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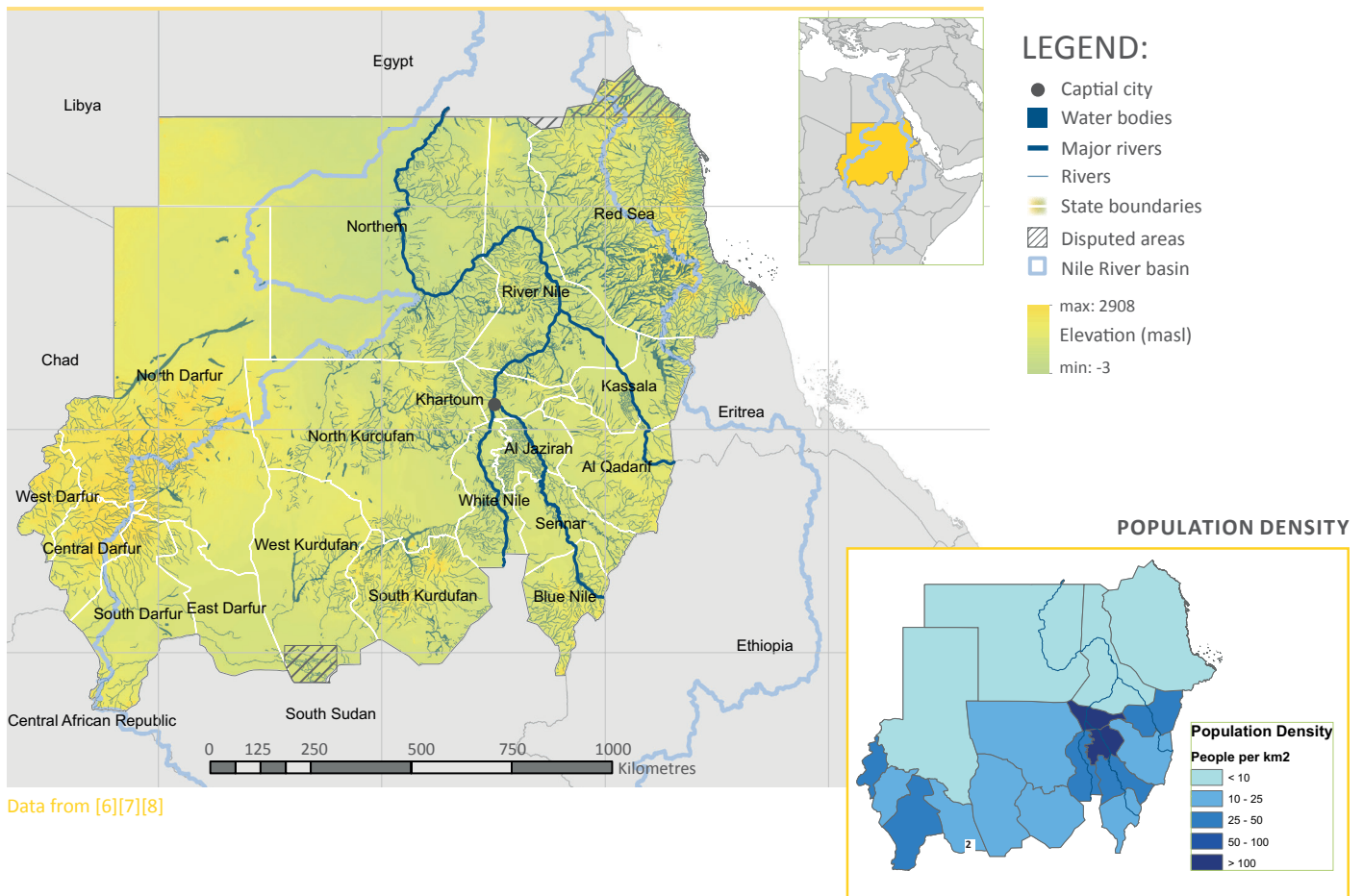
Technology Arts Sciences
TH Köln

Sudan

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The Water-Energy-Food Security Nexus Country Profile

- Sudan is located from 9°N to 22°N in north-eastern Africa; it shares borders with Egypt, Libya, Chad, Central African Republic, South Sudan, Ethiopia and Eritrea as well as the Red Sea.
- Although located in the tropics, the climate extends from a desert climate in the northern regions to a summer-rain climate in the southern regions [1].
- Approximately half of the country (mainly in the northern states) is covered by bare rocks and soil. In the southern regions, agricultural areas, trees, shrubs and herbaceous land cover is dominant [2].
- The second Sudanese civil war lasted from 1983 to 2005, when a peace deal was made. The Darfur crisis started in 2003, and a peace accord with the government was signed in 2010. In 2011, following a unanimous referendum vote, South Sudan gained independence from the rest of Sudan [3].
- Abyei is a disputed area with South Sudan [4] and Bir Tawil and the Hala'ib Triangle are disputed areas with Egypt [5].



Data from [6][7][8]

Data from [9]

Highlighted Nexus-related challenges faced by Sudan:

- Regional conflict and instability have forced millions of people to migrate within the country, forcing more people to face extreme poverty with low water, energy and food securities [10]. Furthermore, civil war and famine in South Sudan has seen vast numbers of people seek safety in Sudan, and cross-border oil flows have been drastically reduced [11].
- The water dependency on water originating outside the country is high, and suitable management of the Grand Ethiopian Renaissance Dam (GERD) will be vital for ensuring that Sudan's water demands are met [12].
- Approximately 5.5 million people in Sudan face food insecurity and 15.9 million people don't use at least basic drinking water services [13][14].
- Poor water management contributes to high levels of wastage in the irrigation schemes [15].
- Power shortages are common, hence there is an urgency from the government to increase the country's energy supply through greater generation from hydropower or imports from Ethiopia [16][17].

GENERAL INFORMATIONⁱ

1,879,400 km² Size ^[14]

40,533,000 Population (2017)^[14]

2.4% Population growth
annual (2017)^[14]

34.2% Urban Population (2017)^[14]

117 billion US\$ Total GDP (2017)^[14]

2,379 US\$ GNI per capitaⁱⁱ (2017)
World average: 10,366 ^[14]

14.9% Poverty headcount ratio at \$1.90 a day (2009)^[14]

