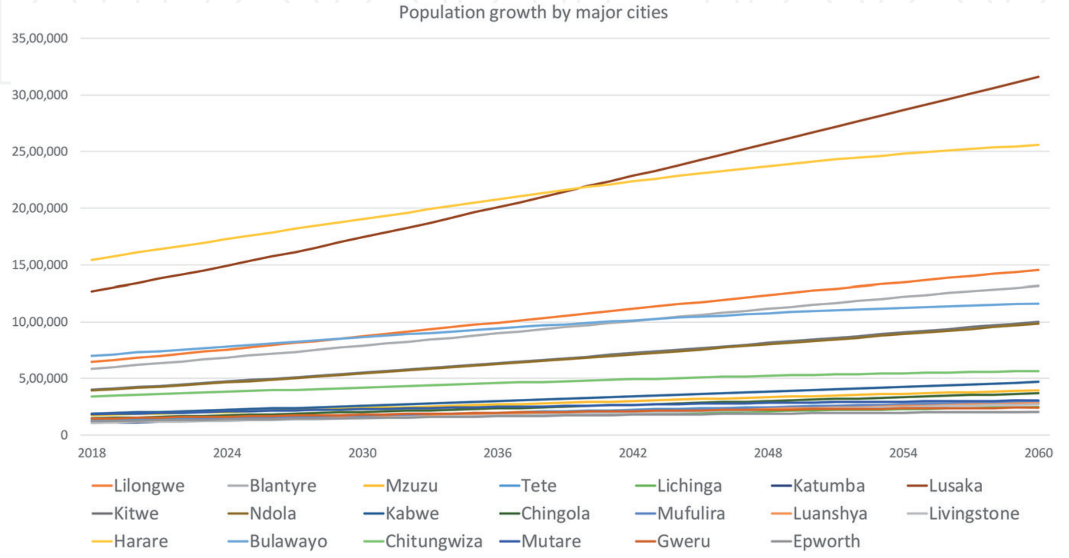

Figure 3.
Population growth by major urban centre.

populated riparian cities are located in Zambia, Zimbabwe and Malawi, with cities located in Mozambique and Tanzania following less vigorous growth. However, 12 non-major urban areas today will become significantly inhabited in the next 40 years attracting investments and necessary infrastructure in order to host the rising population. This transition will also be accompanied by additional pressure on water-energy-food supplies, the demand of which in urban areas tends to be significantly higher. Angola, Botswana and Namibia are not represented in the graph, since none of their major or potentially major cities is placed within ZRB area.

4. Domestic water-energy-food consumption projections within ZRB boundaries

4.1 Domestic future water requirements per country's share within ZRB area

Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments and homes. In this section, the water consumption in the domestic sector for each country is estimated within the ZRB for the period 2016–2060. Data from [5, 7] and the previous section have been used to compute the projected water consumption by private households, where the annual water use per capita is multiplied with the population located in the ZRB for each riparian country.

As presented in **Figure 4**, the water use is expected to increase dramatically if we only consider the demographic growth of the riparian countries. Specifically, the total water use within ZRB is expected to reach 1.8 billion m^3 by 2060, while now it is approximately 0.8 billion m^3. What should be pointed out is that households in Zambia and Zimbabwe consume more water than in Malawi and Mozambique, although they are not dominating demographically within the basin, constituting 25 and 17% of the total population of the basin with the latter two occupying 29 and 24% correspondingly.

Today, most riparian countries withdraw less than 10% of their available freshwater resources, except of Zimbabwe, which withdraws almost 25% of its availability [9]. However, given the countries performance in improving water access as estimated by water, sanitation and hygiene (WASH) [10] only Zimbabwe and

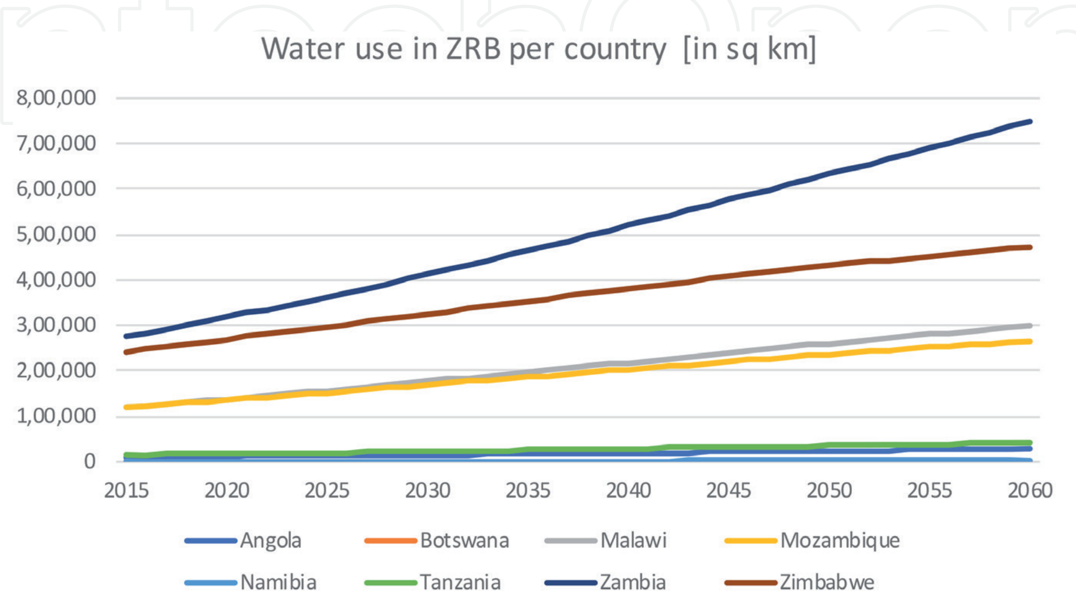

Figure 4.
Water use per country in m^3.

