



UPPSALA
UNIVERSITET

Master thesis in Sustainable Development 2021/45
Examensarbete i Hållbar utveckling

Water-energy-food nexus in India: a review of interlinkages and challenges for a sustainable development

Katsiaryna Rakitskaya

DEPARTMENT OF
EARTH SCIENCES

INSTITUTIONEN FÖR
GEOVETENSKAPER

Master thesis in Sustainable Development 2021/45

Examensarbete i Hållbar utveckling

**Water-energy-food nexus in India:
a review of interlinkages and challenges for a
sustainable development**

Katsiaryna Rakitskaya

**Supervisor: Claudia Teutschbein
Subject Reviewer: Thomas Grabs**

Contents

1. Introduction	1
2. Background	3
2.1. Water-energy-food nexus	3
2.1.1. Origin and definition.....	3
2.1.2. Current state of research on the nexus.....	3
2.2. Basic information about India	5
3. Methodology	8
4. Results	9
4.1. Overview of nexus sectors	9
4.1.1. Water sector	9
4.1.2. Energy sector.....	10
4.1.3. Food sector.....	13
4.2. Current interlinkages between nexus sectors	15
4.2.1. Direct interlinkages	15
4.2.1.1. Water-food nexus	15
4.2.1.2. Water-energy nexus	17
4.2.1.3. Energy-food nexus	18
4.2.2. Indirect interlinkages between sectors.....	19
4.3. Challenges for sustainable development of the water-energy-food nexus in India	20
4.3.1. Environmental perspective.....	20
4.3.2. Economic perspective.....	21
4.3.3. Social perspective.....	22
5. Discussion	25
6. Conclusion	28
7. Acknowledgement	29
8. References	30

Water-energy-food nexus in India: a review of interlinkages and challenges for a sustainable development

KATSIARYNA RAKITSKAYA

Rakitskaya, K., 2021: Water-energy-food nexus in India: a review of interlinkages and challenges for a sustainable development. *Master thesis in Sustainable Development at Uppsala University*, No. 2021/45, 36 pp, 15 ECTS/hp

Abstract:

The water-energy-food nexus approach, where closely-connected water, energy and food sectors and their interlinkages are considered together, can be useful to fully understand and address impediments to these sectors' security and their sustainable development. This study is a review of the current status of the water-energy-food nexus in India, main interlinkages and main challenges to the sustainable development of the nexus. One of the main interlinkages is irrigation in the water-food connection, as the majority of water withdrawn in India is used for agriculture. The water-energy interlinkages are crucial not only in the context of hydropower generation, but also due to the large amounts of water being used for cooling of fossil fuel and nuclear power plants. The pressure on water resources is exacerbated by rainfall reductions in India caused by climate change. Social and economic factors, such as population growth, change in food habits, economic growth and technological advances, further increase the demand for water, energy and food. This all poses significant challenges related to water availability and, as a result, water, food and energy security in India.

Keywords: Sustainable Development, Water-Energy-Food Nexus, Water Security, India

Katsiaryna Rakitskaya, Department of Earth Sciences, Uppsala University, Villavägen 16, SE- 752 36 Uppsala, Sweden

Water-energy-food nexus in India: a review of interlinkages and challenges for a sustainable development

KATSIARYNA RAKITSKAYA

Rakitskaya, K., 2021: Water-energy-food nexus in India: a review of interlinkages and challenges for a sustainable development. *Master thesis in Sustainable Development at Uppsala University*, No. 2021/45, 36 pp, 15 ECTS/hp

Summary: Water, food and energy are closely-connected sectors that are critical for human existence. Therefore, when we want to understand and address the challenges that these three sectors and their sustainable development are facing, we need to consider all of them together. Such an approach is called the water-energy-food nexus approach.

The nexus approach is particularly relevant to India which highly depends on its water resources in ensuring energy and food security. The recent monsoon rainfall reductions caused by climate change are a major challenge, as the monsoon rainfall water stored in reservoirs plays a crucial role in providing supply for agriculture, energy and drinking water throughout the year.

This study is a review - based on available scientific literature – of the current status of the water-energy-food nexus in India, main interlinkages and main challenges to the sustainable development of the nexus. The water-food interlinkage is one of the main interlinkages because around 90% of the water withdrawn in India is used for agriculture, mainly for irrigation. The water-energy interlinkage is another important interlinkage. Around 9% of electricity generation in India comes from hydropower generation. Large amounts of water resources are also used in other types of power generation, for example, for cooling of fossil fuel and nuclear power plants.