0.354 Gini coefficientⁱⁱⁱ (2009)^[14]
Ranked the 39th most unequal of 158 countries rated ^[18]

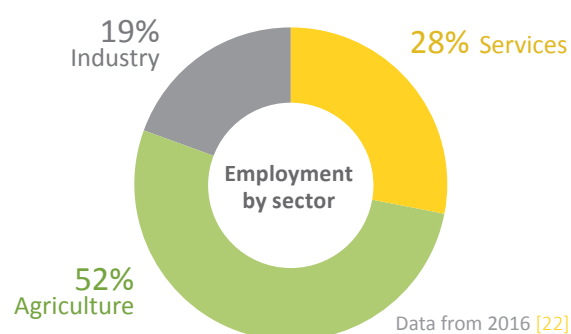
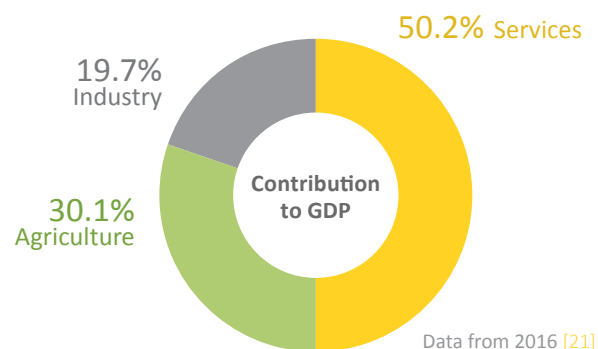
0.502 HDI^{iv} (2017)
Ranked 167th of 188 countries rated^[19]

55.4% School Enrolment, Primary (2012)^[14]

53.5% Literacy rate^v (over 15) (2008)^[14]

64.5 years Life expectancy (2016)^[14]

44.8% Infant mortality rate (2016)^[14]



Population growth^{vi}

1970 10,281,700

1985 17,210,200

2000 27,250,500

2015 38,647,800

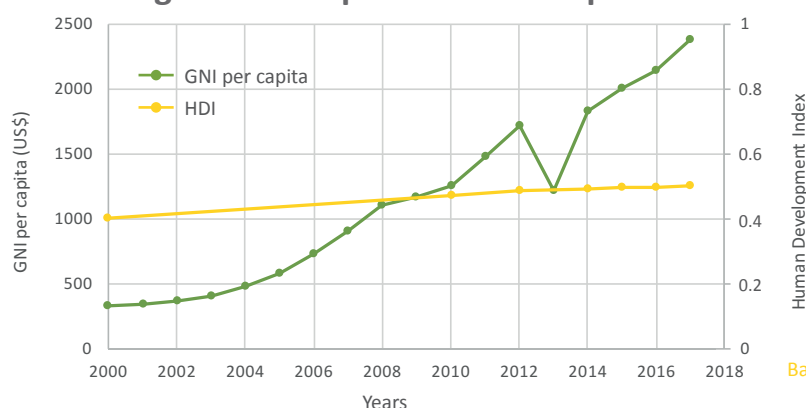
2030 54,842,000

Based on ^[14] ^[20]

Implementation of the Sustainable Development Goals (SDGs): ^[23]

- The government of Sudan has established an institutional structure at the high level with the aim of implementing Agenda 2030 and the SDGs
- The agricultural sector has been identified as a comparative advantage, and the national strategy allocates a minimum of 10% of the government budget to this sector
- Sudan's high debt burden is considered to be unsustainable

GNI growth compared to HDI improvement



Sudan's GNI per capita has increased by 620% since 2000 ^[14]. Despite this increase, poverty is still rife and human development outcomes remain weak ^[24]. Trade sanctions from the United States of America were placed on Sudan from 1997 and were lifted in October 2017 ^[11].

ⁱ Some statistics are only available from before 2011 and therefore cover the geographic area of both Sudan and South Sudan.

ⁱⁱ The gross national income (GNI) is the sum of a nation's gross domestic product and the net income it receives from overseas.

ⁱⁱⁱ The Gini coefficient is used as a gauge of economic inequality, measuring income distribution among a population. The coefficient ranges from 0 to 1, with 0 representing perfect equality and 1 representing perfect inequality.

^{iv} The Human Development Index (HDI) measures a country's overall achievement in social and economic dimensions, using life expectancy, education and per capita income indicators.

^v According to available statistics, the literacy rate has dropped significantly from 2000 to 2008 (the only two data points available). No explanation for such a sharp drop was found.

^{vi} The numbers presented before South Sudan's independence 2011 present the population of only the states that make up present-day Sudan.



WATER SECTOR

The map in the centre of the page shows that spatial variation of annual mean precipitation, as well as plots of mean monthly precipitation at three urban centres to display monthly variability. Most of the country has a desert climate, and the water dependency on water originating as precipitation from outside the country is extremely high at 96% [1]. The erratic and seasonal nature of precipitation places Sudan at a high water security risk, especially in rainfed areas, and the country is subject to devastating droughts and floods [1][25].

<10 to 1,350 mm Annual precipitation
(average of 220 mm) [26]

4,000 x 10⁶ m³/yr Internal renewable water resources^{viii} [1]

996 m³/yr Internal renewable water resources per person [1]

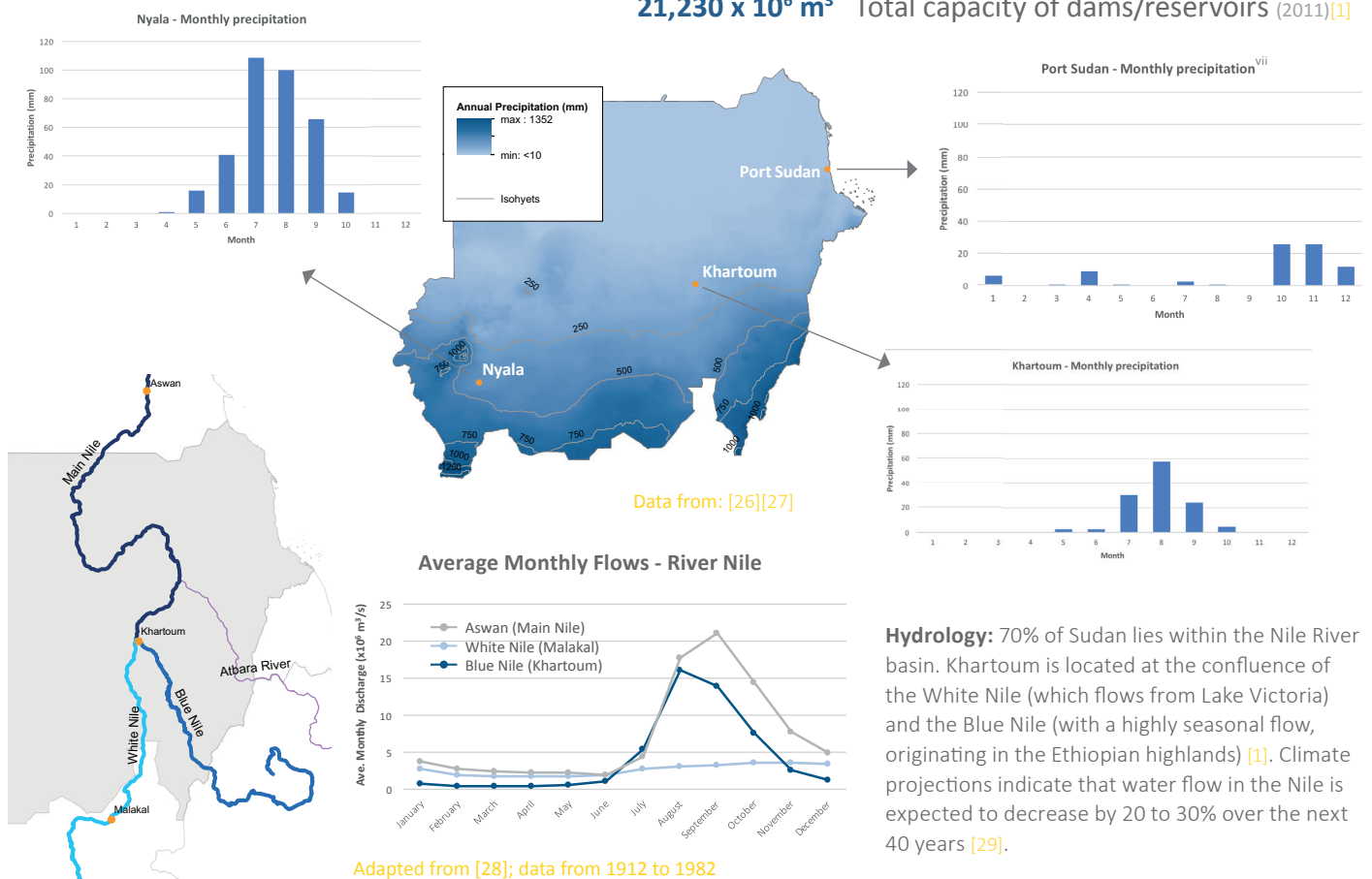
26,935 x 10⁶ m³/yr Total water consumption (2011) [1]