Tanzania are progressing, while Botswana, Malawi, Mozambique, Namibia and Zambia, which withdraw only from 1 to 11% of their freshwater availability are not on track of increasing their access to water, with Namibia having the worst performance. The water stress described above in combination with the climate change, which makes water availability less predictable in many places and it is associated with incidences of flooding, which threaten to destroy water points and sanitation facilities and contaminate water sources, could lead to even lower levels of access to water, increasing so the gap between water availability and water use, which is driven by the high increase of the population in the riparian countries. A lack in providing access to safe water, which is a fundamental human need, would drive protests putting pressure on the government from the society, which could lead in potential conflicts among neighbouring countries through competition for the limited supplies as a matter of national security.

4.2 Domestic future electricity requirements per country's share within ZRB area

As in the previous sector, the electricity consumption per capita in the domestic sector of each riparian country computed from [7] is used to estimate the annual electricity consumption per country's share within the ZRB for the domestic sector considering moderate urbanisation rates and the other SSP2 assumptions.

Figure 5 shows the projected electricity use for the period 2015–2060. By 2060, the total electricity consumption within ZRB is expected to reach 207 TWh, which is more than twice as much as it is today. As before, Zambians living within the ZRB are expected to consume in total more electricity than the inhabitants of Zimbabwe and Mozambique, not because of their demographic advantage, but because of their high electricity use per capita. However, Namibia and Botswana seem to use very low quantities of water for domestic purposes, due to their minor demographic share within ZRB and not due to their actual water needs.

4.3 Domestic future food requirements per country's share within ZRB area

In alignment with the previous two sectors, data for the daily calorie, protein and fat intake needs of an individual for each country from [11] are used to estimate

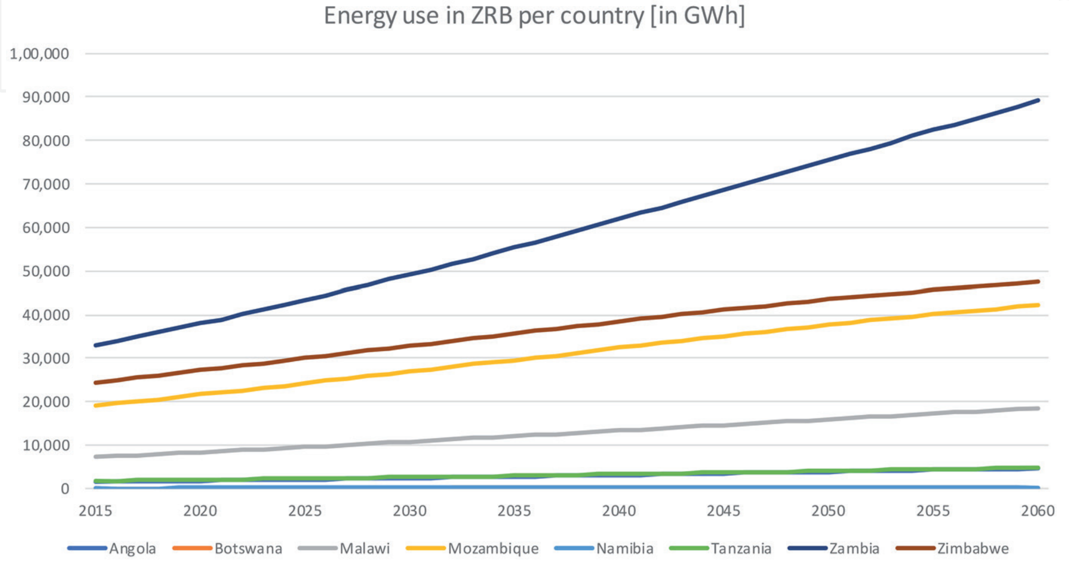

Figure 5.
Electricity use per country in GWh.

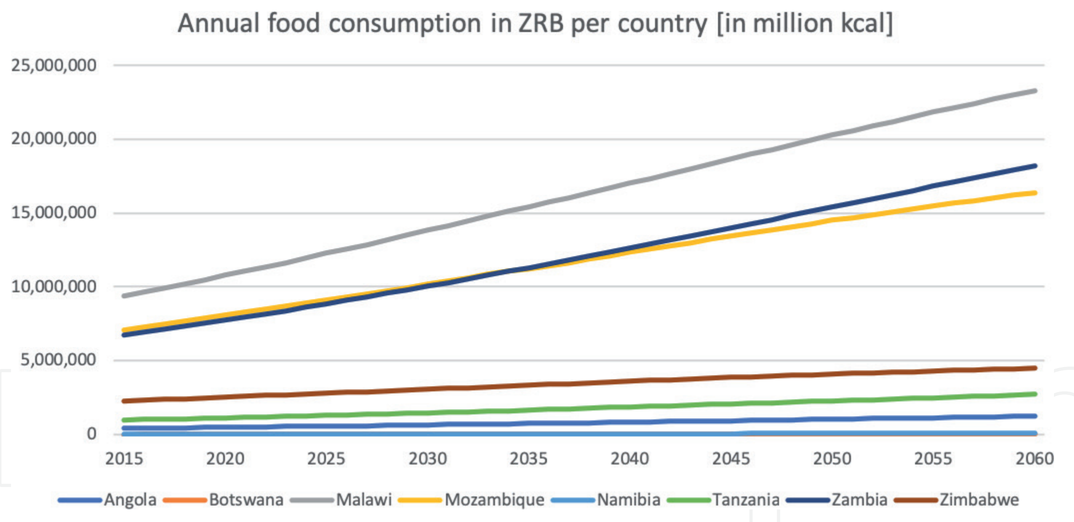

Figure 6.
Food consumption per country in million kcal.