The sustainable development of the water-energy-food nexus in India is affected not only by environmental factors such as climate change, but also economic and social factors such as population growth, economic growth, change in food habits, expansion of global trade and technological advances, which all increase the demand for water, energy, and food. This all puts enormous pressure on water resources in India and threatens the country's water, energy, and food security.

Keywords: Sustainable Development, Water-Energy-Food Nexus, Water Security, India

Katsiaryna Rakitskaya, Department of Earth Sciences, Uppsala University, Villavägen 16, SE- 752 36 Uppsala, Sweden

1. Introduction

Access to water, energy and food and efficient use of these limited resources are the basis for sustainable development. However, continuing growth of global population with a constant increase in the demand for water, energy and food may result in a shortage of these resources (Yillia, 2016; Barik et al., 2017; de Amorim et al., 2018). The United Nations estimate the global population to increase from 7.7 billion people in 2019 to 10.9 billion in 2100 (United Nations, 2019). In addition, consequences of climate change such as sea level rise, droughts, cyclones and floods will continue to cause long-lasting impacts on water, energy and food security (Barik et al., 2017).

Water, energy and food sectors are connected in a nexus where each sector influences the others. For example, water is used in agriculture and energy production, and energy is used to extract, treat and redistribute water (Rasul, 2016; Barik et al., 2017). Therefore, understanding and addressing issues of water, energy and food security require an integrated approach where these three closely connected sectors are considered together. Such an approach is called the water-energy-food nexus approach.

The nexus approach is particularly relevant to South Asia that, despite its rapid economic growth, is suffering from water, energy and food insecurity (Rasul, 2014; Rasul et al., 2019).

For example, South Asia is one of the world regions with the highest water stress ratio (Figure 1), which compares total water withdrawals for industrial, domestic, livestock and irrigation use with available renewable water supplies.

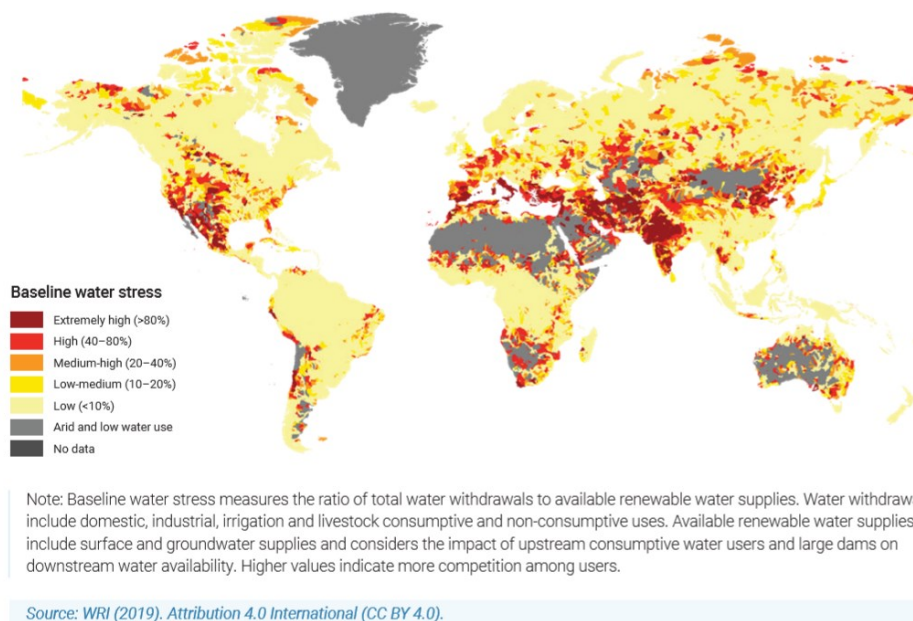


Figure 1. Map of the world’s annual baseline water stress (UNESCO, 2020)

India, which is South Asia’s biggest and most populous country, mainly depends on the southwest monsoon rainfall that contributes about 75–90% of the total annual rainfall (Varikoden et al., 2019). During the monsoon season, rainfall water is stored in reservoirs to provide supply for agriculture, energy and drinking water throughout the entire year (Thatte, 2018). However, the last decades have seen monsoon rainfall reductions affecting water availability in India (Ghosh et al., 2016; Barik et al., 2017; Asoka et al., 2018).

A delayed monsoon in India in 2012 caused an increase in the demand for energy to pump groundwater for irrigation, resulting in a hydropower shortage and blackouts. Later, water shortages between 2013 and 2016 caused a large number of India’s major thermal power stations to shut down. Northwest India, which can be called India’s bread basket with its large production of rice and wheat, has also experienced severe groundwater stress because of the increased water demand for irrigation (OECD & Indian Council for Research on International Economic Relations, 2018; UNESCO, 2020).