96% Water dependency ratio^{ix} [1]

58.9% Population with access to improved drinking water sources (2015)[14]

34.6% Population with access to improved sanitation facilities (2015)[14]

21,230 x 10⁶ m³ Total capacity of dams/reservoirs (2011)[1]

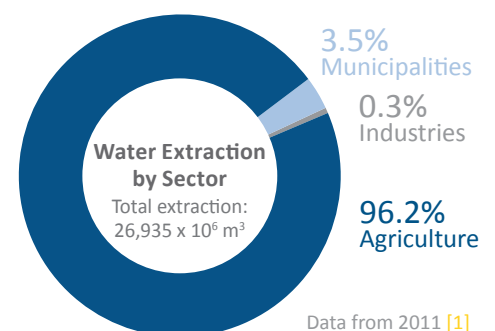


Hydrology: 70% of Sudan lies within the Nile River basin. Khartoum is located at the confluence of the White Nile (which flows from Lake Victoria) and the Blue Nile (with a highly seasonal flow, originating in the Ethiopian highlands) [1]. Climate projections indicate that water flow in the Nile is expected to decrease by 20 to 30% over the next 40 years [29].

Grand Ethiopian Renaissance Dam: At the end of 2018, the construction of the GERD (total volume: 74 billion m³) on the Blue Nile River in Ethiopia is almost complete [30]. If and when in operation, the downstream hydrology will be massively altered [31][32][33].

Water use: 96.2% of all extracted water is used for agriculture, mostly from surface water resources, and the irrigation efficiency is low [1][34]. Groundwater is only used in limited areas, and predominantly for municipal water supply [1]. However, groundwater exploitation to meet increasing water demand is taking place in an unplanned manner, and some problems are overexploitation, reduction of reliable yield and deterioration of quality [35].

Small water reservoirs (called hafirs) are important for water supply in villages and to farmers in remote areas [1].



vii. For extremely low precipitation regions such Port Sudan, the satellite product that was used to generate the map has diminished accuracy [36]. Therefore, data from the hydrometeorological station was used to generate the monthly average precipitation graph for Port Sudan.

viii. The internal renewable water resources are the part of the water resources (surface water and groundwater) that is generated from precipitation within the country.

ix. The water dependency ratio is defined as percentage of total renewable water resources that originate outside of the country.

Access to electricity is low, and there is a large discrepancy between the population with access to electricity in urban areas (70%) and those in rural areas (22%) [14].

55.8% of electricity is supplied by hydropower. Despite their high potential, the exploitation of wind and solar energy is not widespread, and geothermal sources have not been exploited [37].

0.3 metric tonnes per capita

CO₂ emissions
world average: 4.97 (2014)[14]

190 kWh per capita

Electric power consumption
world average: 3,125 (2014)[14]

11,796 GWh

Total electric power consumption (2016)[21]

14,431 GWh

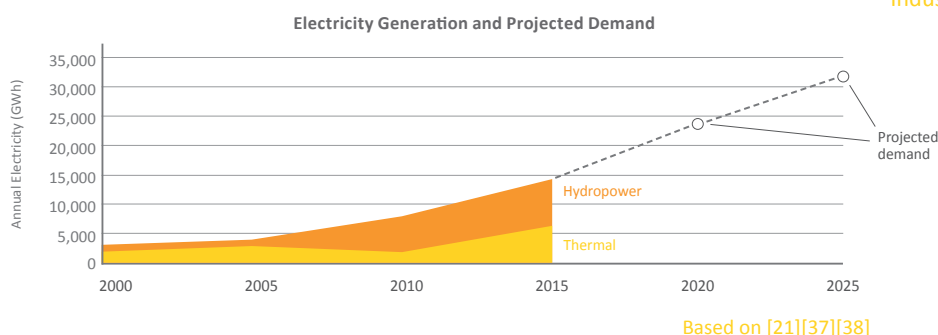
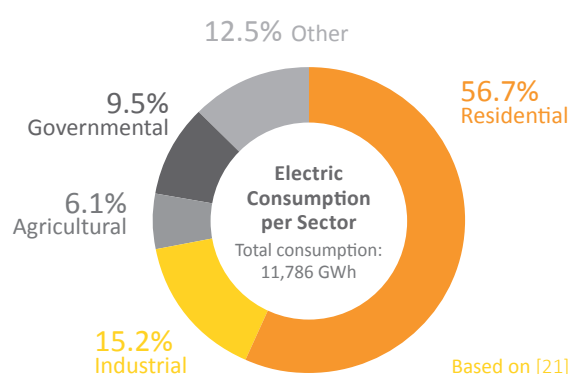
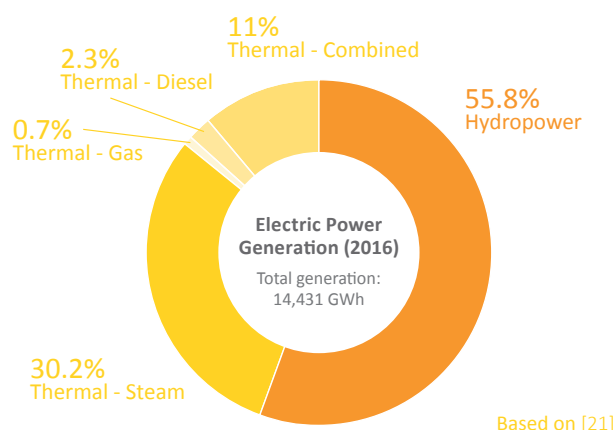
Total electricity production^{vii} (2016)[21]