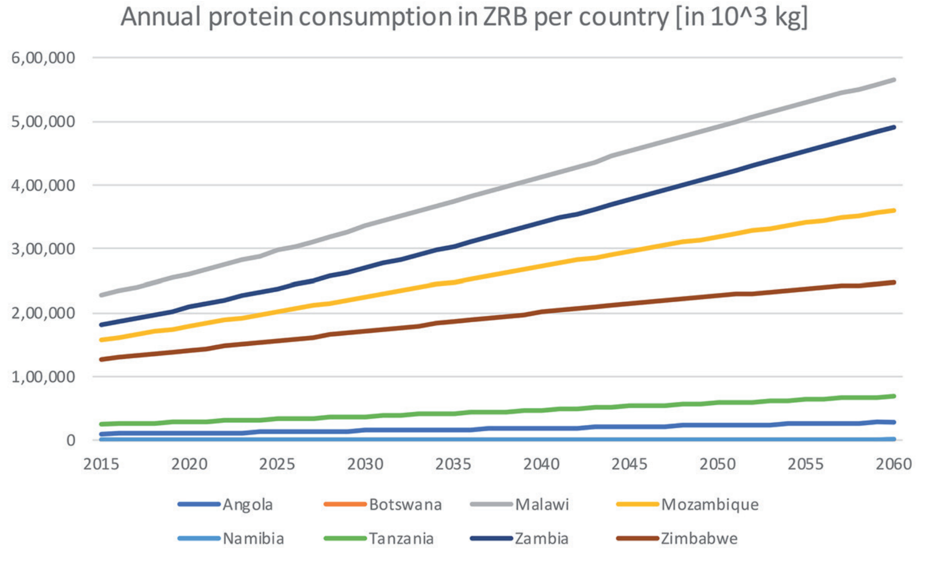

Figure 7.
Protein consumption per country in tonnes.

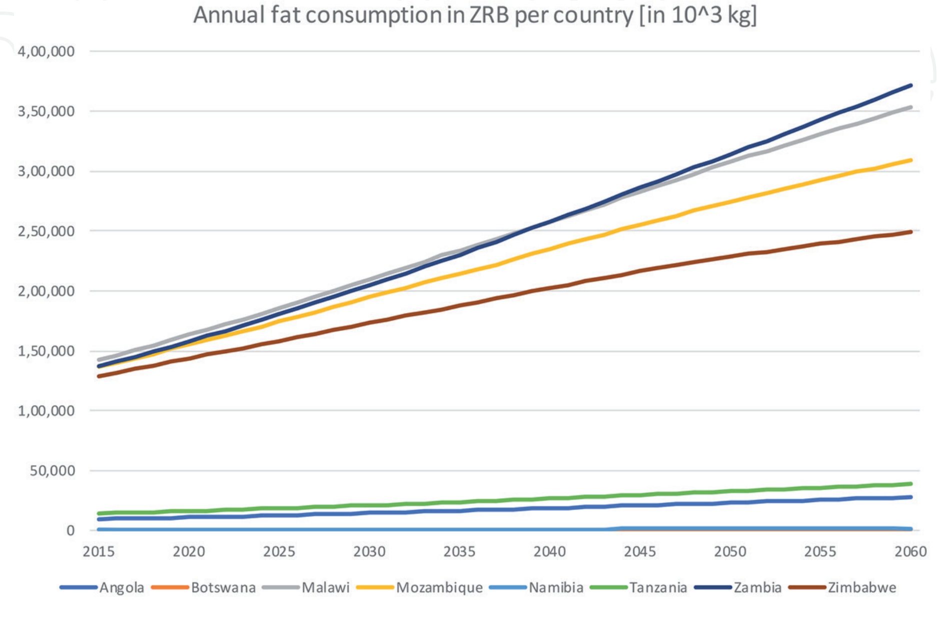

Figure 8.
Fat consumption per country in tonnes.

the long-term food demand. Based on these data, the annual food consumption per person is computed and multiplied with the population projections per country estimated in the previous chapter under SSP2 assumptions to obtain the estimates corresponding to the river basin scale. The outputs of these projections per national consumption of people living within the basin can be seen in **Figures 6–8**. The growth pattern does not change significantly among the graphs. In all graphs Malawi, Zambia and Mozambique have the greatest consumptions, with Malawi being the leader. In terms of total calorie intakes, the total expected consumption in ZRB in 2060 will reach 66.4 trillion calories, with Malawi consuming 35% of them. In terms of protein and fat intakes, the total consumption will reach 1.7 and 1.3 gigatonnes, respectively, with Malawi consuming 32 and 26% in each case.

5. Economic development

WEF future consumption is not only driven by demographic parameters, but by economic development as well. In order to understand the current economic situation and hence, the economic growth of the riparian countries under the SSP2 pathway, indices such Gross Domestic Value (GDP), GDP per capita, employment need to be investigated.