Climate change is expected to further affect water, energy and food security with rising temperatures, more variation in rainfall, and higher frequency of floods and droughts (Rasul et al., 2019).

India and other South Asian countries need to improve their water, energy and food security and enhance preparedness and resilience against future challenges. Therefore, advanced research on water-energy-food connections and the mechanism of impacts of climate change and other events is required.

AIM OF THE STUDY

This study is a review of the current status of the water-energy-food nexus in India focusing on the connections among the three sectors and potential challenges.

The review is based on available scientific literature and publications by international organizations and the Indian government and could serve as a basic starting-point reference for in-depth research on water-energy-food-climate connections.

RESEARCH QUESTIONS

The following two research questions were formulated to assess the status of the water-energy-food nexus in India and identify challenges.

1. What are the main interlinkages between water, energy, and food in India?
2. What are the main challenges for the sustainable development of the water-energy-food nexus in India from an environmental, economic, and social perspective?

STRUCTURE OF THE REPORT

This report is divided into five chapters. The first chapter introduces the subject and lays out the context, rationale and aims of the research study. The second chapter provides background information by explaining the concept of the water-energy-food nexus and giving basic information about India. The third chapter covers the applied methodology and describes the methods for searching, choosing, and using data sources. In the fourth chapter, results with findings on research questions are presented. The fifth chapter discusses the results and provides reflection on their implications and possible limitations.

2. Background

2.1. Water-energy-food nexus

2.1.1. Origin and definition

The concept of the water-energy-food nexus (WEF nexus) has been receiving great attention in the last decade (Staupe-Delgado, 2019). However, as de Amorim *et al.* (2018) argue, the connections between water, energy and food were already acknowledged as early as in the 1970s when the concept of Integrated Water Resource Management (IWRM) was formed. The IWRM aimed to promote awareness about water security in the world, while recognizing that water is a crucial resource for sustainable development which includes social and economic aspects (de Amorim *et al.*, 2018).

Later, at the World Economic Forum Annual Meeting in 2008, a nexus of water, energy and food was identified (Daher & Mohtar, 2015). The Bonn Conference of 2011 further popularized the nexus approach internationally as a way towards sustainable development (Mohtar & Lawford, 2016). The World Economic Forum Water Initiative published a report in the same year, which listed a number of factors that would drive the demand for water, energy, and food resources in the next decades. Those drivers included population growth, economic growth, urbanization, changing diets and consumption patterns as the population becomes richer (The World Economic Forum Water Initiative, 2011). In 2014, the FAO used the nexus to analyze the effects of the global resource system on agriculture. In 2015, the WEF nexus was named one of the biggest risks to the world's economic stability by the World Economic Forum (Liu *et al.*, 2017).

Although the definition of the water-energy-food nexus may vary across different sources, the main idea is that water, energy and food sectors are interconnected and security of one of them depends on the other two (Abulibdeh & Zaidan, 2020). The difference between the IWRM and the nexus is that the former focuses on water as a starting point in the analysis of connections, while the WEF nexus approach starts with consideration of interlinkages throughout the whole system and then looks at the two-way interlinkages among water, energy, and food individually.

Amid the pressure from population growth, climate change, globalization and urbanization, the nexus approach can be used to increase efficiency of the whole system, build synergies and minimize trade-offs between sectors (Martin-Nagle *et al.*, 2011).

2.1.2. Current state of research on the nexus

In 2017, Liu *et al.* (2017) wrote that the scientific exploration of the WEF framework was just beginning, although studies about two-sector connections had made some progress. According to the authors, the description of those connections in a quantitative sense was lacking.

In 2019, Ghodsvali *et al.* (2019) conducted a systematic literature review of the transdisciplinary research on the WEF nexus and its current concepts and methods. The study pointed out a shift to the transdisciplinary perspective to make the nexus more practical in the real world. It also revealed a shift in research to consideration of diverse nexus actors and their interrelationships to better identify governance solutions. However, the authors stressed that although the transdisciplinary perspective was widely accepted, understanding of potentials and limits of transdisciplinary nexus thinking was lacking (Ghodsvali *et al.*, 2019).