440 GWh

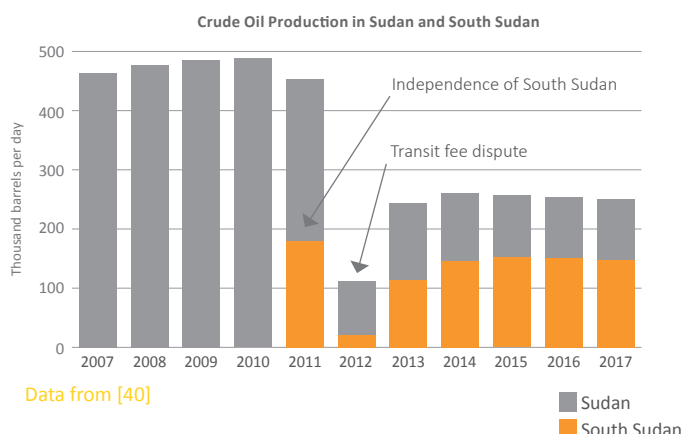
Imported electricity (from Ethiopia) (2016) [21]

38.5%

Percentage of population with access to electricity (2016)[14]



Electricity insecurity: There are regular power shortages in Sudan, especially in the summer months from late April to July, and electricity is imported from Ethiopia [39]. With the operation of the almost-completed GERD, electricity imports are set to increase with a 500-kV transmission line connecting the GERD with Khartoum [17].



Fuel production: 75% of Sudan's oil production fields were lost due to the secession of South Sudan in 2011. Disruptions in oil production have had negative effects on the economies of both countries [40].

There are two interconnected grids in Sudan: the Blue Nile and Western grids as well as an additional 14 local distribution networks from thermal generators [40]. Traditional biomass (mainly fuelwood and charcoal) is relied on for most energy needs of the populations, mostly in the countryside, that are not connected to the grids [37]. To address the low electricity access, the Sudanese Electricity Distribution Company is undertaking "The Rural Area Electrification by Solar Energy Project", which aims to serve over one million households by 2031 [41].

In line with the Paris Agreement, Sudan's Intended Nationally Determined Contributions include an objective to attain a 20% mix of renewable energy in their power system by 2030 [29]. Plans also exist to increase the country's hydroelectric power generation [16].

^x A publication from Rabah et al. (2016) states that available energy balance data only accounts for energy produced by the public sectors, and therefore these reported values are an underestimation of the actual energy production [42].

^{xi} The sector labelled as "other" is listed as "standardised" in the Annual Report. Its description is that it "includes commercial and light freight sectors" [21].



FOOD AND AGRICULTURAL SECTOR

Recent estimates state that approximately 5.5 million people in Sudan face food insecurity and the chronic malnutrition rate is 38% [13]. Over 70% of the population depend upon crop production and/or livestock husbandry to support their livelihoods [29].

The major irrigation schemes are the Gezira, Rahad, New Halfa, Elssuki, White Nile and Blue Nile schemes [10].

750 million US\$

Agricultural exports (2016)[21]

1,776 million US\$

Imports of foodstuffs (2016)[21]

228,100 km²

Cultivated area (2014/2015)[21]

16,000 km²

Irrigated area (2014/2015)[21]

4.6 kg per hectare of arable land

Fertiliser use

world average: 138 (2015)[14]

11.7% of GDP

Value added by agricultural products (2016)[21]

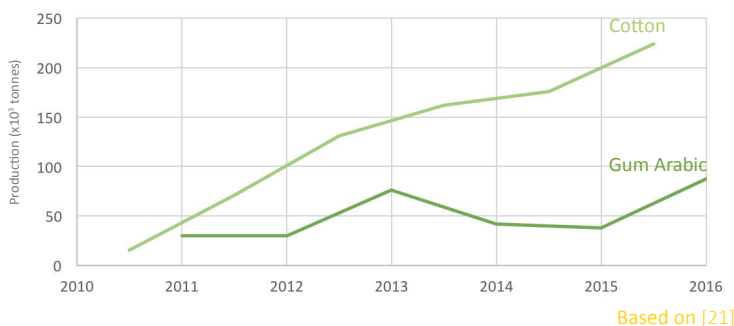
18.1% of GDP

Value added by animal resources (2016)[21]

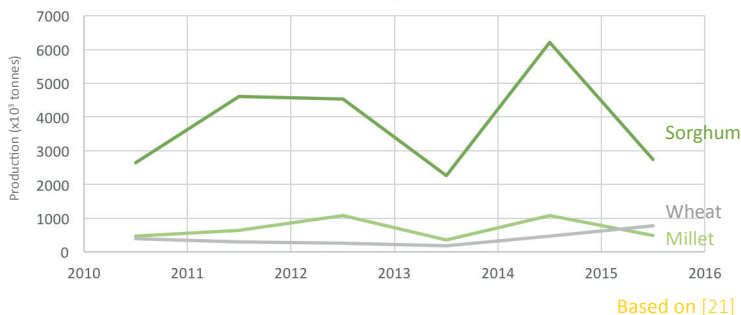
25.6% of population

Prevalence of undernourishment (2015)[14]

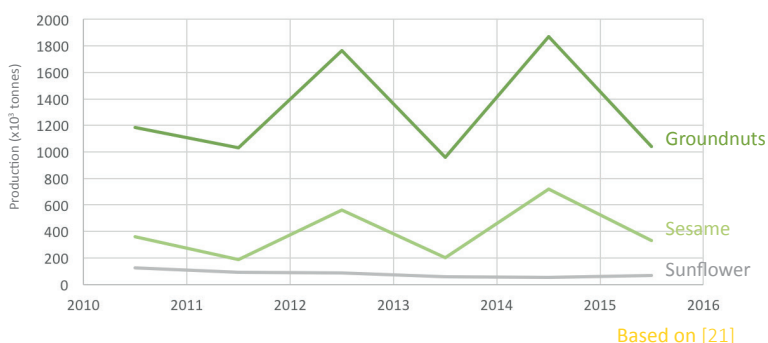
Non-food crop production



Main food crop production



Main oil seeds production



Major Agricultural Schemes



Irrigated Agricultural Schemes

Mechanized Agricultural Schemes (planned and unplanned)

Source: [43]

The major crops in Sudan are cotton, gum Arabic, food crops and oil seeds [21]. Up until the late 1990s, agricultural exports were the main source in foreign income in Sudan, before this was replaced by oil exports [10].

- Sudan is a net importer of both food and essential agricultural inputs [10].
- On average, Sudanese people spend 61% of their income on food, and food price increases have severe impacts on food security [44].

ENVIRONMENT

2.3% of total land area Protected land areas (2016)[14]

16% of territorial waters Protected water areas (2016)[14]

Solid waste management and sewage treatment is reported as inadequate in all of Sudan's cities, with rubbish typically accumulating close to its point of origin [43]. Only 0.6% of the population is connected to a sewerage network [45].