Short-term GDP projections (2018–2023) are based on GDP growth rates and data deriving by [9, 12], while long-term GDP projections (2023–2060) have been made using an AR(1) with one lag model (random walk) with constant slope using data from the post-war period from 1980 to 2017. However, the uncertainty associated with the long-term projections and the intense growth of the riparian countries in the recent future influences significantly the projections making them unreliable after year 2040. The reason why 2040 is selected as a turning point is that no specific plans are available for the period following and hence, a remarkably rapid growth could not be justified neither by development plans nor by past data. Hence, for the period 2040–2060 proxies from other similar countries (in terms of development) are used through splitting the period in decades and using different growth rates.

The growth in the period 2018–2040 will be significantly high, since in this period, the development is enhanced by the 2030 development goals of those countries and the international movements for better life standards in African countries. For example, universal, affordable and sustainable access to WASH is a key public health issue within international development and the main focus of Sustainable Development Goal 6 (SDG 6). According to the performance statistics for 2015, Tanzania and Zimbabwe are placed among the high-performing countries, while Namibia among the low-performing countries [10]. Hence, the GDP growth rates must be in alignment with these ratings until 2030, with high-performing countries growing faster (p.es. Tanzania's GDP is growing with 8.3% rate) than the low-performing countries (p.es. Namibia's GDP is growing with 4.7%).

As presented in **Figure 9**, Angola's GDP is almost as high as the GDP of all the other riparian countries combined, reaching $125 billion in 2017. However, its GDP growth (18%) over the 7-year period from 2017 to 2023 is not as high as the one in the other countries. According to [13], growth in Angola will accelerate, as a result of increased industrial activity and improving energy supplies, while the new administration of President João Lourenço is committed to restoring macroeconomic stability and implementing reforms. Since the last year's election, the administration has started to implement relevant policies including dismissing officials linked to the previous administration, launching investigations into possible misappropriation of funds at several public entities, and creating a specialised anti-corruption unit. Additionally, the impact of a dramatic drop in oil prices that

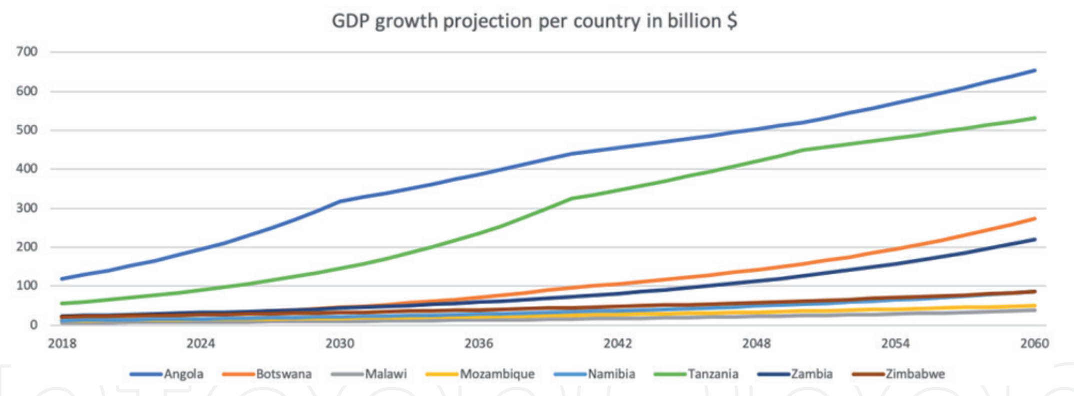

Figure 9.
GDP growth projections per country.

started in mid-2014 in the economy led the officials to address vulnerabilities more forcefully and diversify the economy away from oil, including a significant—17½% of GDP—improvement in the non-oil primary fiscal balance over 2015–2016 [14].

Economic growth in Botswana will be a result of advancements in all main sectors of the economy, but mainly by mineral prices. The outlook for the mining sector of Botswana is positive due to an anticipated increase in demand for Botswana's rough diamonds, with diamonds comprising 75% of the country's total exports. The non-mining sectors are also expected to pick up further, driven by structural reforms, including an amended immigration law that ensures rattling processing of work and residence permits and a move that provides utilities at reasonable prices to encourage domestic manufacturers. Construction is anticipated to continue being benefited by the on-going fiscal stimulus [15].

Prospects have been enhanced in Malawi after the reestablishment of its relations with foreign donors. Malawi's growth ensues from agricultural improvements, stable macroeconomic fundamentals, the recovery in global commodity prices and continued foreign direct investment inflows [15]. However, weather-related shocks are key risks to export commodities such as tea, tobacco and other products, as experienced in 2017, due to high dependence on rain-fed agriculture. The long dry spell in the first half of 2018 and fall 2018's armyworm infestation reduced the maize output, contributing substantially to GDP deceleration in 2018.

Additionally, Magufuli's presidency in Tanzania is expected to create the necessary circumstances for a boost in economic performance of the country, such as road building or fighting corruption. As reported by [14], economic growth in Tanzania has been relatively strong in the past decade resulting from wise macroeconomic policies and consecutive Fund programs, which contributed to low inflation and contained public sector debt.

In Zimbabwe, policy-related macroeconomic instability remains a key challenge for private sector development. In particular, the macroeconomic instability is related to lack of funding, land tenure and investment regulations, high-input costs and outdated machinery, inefficient government bureaucracy, and inadequate infrastructure (particularly energy). However, the country has one of the most youthful populations consisting of 36% of the total population, with the population ages 15–34 [15]. The agricultural sector and mining are expected to be the main drivers of growth, backed by increased public and private investment. Lastly, the government has adopted and is implementing prudent fiscal policy underpinned by adherence to fiscal rules reprioritizing capital expenditure through commitment to increase the budget on capital expenditures from 16% of total budget expenditures in 2018 to over 25% in 2019 and 2020.