In 2019, Staupe-Delgado (2019) studied how the concepts of water, energy, food and environmental security in the nexus had been approached in the literature. According to the authors, some individual studies focused on one sector of the nexus and then examined its connections with and effects on the other sectors. However, some adopted a holistic approach to examine how various nexus challenges are dealt with on a national level around the world. Some policy and economics studies showed how the nexus approach could

be connected to global networks for sustainable development. The authors also pointed out the lack of transdisciplinarity and integration in the analysis of sustainability challenges from a nexus perspective and added that the analysis of the nexus needed to be more people- and policy-centered.

In 2020, Endo et al. (2020) conducted an analysis of review articles published in the past three years to study the current status of the WEF nexus, its tools and methods. The analysis revealed geographical and academic expansion of the WEF nexus studies and showed that the concept of the nexus approach had been improved since at least the Bonn Conference of 2011. However, the authors pointed out that the WEF nexus approach did not have its own methods and tools and required a combination of social and natural sciences, and quantitative and qualitative methods and tools (Endo et al., 2020).

2.2. Basic information about India

India is the 7th largest and the second most populous country in the world, with an estimated total population of 1.3 billion (World Bank, 2020).

Most of the country's territory has a high population density, except for the Himalayan mountains in the north and western deserts. Around 45% of the land is used for agriculture, while forests occupy over 24% of the land. Although urbanization rates are high throughout India, 66% of the population live in rural areas (IEA, 2020, World Bank, 2020).

India's economy includes various modern industries and services, modern agriculture, as well as traditional village farming and handicrafts (IEA, 2020). Dependence on the agricultural sector in terms of its share in the gross domestic product (GDP) has reduced over the last few decades, while the emphasis on industries and services has been increasing (Barik et al., 2017). However, more than 50% of the workforce are still engaged in the agricultural sector (NITI Aayog, 2018).

Table 1 shows the main indicators of India and other South Asian countries. India is the biggest and most populous country in South Asia. Although India's GDP at purchasing power parity of around 9 trillion US dollars is much higher than that of all other countries in the region, its gross national income (GNI) per capita of 2,020 US dollars is lower than that in the Maldives (9,280 US dollars) and Sri Lanka (4,060 US dollars). India has been classified by the World Bank as a lower-middle-income country since 2007, while the Maldives and Sri Lanka were moved to the upper-middle-income category in 2010 and 2018, respectively.

However, India's economy has shown strong performance in recent decades, poverty levels have decreased significantly, access to energy for citizens has improved, and cleaner energy has been penetrating the economy (IEA, 2020).

Table 1. Main indicators of South Asian countries (World Bank, 2020)

	Population, million (2018)	Land area, thousand km ² (2018)	GDP (PPP), billion US\$ (2018)	GNI per capita, US\$ (2018)	Classification by income (GNI per capita) (2018)
India	1,353	2,973	9,058	2,020	Lower middle (since 2007)
Afghanistan	37	653	83	550	Low
Bangladesh	161	130	734	1,750	Lower middle (since 2014)
Bhutan	0.8	38	9	2,970	Lower middle (since 2006)
Maldives	0.5	0.3	10	9,280	Upper middle (since 2010)
Nepal	28	143	94	970	Low
Pakistan	212	771	1,030	1,590	Lower middle (since 2008)
Sri Lanka	22	63	287	4,060	Upper middle (since 2018)

Climatic characteristics of India

India's agricultural land spreads throughout six climatic subtypes with the north having alpine tundra and continental climate with varying temperatures, the south-west having a humid tropical climate, the west being an arid desert, and the north-east and coastal regions receiving abundant rainfalls (OECD & Indian Council for Research on International Economic Relations, 2018).

Rainfall and monsoon

India's annual rainfall is about 1170 mm, which is slightly above the world average (Thatte, 2018). At the same time, the country has regions with the highest rainfall in the world (Thakur, 2020). Mawsynram in

Northeast India is considered the wettest place on the planet with an annual rainfall of over 10,000 mm (Arora & Tiwari, 2018; Pradhan et al., 2019).

Around 50% of annual precipitation in India is attributed to streamflow (yield of river basins), 11% to replenishable groundwater resources, and 38% to evapotranspiration (water lost to the atmosphere from the ground surface, evaporation from the groundwater table, and the transpiration of groundwater by plants) (Jain, 2012).

The biggest factor affecting the climate on the Indian Peninsula is the Indian summer monsoon that brings between 75% and 90% of the annual rainfall, replenishing surface and groundwater resources (Varikoden, et al. 2019).