Agriculture is cited as having led to serious environmental problems, including land degradation, riverbank erosion, invasive species and water pollution. Poorly managed rainfed agriculture has been responsible for large-scale forest clearance [43].

Sudan began their first programme to combat desertification in 1978, with the establishment of the National Desertification Control and Monitoring Unit [46]. Three compounding desertification processes are identified as underway in Sudan [43]:

- Climate-based conversion of land types from semi-desert to desert.
- Degradation of existing desert environments.
- Conversion of land types from semi-desert to desert by human action.

xii. This value differs significantly to the 7% reported by the FAO [53].

xiii. This value is from 2005, before the independence of South Sudan.



WATER - ENERGY INTERCONNECTIONS

Water for Energy

In 2016, 55.8% of electricity production in Sudan was from [21]. Therefore, the country's energy security is highly reliant on river discharges.

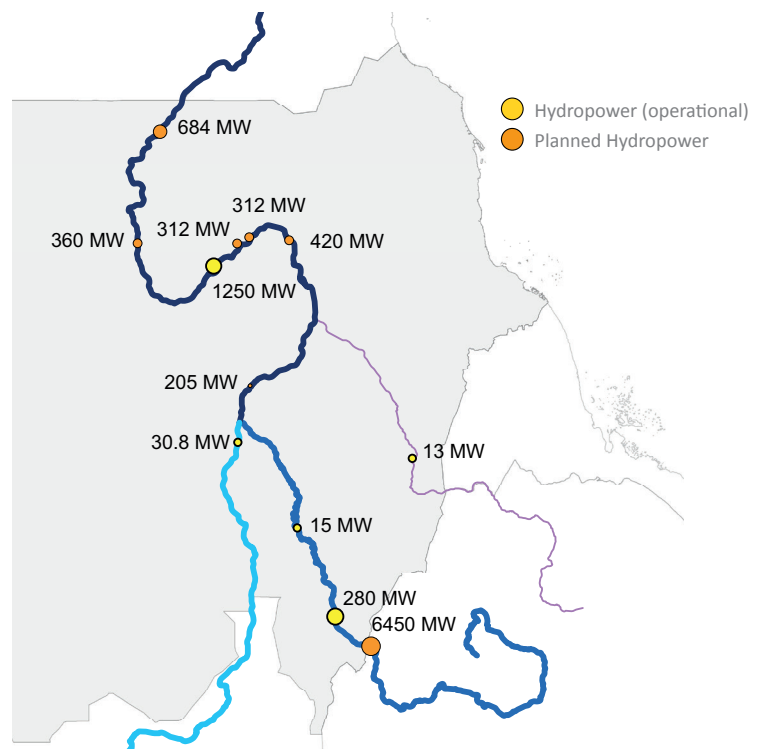
Five operational hydropower stations are located on the Blue Nile, White Nile and Atbara River [47].

Sudan regularly faces a power deficit in supply peak hours, and the government plans to increase the hydroelectric power generation capacity by 500MW by 2020 [16].

The planned capacity of the GERD (located in Ethiopia but also shown on the map), is significantly greater than any of the hydropower generation plants located in Sudan. Sudan has agreed to increase electricity imports from Ethiopia when the GERD is operational [17].

Energy for Water

Two desalination plants produce 65,000 m³ of drinking water per day in Port Sudan. However, their operation is identified as costly and suffering from continuous breakdowns because of electricity cuts and pump maintenance [50].

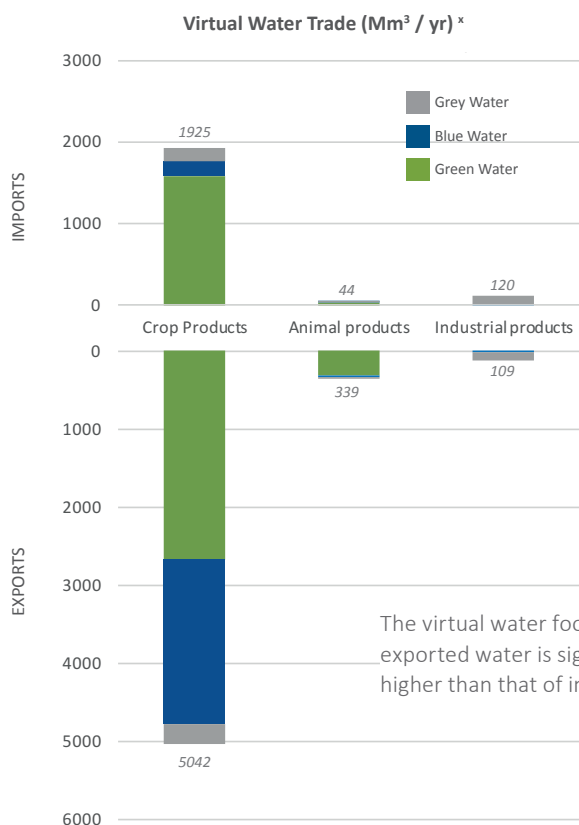


Based on [47][48][49]



WATER - FOOD INTERCONNECTIONS

Irrigation schemes are prevalent in the country's east, while rainfed agriculture is mainly practiced in the south of the country [1]. Some of the major crops (eg. cotton) are very water-intensive [10]. The high use of pesticides in agriculture has caused widespread pollution of surface waters and irrigation canals [43]



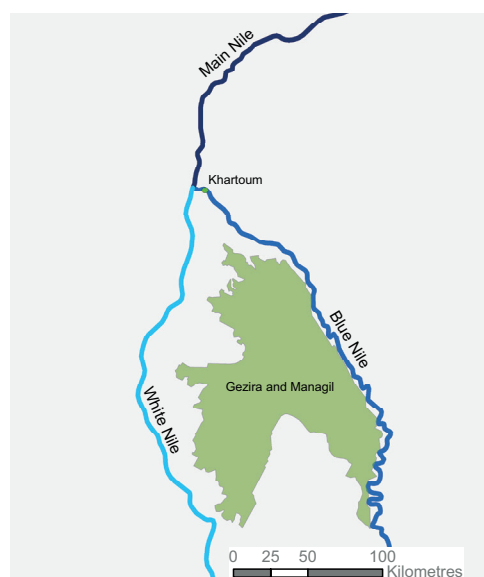
Based on [53]

Gezira Irrigation Scheme

The largest irrigation scheme in Sudan is the Gezira Irrigation scheme (with the Managil extension) covering 870,000 ha. It is a gravity irrigation system which accounts for almost 50% of the total irrigated lands in the country [1][15]. The annual irrigation crop season extends from June to March. With such a high crop demand, the Sennar Dam was built to ensure the irrigation requirements would be met [15].

The combined design capacity of the Gezira and Managil irrigation systems is 30.5 x 10⁶ m³/day. This accounts for one third of Sudan's share of the Nile waters [15].