The medium-term outlook of Namibia is mixed. Aggregate demand is expected to recover steadily, as private activity picks up and new infrastructure projects are implemented as part of the stimulus package. Growth will also be driven by increased capacity utilisation in a new uranium mine as well as by improved business confidence, since reforms are accelerated. However, growth could remain weak if growth in key trading partners, such as South Africa, continues to be slow or if international prices of Namibia's commodity exports fall. Uncertainty over land reform and the economic empowerment agenda could also constrain the growth outlook. The government's assurance that land will not be expropriated without compensation should help ease such concerns.

Investment in Mozambique is being delayed by the government's default in January 2017 and the increased debt, while growth in Mozambique will additionally be restrained due to political tensions. Recently, a massive popular protest against fuel price increases has taken place. On top of that, downside risks to Mozambique's economic growth include rising prices for key imports such as fuel and food and economic difficulties in South Africa, Mozambique's second largest export destination. Lastly, according to [15], Mozambique's public debt is in distress and failure to agree on restructuring debt and restoring investor confidence could deepen economic hardship and slow growth.

The persisting dependence of Zambia's growth on the price of copper, which fell by more than 18% in 2018, will be restrained by deficiencies in the electricity supply, 97% of which is generated by hydropower, and by lower demand from China associated with escalating trade tensions [13, 15]. To improve investor confidence in Zambia and hence, debt sustainability, which is another key challenge of Zambia's economy, the government announced measures aimed at improving debt sustainability and returning to a rating of moderate risk of debt distress. The measures include an indefinite postponement of new infrastructure projects and the cancellation of some contracted loans that are yet to disburse.

However, considering the historical data of all riparian countries—except of Botswana, which is one of Africa's most stable countries with continuous multiparty democracy—political instability is increased driving so the levels of uncertainty attached to the projections of these countries higher. The estimations of [12] show that by the end of 2023, the GDP in Tanzania, Malawi and Mozambique will be increased by 45, 35 and 35% correspondingly, probably due to expected improvements in the political system of those countries, which have been associated with mismanagement, pressure on the media and corruption. Malawi's elections will take place with three competing parties in May 21st, 2019, Mozambique's elections in October 2019, Tanzania's elections are scheduled in 2020 [16].

In terms of WEF nexus, GDP growth can be constrained or accelerated by water, energy and food risks. Increasing GDP could increase further the demand for water, energy and food, as more and more people could afford to consume higher quantities of these goods. Consequently, an increased burden could be placed on the management of the resources, which except of smoothing people's lives are also initial inputs for the economic growth. Hence, if they are not managed efficiently, they could even slow down the growth of the economy.

6. Water-energy consumption projections per economic sector within ZRB boundaries

6.1 GDP composition

Water and energy are significant inputs of all sectors of the economy. In this case, the economy is assumed to be driven by three main sectors: agriculture, industry and services. The current share of each sector to the GDP of each riparian

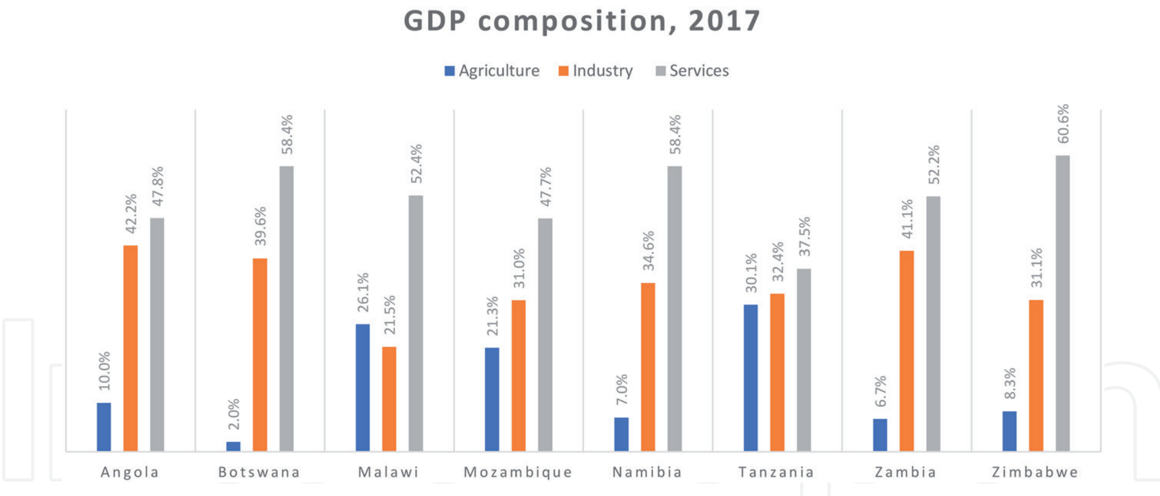

Figure 10.
GDP composition per country, 2017 (source: [9]).

country in terms of added value is illustrated in **Figure 10**, with *agriculture sector* including forestry and fishing, *industry sector* including construction and data deriving by [9]. Services is the driving sector of the economy of all riparian countries, as presented in **Figure 10**. In particular, it skyrockets in Zimbabwe reaching 61%, while it takes its lowest value in Tanzania with only 38% GDP share. In terms of agriculture, only Tanzania, Malawi and Mozambique have a considerable presence in the economy, while comparatively Angola (the second largest oil producers in Africa), Zambia (the second largest copper producer in Africa after Congo) and Botswana (one of the world's major diamond producers) are more industrial countries.

6.2 Future water requirements per economic sector

The water use associated with the industrial, agricultural and service sectors differs significantly not only across the sectors, but across countries as well. It is clear that the majority of freshwater withdrawals occur within industry sector, the annual consumption of which in 2017 varied from 13 billion cubic meters in Namibia to 611 billion cubic meters in Angola. Such a difference is not attributed to the difference in their industry sector's share of added value to their GDP, which is only 8%, but to their vast GDP difference, which implies a significant disparity in the size of the industry sector in each country. Indeed, according to the World Bank [9], the value of the industry sector in Angola is $52.3 billion, which is four times higher than the annual GDP of Namibia.

In order to compare the annual water consumption of the three sectors, we can consider the average water use in 2017 of the aggregated water consumptions of the eight riparian countries in each sector. As shown above, almost all freshwater withdrawals are consumed by the industry sector, which on average needs 134.5 billion cubic meters per year, while the agriculture needs only 1.1 billion cubic meters and the service sector less than 0.3 billion cubic meters. In order to come up with these numbers, data from [9] are used for annual freshwater withdrawals per sector to calculate the water use in billion cubic meters per 1% of added value in the GDP. Due to lack of data, this step was necessary in order to get an average water use per country, compute the current values and estimate the total water use per sector and per country.

Another interesting aspect of the water use per sector is its projection in the future. Considering the trends on GDP composition projection estimated in [5] and the average water use per sector and country, annual projections

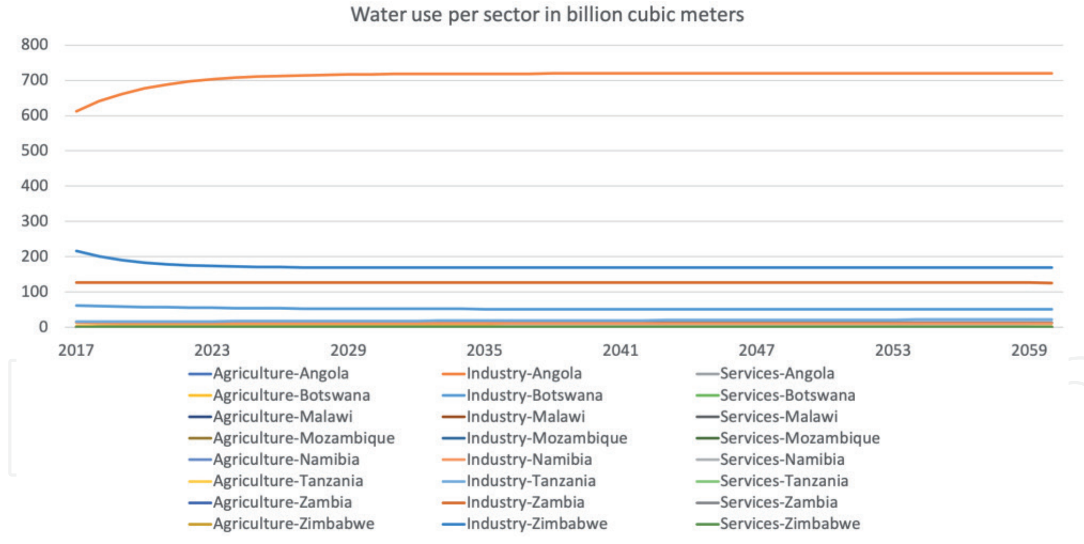

Figure 11.
Water use projections per sector per country.

have been computed and illustrated in **Figure 11**. As SSP2 scenario commands, without any dramatic changes in the distribution of the economy of the riparian countries, water use will keep on being extremely high for the industry sector of Angola, Zambia and Zimbabwe varying between 126 and 719 billion cubic meters in 2060.

As described in the previous section, access to freshwater is a crucial aspect of how future needs will be met. In terms of economic sectors, traditionally agriculture seems to require the majority of freshwater withdrawals at the most riparian countries with the range from 70 to 89% of the total withdrawals of each country. This means that in some countries, the economic activity of which is based on the agriculture, such as Tanzania, Malawi and Mozambique, will be highly sensitive on water withdrawal fluctuations as a result of increased population, low improvement rates of water access and climate change [9, 10]. A decrease in the economic activity deriving from agriculture would not only lower the GDP of the country but increase significantly the unemployment rates and the potential conflicts between the riparian countries in regards with the dominance over the freshwater supplies. Historically, water supply systems have been the objectives of military action and instruments of war, as water demand increases and water supply becomes more problematic and uncertain as a result of global climate change.

6.3 Future energy requirements per economic sector

In order to replace mainstream sources of energy with more efficient and better targeted social safety nets for the most vulnerable energy sources, some countries make significant use of subsidies. In particular, as presented in [15]. Zimbabwe, Zambia and Mozambique received the highest subsidies among the other African countries. In Zambia, mining output is expected to increase by 4–5% in 2019, benefiting from improvements in electricity generation associated with the replenishment of the Kariba Dam due to good weather conditions [15].

Aiming to boost domestic supply of local products, some of the riparian countries chose more conservative policies, such as banning imports or implementing tariffs. For instance, Botswana, Zambia, and Zimbabwe ban imports of poultry, maize meal and cooking oil, while Zimbabwe's competition and tariff by-laws require supermarkets to buy domestically at least 20% of the goods they are selling.

As far as these policies are being performed, domestic agriculture, fishing and animal husbandry will be boosted by facing a comparatively more protected demand and fair prices.