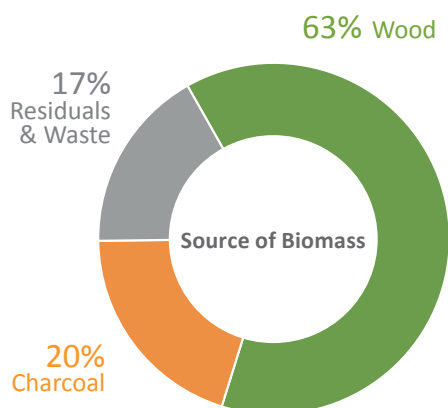
Poor distribution of water and management practices are identified as contributing to severe water wastage problems in the scheme. A large amount of sediment entering the irrigation scheme is another key problem [15].



Based on [52]



ENERGY - FOOD INTERCONNECTIONS



Based on [56]

Agriculture for Energy

Biomass plays an important role in the provisioning of energy, with an estimated 51% of energy consumption deriving from this source. South Sudan was the source of most fuel wood and charcoal used mainly for cooking and providing industrial heat, and therefore the secession of the country has affected biomass availability in Sudan [54].

Residuals from the sugar cane industry are identified as a very important source of current and potential biomass [55].

Energy for Food & Agriculture

Water pumping techniques are increasingly used in irrigation schemes in Sudan, substituting traditional flood irrigation and water wheel irrigation techniques. In 2000, the irrigated area where pumps were used to lift water was 346,680 ha [1]. Water for irrigation is also often pumped from aquifers [10].

xiv. Virtual water refers to the amount of water needed for the production of food and other products. It can be separated into green water (water from precipitation that is stored in the root zone of the soil), blue water (water sourced from surface or groundwater resources) and grey water (the fresh water required to assimilate pollutants to meet specific water quality standards).

xv. The virtual water trade for Sudan was calculated using values over the time period 1996 to 2005; i.e. before the independence of South Sudan.

GOVERNANCE

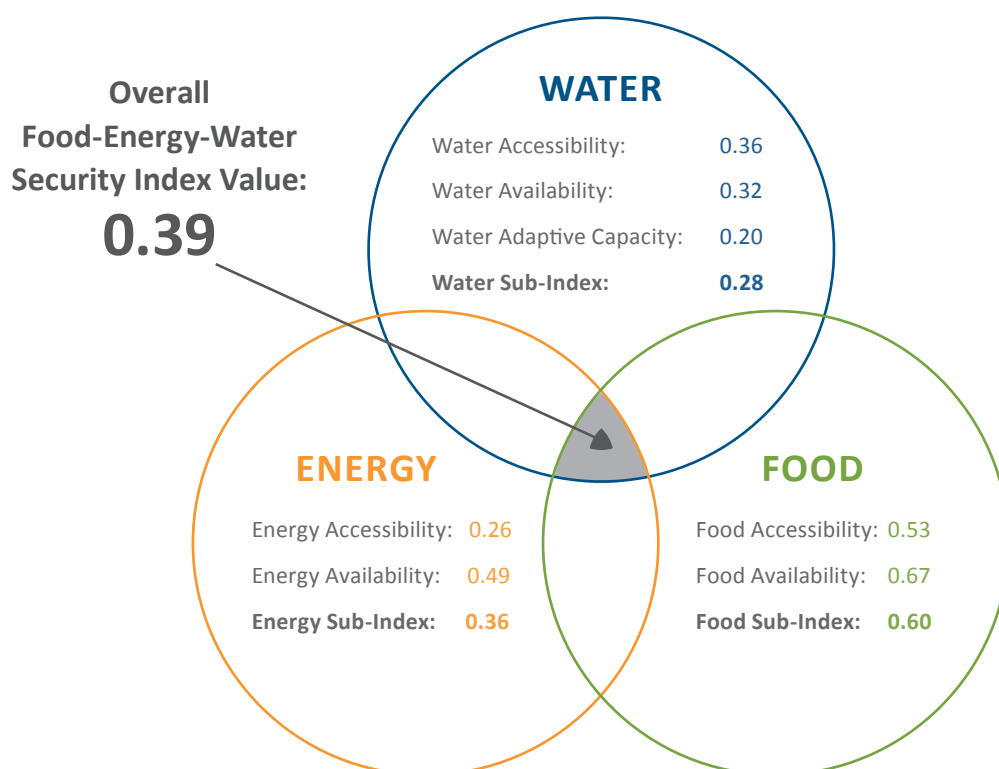
- Under the 1959 Nile Waters Agreement, Sudan has the right to use 18.5 billion m³ of Nile water per year [57].
- The Nile Basin Initiative, founded in 1999, is an intergovernmental partnership of the 10 Nile basin countries. Their aims include developing the Nile Basin water resources in a sustainable and equitable way and to ensure optimal resources use [58].
- At the time of the elaboration of this document, there are disagreements between Sudan, Egypt and Ethiopia because of the proposed GERD project [59][60].
 - Sudan has shown support for the GERD project due to its need for electricity generated there, and this support has strained relations with Egyptian officials, who are concerned about reduced water availability for irrigation [61].
 - A study quantifying the impacts of cooperation between Sudan and Ethiopia on the WEF Nexus with GERD operations showed a clear economic benefit to Sudan when cooperating with Ethiopia [12].
- In the agricultural sector, a 5-year Economic reform programme (2015-2019) aims for the sector to achieve self-sufficiency and increase exports [21].
- Sudan shares seven transboundary aquifers with neighbouring countries and there are no sharing agreements over these resources [1].
- The lack of environmental governance in Sudan is said to be exacerbated by a lack of a shared vision or coordination between institutions that are mandated to manage natural resources [62].
- The ongoing dispute about the Jonglei project in South Sudan is an unresolved governance issue related to the water-food Nexus [63].

NEXUS EVALUATION

Applying the Pardee RAND Food-Energy-Water Security Index

To gain insight into the security level of each Nexus element and the overall resources security, we present the Pardee RAND Index for Sudan. It is calculated the following way:

- The Index is based on availability and accessibility of the resource, and in the case of the water, an analysis of the adaptive capacity is also part of the calculation.
- Normalised scores are derived by assigning a value between 0 and 1, where 0 represents the minimum value and a score of 1 represents the conditions for that sub-index which are sufficient to meet basic needs.
- All three Nexus elements are equally weighted to determine the overall security index value [64].



REFERENCES

- ¹ Food and Agriculture Organization of the United Nations (2015), 'AQUASTAT: Sudan', Available from: http://www.fao.org/nr/water/aquastat/countries_regions/SDN/
- ² Food and Agriculture Organization of the United Nations (2012), 'The Land Cover Atlas of Sudan', Available from: <http://www.fao.org/3/a-be896e.pdf>
- ³ BBC News (2018), 'Sudan profile - Timeline', Available from: <https://www.bbc.com/news/world-africa-14095300>
- ⁴ United Nations Security Council (2017), 'Report of the Secretary-General on the situation in Abyei', Available from: <https://reliefweb.int/sites/reliefweb.int/files/resources/N1723211.pdf>
- ⁵ Azikiwe, A. (2018), 'Sudan- Egypt Relations Further Strained over Territorial Dispute. The Hala'ib Triangle', Global Research, Available from: <https://www.globalresearch.ca/sudan-egypt-relations-further-strained-over-territorial-dispute-the-halaib-triangle/5625724>
- ⁶ DIVA-GIS (n.d.), 'Free Spatial Data', Available from: <http://www.diva-gis.org/Data>
- ⁷ FAO GeoNetwork (n.d.), 'Hydrological Basins in Africa', Available from: <http://www.fao.org/geonetwork/srv/en/metadata.show?id=296>
- ⁸ Natural Earth (n.d.), 'Admin 0 – Breakaway, Disputed Areas', Available from: <https://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-admin-0-breakaway-disputed-areas/>
- ⁹ City Population (2017), 'Sudan', Available from: <http://www.citypopulation.de/Sudan.html>
- ¹⁰ Mahgoub, F. (2014), 'Current Status of Agriculture and Future Challenges in Sudan', Nordiska Afrikainstitutet, Uppsala, Lightning Source UK Ltd.
- ¹¹ World Bank (n.d., a), 'Overview: The World Bank in Sudan', Available from: <http://www.worldbank.org/en/country/sudan/overview> [Accessed on: 26 September 2018]
- ¹² Basheer, M., Wheeler, KG., Ribbe, L., Majdalawi, M., Abdo, G. & Zagana, EA. (2018), 'Quantifying and evaluating the impacts of cooperation in transboundary river basins on the Water-Energy-Food nexus: The Blue Nile Basin', Science of the Total Environment, vol. 630, pp. 1309-1323
- ¹³ World Food Programme (n.d.), 'Sudan', Available from: <http://www1.wfp.org/countries/sudan> [Accessed on 19 October 2018]
- ¹⁴ World Bank (n.d., b), 'Sudan Country Database', Available from: <https://data.worldbank.org/country/sudan>
- ¹⁵ Al Zayed, I., Elagib, N., Ribbe, L. & Heinrich, J. (2015), 'Spatio-temporal performance of large-scale Gezira Irrigation Scheme, Sudan', Agricultural Systems, vol. 133, pp. 131-132
- ¹⁶ Poindexter, GB. (2015), 'Sudan releases plans to add 500 MW of hydroelectric capacity by 2020', hydro Review, Available from: <https://www.hydroworld.com/articles/2015/08/sudan-releases-plans-to-add-500-mw-of-hydroelectricity-by-2020.html>
- ¹⁷ NewsBase (2017), 'Sudan Agrees To Boost Electricity Imports From Ethiopia', Edited by Richard Lockhart, Available from: <https://newsbase.com/topstories/sudan-agrees-boost-electricity-imports-ethiopia>
- ¹⁸ Indexmundi (n.d.), 'GINI index (World Bank estimate) - Country Ranking', Available from: <https://www.indexmundi.com/facts/indicators/SI.POV.GINI/rankings>
- ¹⁹ United Nations Development Programme (n.d.), 'Sudan: Human Development Indicators', Available from: <http://hdr.undp.org/en/countries/profiles/SDN>
- ²⁰ United Nations (2017), 'World Population Prospects: The 2017 Revision, Key Findings & Advance Tables', Working Paper No. ESA/P/WP/248
- ²¹ Central Bank of Sudan (2016), '56th Annual Report: 2016', Available from: <https://cbos.gov.sd/en/publication-type/annual-reports>
- ²² World Bank (2018), 'Jobs Data: Sudan', Available from: <http://datatopics.worldbank.org/jobs/country/sudan>
- ²³ United Nations (n.d.), 'Sudan: Voluntary National Review 2018', Available from: <https://sustainabledevelopment.un.org/memberstates/sudan>
- ²⁴ Ahmed, NME. (2015), 'Fighting Poverty in Sudan', Paper prepared for the IARIW-CAPMAS Special Conference "Experiences and Challenges in Measuring Income, Wealth, Poverty and Inequality in the Middle East and North Africa", Available from: <http://iariw.org/egypt2015/nuha-ahmed.pdf>
- ²⁵ World Bank (2013), 'World Bank Supports Sustainable Livelihoods and Landscapes in Sudan', Press Release, Available from: <http://www.worldbank.org/en/news/press-release/2013/12/19/world-bank-sustainable-livelihoods-landscapes-sudan>
- ²⁶ Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. & Michaelsen, J. (2015), 'The climate hazards infrared precipitation with stations - a new environmental record for monitoring extremes', Scientific Data 2, 150066
- ²⁷ World Meteorological Organization (n.d.), 'Sudan', Available from: <https://worldweather.wmo.int/085/m085.htm>
- ²⁸ Said, R. (1993), 'The River Nile Geology, Hydrology, and Utilization', Pergamon Press, Oxford, 320 p
- ²⁹ Republic of Sudan (2015), 'Intended Nationally Determined Contributions (INDCs)' Available from: <http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Sudan/1/28Oct15-Sudan%20INDC.pdf>