Mozambique could become one of the largest exporters of natural gas in the world by 2020 (the country hosts the third largest reserve in Africa) thanks to the discovery of new reserves. Lastly, the planned construction of natural gas plants as well as a new dam should allow the country to increase its electricity exports to neighbouring countries. Export infrastructure (railroads, deep water ports, liquefied natural gas plants) is also under construction. The country is expected to export natural gas and coal to Asia by 2020.

7. Summary of SSPs

In this chapter, a future scenario for eight riparian countries has been developed and presented explicitly, while two more scenarios have been analysed in comparison with the baseline scenario, SSP2.

7.1 Summary of middle of the road scenario (SSP2)

7.1.1 Society

This path follows a pattern of action that is consistent with the experience of the last century. Under this scenario, the ZRB can expect to see the total population living within the basin after considering urbanisation trends to reach 99 million people by 2060 with 3 million of them being due to urbanisation assumptions. Education levels are moderate limiting so, the social and human capital of the riparian countries, but explaining the significant increase in the population.

7.1.2 WEF nexus

As presented in the previous sections above, water, energy and food consumptions within ZRB are expected to increase significantly by 2060, due to high population growth. The total water use within ZRB is expected to increase up to 1.8 billion m^3 from 0.8 billion m^3, which is the current value, while the climate change in combination with the water stress could increase the gap between water demand and supply. The total energy consumption within ZRB is expected to reach 207 TWh by 2060, which is more than twice as much as it is today. In terms of total calorie intakes, the total expected consumption in ZRB in 2060 will reach 66.4 trillion calories, with Malawi consuming 35% of them. In terms of protein and fat intakes, the total consumption will reach 1.7 and 1.3 Gigatonnes, respectively, with Malawi consuming 32 and 26% in each case.

7.1.3 Economy

In SSP2, although all countries are developing, some of them are making greater progress than the others. Given the historical patterns, the forecasting shows that Angola, Tanzania and Botswana, which are relatively richer in absolute values than Malawi and Namibia, are expected to increase with a higher pace (around 8%) than the other countries, which can accelerate with rate between 3.3 and 5.3%. Hence, existing inequalities are increasing more and more creating a greater gap between developing and developed world. Economic growth is followed by increased employment as well, with agriculture sector playing a significant role in that trend.

7.1.4 Climate change

Limited pro-active initiatives are considered from both Government and institutions in SSP2. The world is semi-open globalised, while the policies do not prioritise sustainability and the institutions are modestly effective. On top of that, extensive use of fossil fuels leads to continued degradation of the environmental assets, while the challenge to mitigate or adapt to these effects is moderate.

7.2 Alternative SSPs: SSP1 and SSP5

While the previous sections depict in detail the SSP2 scenario, where global development follows a middle of the road path, this section considers two alternative futures under SSP1 and SSP5. SSP1 is perceived as the sustainable pathway focusing on the role of the environmental services in the economy, while SSP5 is the economically driven scenario, which, although recognises the economic impacts of the environmental degradation on the economy, does not take pro-active actions, but it focuses on technology improvements able to mitigate the skyrocketed emissions of the human activity.

7.2.1 Sustainability conscious scenario (SSP1)

7.2.1.1 Society

SSP1 envisions a development path with increased investment in education and health. Hence, greater access to education is leading to a relatively rapid demographic transition, due to birth controls and lower child mortality rates, which tones down the moderate population growth noted in SSP2, and also increases the human and social capital of the economy [17]. By contrast, urbanisation is assumed to be rapid in SSP1, which drives high income growth. Under this scenario, urbanisation is desired given the high efficiency that compact urban areas may achieve.

7.2.1.2 WEF nexus

WEF projections would also diversify in the SSP1 and SSP5 as a result of different population inputs. In particular, since the population will decrease and that the urbanisation levels will remain as high as in SSP2, the final population within the basin will be significantly lower and hence the needs for water, energy and food will not increase dramatically.

7.2.1.3 Economy

The main feature of this narrative is the achievement of development goals while following a path of sustainability that moves towards a less intensive use of resources. As presented in **Table 1**, the economic development in SSP1 is expected to be high, with GDP growing more rapidly than the one illustrated in **Figure 9**. The drive of economic growth in this scenario is the fact that the human well-being is redefined in SSP1 considering the environmental services, which are included in the economic development initiatives and in the overall shift of the economy to environmentally friendly actions with the help of rapid technology improvements. Employment in SSP1 will also be rapid following the great economic development of the countries, overpassing the levels of SSP2.

7.2.1.4 Climate change

By contrast, in SSP1, sustainable development is the central focus of all policies across the world, which is connected in decision-making with strong and effective institutions. Renewable sources of energy lead to an optimal treatment of the natural capital, while the need for mitigation or adaptation remains low.

7.2.2 Fossil fuel-driven scenario (SSP5)

7.2.2.1 Society

Similarly to SSP1, SSP5 envisions a development path with increased investment in education and health. Hence, greater access to education is leading to a relatively rapid demographic transition, due to birth controls and lower child mortality rates, which tones down the moderate population growth noted in SSP2, and also increases the human and social capital of the economy [17]. By contrast, urbanisation is assumed to be extremely rapid in SSP5, driving high-income growth. Cities attract migration due to other reasons from SSP1, such as rapid technological change allowing for large-scale engineering projects to develop desirable housing.

7.2.2.2 WEF nexus

WEF projections in this scenario would also diversify than SSP2 as a result of different population inputs. Likewise SSP1 case, population per country will decrease, revealing so the water, energy and food needs per person will also decrease. However, in this case, the urbanisation levels are more rapid than the other two paths, which means that the final population within the basin can be as much as in SSP2 declaring so the similar needs for water, energy and food.

7.2.2.3 Economy

The main characteristic of this narrative is the rapid development of the economy and the intensive use of fossil fuels. As presented in **Table 1**, the economic development in SSP1 is expected to be high, with GDP growing more rapidly than the one illustrated in **Figure 9**. However, the economic strategy of this scenario differs considerably than the SSP1 and SSP2, letting so GDP growth rates take their highest possible values. Innovation and investments are the most preferable options in SSP5, where technological progress and competitive markets drive growth. Employment in this scenario will also be rapid following the great economic development of the countries.

7.2.2.4 Climate change

In SSP5, free markets and emphasis on human capital drive the economy under a strongly globalised status quo administrated by effective institutions. High economic growth driven by energy based on fossil-fuels leads to increases in GHG emissions and so, great mitigation challenges. However, although the dominance of fossil fuels impacts significantly the environment, it does not degrade it more than SSP1, due to high mitigation policies, which control environmental processes through highly engineered systems, nevertheless with no focus on adaptation.

8. Conclusions

This section presented extensively projections regarding different aspects of the SSP2 scenario and then it compared them to SSP1 and SSP5 scenarios for two case studies. The SSP2 scenario illustrates the case, where the global development follows a middle of the road path, with most variables taking moderate values; the SSP1 describes a sustainable pathway focusing on the role of the environmental services in the economy, while SSP5 focuses on the economic progress only, where negative externalities on the environment are treated as a cost and hence mitigated. Demographic and economic indicators have been populated and forecasted, among which are lying population projections per country/major and potentially major city, WEF projections per country within ZRB area, GDP, GDP composition and projections until 2060.

In demographic terms, the total population living within ZRB is clearly affected by a moderate urbanisation trend as assumed in SSP2, while education levels are moderate limiting so the social and human capital of the riparian countries. In SSP1 and SSP5, access to education is greater leading so to birth control, which tones down the moderate population growth noted in SSP2, and also increases the human and social capital of these economies. By contrast, urbanisation is assumed to be rapid in both SSP1 and SSP5, which drives high-income growth. Note, however, that in SSP1, urbanisation is desired given the high efficiency that compact urban areas may achieve, while in SSP5, cities attract migration due to other reasons, such as rapid technological change allowing for large-scale engineering projects to develop desirable housing.

In economic terms, although all countries are developing, some of them are making greater progress than the others, driving existing inequalities to increase more and more and leave a greater gap between developing and developed world. However, although the economic development in both SSP1 and SSP5 is expected to be high, it will be more balanced than in SSP1 scenario decreasing so the existing inequalities. Note, though that the high-economic growth illustrated in the former scenarios is originated from two diametrically opposed strategies. Human well-being is redefined in SSP1 considering the environmental services, which lead development initiatives and the overall shift of the economy towards environmentally friendly actions with the help of rapid technology improvements. On the other side, innovation and investments are the most desirable options in SSP5, where growth is driven by technological progress and competitive markets. However, high fossil-fuel reliance in alignment with the high economic growth leads to higher GHG emissions and hence, higher mitigation challenge.

Lastly, in terms of climate change, limited pro-active initiatives are considered from both Government and institutions in SSP2. The semi-open globalised political environment in addition with the modestly effective institutions fails to prioritise policies regarding sustainability. On top of that, extensive use of fossil fuels leads to continued degradation of the environmental assets, while mitigation and adaptation challenges are moderate. In contrast, in SSP1 sustainable development is the central focus of all policies across the world, which is connected in decision-making with strong and effective institutions. Renewable sources of energy lead to an optimal treatment of the natural capital, while the need for mitigation or adaptation remains low. In SSP5, free markets and emphasis on human capital drive the economy under a strongly globalised status quo administrated by effective institutions. The dominance of fossil fuels impacts significantly the environment, but it does not degrade it more than SSP1, due to high mitigation policies, which control environmental processes through highly engineered systems, nevertheless with no focus on adaptation.

The impact of climate change on access to freshwater will be highly visible under the SSP2 scenario, where the population growth is higher than the other two scenarios and no dramatic improvements in infrastructure are taken. However, the SSP1 scenario seems to handle in the best possible way the climate change uncertainty by having low population growth and increased access to water due to investments, while the SSP1 climate change impacts would be closer to the SSP2, as although population increase with lower to SSP2 rates, the investments in fossil fuels will increase CO_2 emissions, making the climate change impacts more extreme. In addition to the above, improving standards of living would increase further the water requirements of the citizens widening the gap between demand and supply in all three scenarios. Water scarce will increase competition over water supply driving so the political and societal instability within and between the countries.

Energy and food sectors will also be affected by the climate change as they are both based on water access. Hence, under SSP2 and SSP5, energy and food sectors will be significantly disturbed enhancing potential conflicts and wars between the countries as a result of social pressure. SSP1 seems to be the only case, where the adverse effects of climate change are mitigated as a result of the increased investments in water access and lower use of carbon-intensive technologies, as the oil price is high, and renewable energy gets competitive against fossil fuels.

This study has potential limitations. The projections taken place in the model are based on international organisations and studies. Moreover, the lack of data constituted the necessary use of proxies of other similar cases, simplifying so, the individuality of each country. Last but not least, the long-term time horizon is accompanied with great uncertainty. The projections are therefore subject to biases and confounding that may have influenced the results of this section. The breakdown in shorter terms of the indicators analysed in this study could give a more precise understanding of the future status quo in the two CS.

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