- 30 Embassy of Ethiopia (2018), '2018, a pivotal year for Ethiopia's electricity sector', Available from: <https://ethiopianembassy.be/en/2018/02/08/2018-a-pivotal-year-for-ethiopia-electricity-sector/>
- 31 Zhang, Y., Block, P., Hammond, M. & King, A. (2015), 'Ethiopia's Grand Renaissance Dam: Implications for Downstream Riparian Countries', *Journal of Water Resources Planning and Management*, vol. 141, Iss. 9.
- 32 Wheeler, KG., Basheer, M., Mekonnen, T. Eltoun, SO., Mersha, A., Abdo, GM., Zagana, EA., Hall, JW. & Dadson, SJ. (2016), 'Cooperative filling approaches for the Grand Ethiopian Renaissance Dam', *Water International*, vol. 41, Iss. 4. pp. 611-634.
- 33 Liersch, S., Koch, H. & Hattermann, FF. (2017), 'Management Scenarios of the Grand Ethiopian Renaissance Dam and Their Impacts under Recent and Future Climates', *Water*, vol. 9, Iss. 10.
- 34 Siddig, KHA. & Babiker, BI. (2011), 'Agricultural Efficiency Gains and Trade Liberalization in Sudan', Department of Agricultural Economics, Faculty of Agriculture, Khartoum University, Available from: <https://ageconsearch.umn.edu/bitstream/112786/2/Agricultural-Efficiency-AgEcon1.pdf>
- 35 Abdo, G. & Salih, A. (2012), 'Challenges facing groundwater management in Sudan', *Global Advanced Research Journal of Physical and Applied Sciences*, Available from: <http://garj.org/full-articles/challenges-facing-groundwater-management-in-sudan.pdf?view=download>
- 36 Zambrano-Bigiarini, M., Nauditt, A., Birkel, C., Verbist, K., and Ribbe, L. (2017), 'Temporal and spatial evaluation of satellite-based rainfall estimates across the complex topographical and climatic gradients of Chile', *Hydrology and Earth System Sciences*, vol. 21, pp. 1295-1320.
- 37 United Nations Environment Programme (2017), 'Energy profile: Sudan', Available from: <http://wedocs.unep.org/handle/20.500.11822/20596>
- 38 Eastern Africa Power Pool (2014), 'EAPP Regional Power System Master Plan Volume I: Main Report', Addis Ababa.
- 39 Sudan Vision (2017), 'Sudan to Build Power Transmission Line from Ethiopia's GERD: Minister', Available from: <http://www.svdaily.net/index.php/new-posts/local-news/1147-sudan-to-build-power-transmission-line-from-ethiopia-s-gerd-minister?start=108>
- 40 U.S. Energy Information Administration (2018), 'Country Analysis Brief: Sudan and South Sudan', Updated: March 5, 2018, Available from: <https://www.connaissancedesenergies.org/sites/default/files/pdf-pt-vue/sudan.pdf>
- 41 Sudanese Electricity Distribution Company (n.d.), 'The Rural Area Electrification by Solar Energy Project', Available from: <http://www.sedc.com.sd/en/-4>
- 42 Rabah, AA., Nimer, HB., Doud, KR. & Ahmed QA. (2016), 'Modelling of Sudan's Energy Supply, Transformation, and Demand', *Journal of Energy*
- 43 United Nations Environment Programme (2007), 'Sudan: Post-Conflict Environmental Assessment', Available from: <http://wedocs.unep.org/handle/20.500.11822/7712>
- 44 Food and Agriculture Organization of the United Nations (2011), 'Soaring Food Prices and its Policy Implications in North Sudan: A Policy Brief', Available from: [http://www.fao.org/fileadmin/user_upload/sifsia/docs/Policy%20Brief%20Soaring%20Food%20Prices%201%20\(SE2\).pdf](http://www.fao.org/fileadmin/user_upload/sifsia/docs/Policy%20Brief%20Soaring%20Food%20Prices%201%20(SE2).pdf)
- 45 World Health Organization (2005), 'A regional overview of wastewater management and reuse in the Eastern Mediterranean Region', Regional Office for the Eastern Mediterranean & Regional Centre for Environmental Health Activities, Available from: <http://applications.emro.who.int/dsaf/dsa759.pdf>
- 46 Abdel Latif, MA. & Elhag, MM. (2015), 'Combating Desertification in Sudan', *Environment and Ecology at the beginning of the 21st century*, pp.256-266
- 47 Ministry of Electricity and Dams (2012), 'Water Resources Management', [Powerpoint presentation], Ministry of Electricity and Dams, Dams Implementation Unit, Available from: http://www.sesric.org/Presentations/Water_Management_Symposium/Sudan/Sudan.pdf
- 48 Food and Agriculture Organization of the United Nations (2016), 'Dams', Available from: <http://www.fao.org/nr/water/aquastat/dams/index.stm>
- 49 International Hydropower Association (n.d.), 'Ethiopia - Grand Ethiopian Renaissance Dam (GERD)', Available from: Ethiopia - Grand Ethiopian Renaissance Dam (GERD)
- 50 Abdel Ati, H., Pavanello, S., Jaspars, S., Hashim, AA., Idriss, M. & Pantuliano, S. (2011), 'City limits: urbanisation and vulnerability in Sudan: Port Sudan case study', Humanitarian Policy Group, London
- 51 Food and Agriculture Organization of the United Nations (n.d.), 'Sudan', Factsheet, Available from: http://fenixservices.fao.org/faostat/static/documents/CountryProfile/pdf/syb_276.pdf
- 52 Ministry of Irrigation and Hydro-electric Energy of Sudan (1977), 'Blue Nile Waters Study Phase IA: Availability and Use of Blue Nile Water'
- 53 Mekonnen, MM. & Hoekstra, AY. (2011), 'The green, blue and grey water footprint of crops and derived crop products', *Hydrology and Earth System Sciences*, vol. 15, pp. 1577-1600.
- 54 Abdelraheem, HF., Lang, A. & Elsayed, MEA. (2013), 'Jatropha Curcas: A Viable Alternative Source of Clean Energy to Meet Sudan's Growing Energy Demand', International Conference on Computing, Electrical and Electronic Engineering, Khartoum
- 55 Omer, AM. (2003), 'Biomass energy potential and future prospect in Sudan', *Renewable and Sustainable Energy Reviews*, vol. 9, pp. 1-27

- ⁵⁶ Abdelraheem, HF. (2014), 'Production of transport biofuels in Sudan for replacement of petroleum fuels: The fundamental issues', Conference: Biofuels Workshop, Khartoum.
- ⁵⁷ Abdalla, IH. (1971), 'The 1959 Nile Waters Agreement in Sudanese-Egyptian Relations', *Middle Eastern Studies*, vol. 7, No. 3, pp. 329-341
- ⁵⁸ Nile Basin Initiative (n.d.), 'Who We Are', Available from: <http://www.nilebasin.org/index.php/nbi/who-we-are>, [Accessed 12 October 2018]
- ⁵⁹ Yihdego, Z., Rieu-Clarke, A. & Cascão, AE. (2016), 'How has the Grand Ethiopian Renaissance Dam changed the legal, political, economic and scientific dynamics in the Nile Basin?', *Water International*, vol. 41, Iss. 4, pp. 503 - 511
- ⁶⁰ Egypt Today (2018), 'Egypt, Sudan, Ethiopia resume tripartite talks on GERD in Khartoum', Available from: <http://www.egypttoday.com/Article/1/47025/Egypt-Sudan-Ethiopia-resume-tripartite-talks-on-GERD-in-Khartoum>
- ⁶¹ Reuters (2018), 'No breakthrough in Ethiopian dam talks, Egypt says', Available from: <https://www.reuters.com/article/us-egypt-ethiopia-dam/no-breakthrough-in-ethiopian-dam-talks-egypt-says-idUSKBN1I81YL>
- ⁶² United Nations Environment Programme (2012), 'Environmental Governance in Sudan: An Expert Review', Available from: https://postconflict.unep.ch/publications/sudan/UNEP_Sudan_environmental_governance_review_2012.pdf
- ⁶³ Link, PM., Scheffran, J. & Ide, T. (2016), 'Conflict and cooperation in the water-security nexus: a global comparative analysis of river basins under climate change', *WIREs Water*, July/August 2016, pp. 495-515
- ⁶⁴ Willis, H.H., Groves, D.G., Ringel, J.S., Mao, Z., Efron, S. & Abbott, M. (2016), 'Developing the Pardee RAND Food-Energy-Water Security Index: Toward a Global Standardized, Quantitative, and Transparent Resource Assessment', RAND Corporation, Santa Monica, Calif.