The months of June–July–August–September (JJAS) are considered the monsoon season. According to Thatte (2018), the main factors affecting the monsoon rainfall are:

- (1) Differing temperatures at the surface among the Northern Oceans, the Atlantic and Pacific;
- (2) El Niño and La Niña, which are weather patterns synonymous with “droughts” and “floods,” respectively;
- (3) Temperatures at the surface in the Indian Ocean and atmospheric pressure at the surface in the eastern Asian oceans;
- (4) Differing temperatures at the surface between the Arabian Sea and the Bay of Bengal, a phenomenon called the Indian Ocean Dipole;
- (5) Temperatures of the land surface in the north-west of Europe; and
- (6) Amount of warm water in the Pacific Ocean.

Mean rainfall data for the period between 1981 and 2019 (Figure 2) clearly shows that India has great spatial variation in terms of the amount of rainfall (WMO, 2020).

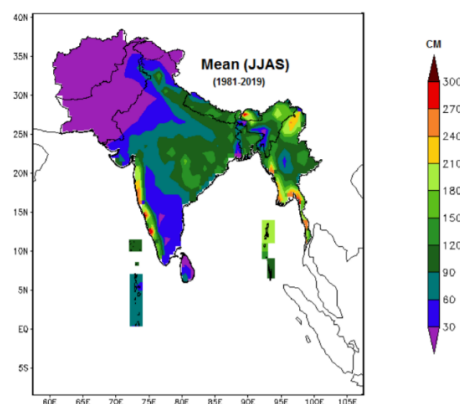


Figure 2. Rainfall climatology for the period 1981-2019: Rainfall data over South Asia (Mean for JJAS: June-July-August-September) (WMO 2020)

However, according to several recent studies, the Indian monsoon has been weakening as the western Indian Ocean has been becoming warmer, land use and land cover have been changing on a large scale, and aerosol emissions have been increasing. At the same time, extreme rainfall events have increased (Barik et al., 2017).

Natural disasters

India is vulnerable to a large number of climate-related natural disasters, such as floods, droughts, cyclones, and river erosion. More than 12% (40 million hectares) of India’s land is prone to floods and river erosion; 68% of cultivable area is vulnerable to droughts; the coastline of 5,700 km out of 7,516 km is prone to cyclones; and landslides and avalanches are also a risk in some areas (NDMA, 2020).

The Indian Monsoon, erodible and steep mountains, and highly silted river systems make India one of the

most flood-prone countries in the world (Ministry of Home Affairs, 2011).

3. Methodology

This study is based on bibliographical and qualitative research which included reviewing scientific articles obtained through online search platforms (Uppsala University library, Google Scholar, ScienceDirect, etc.), data and publications by international organizations (Asian Development Bank, Food and Agriculture Organization, United Nations, UNESCO, World Bank, World Economic Forum, etc.), and publicly available information from websites of India’s governmental agencies.

Relevant articles were further chosen after scanning their abstracts. Articles published within the past three years (from 2016) were given particular attention.

A spreadsheet with all sources was created to ensure sufficiency of information and diversity of types of documents and content (Figure 3).

All sources in the spreadsheet were classified in the following way:

G/I/SA: General, India or South Asia

WEFC: Nexus sectors covered (Water, Energy, Food, Climate)

YEAR: Year of publication

DOC TYPE: Type of the document

AC_ART: Academic article

ORG_REP: Organization’s report

ORG_DATA: Organization’s data

GOV_REP: Government’s report

GOV_DATA: Government’s data

GOV_DOC: Government’s document

1/2.1/2.2/3/4.1-W/4.1-E/4.1-F/4.2-WF/4.2-WE/4.2-EF/4.2-Ind/4.3-Env/4.3-Soc/4.3-Econ/5: Codes for all chapters and sections of this report

A	C	D	E	G	J	L	M	N	O	P	Q	R	S	T	U	V	X	Y	Z	AA
	G/I/SA	WEFC	NAME	YEAR	DOC TYPE	1	2.1	2.2	3	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.2	4.2	4.2	5
										W	E	F	WF	WE	EF	Ind	Env	Soc	Econ	
1	I	WEF	1. Barik_Water–food–energy nexus with	2017	AC_ART	X		X					X		X		X			
47	I	F	47. OECD_Agricultural Policies in India	2018	ORG_REP							X						X	X	
84	SA	G	84. WB data South Asia	2020	ORG_DATA			X												
110	I	E	110. Energy Statistics 2020	2020	GOV_REP					X										
111	I	WEG	111. EnviStats 2020	2020	GOV_DATA															
114	I	E	114. Electricity Act 2014	2014	GOV_DOC					X										

Figure 3. A part of the spreadsheet used for source classification

The spreadsheet shows what sections each source is used for. Sorting and filtering by content, year, type, and section allows to easily check required information.

Interlinkages identified as “main interlinkages” are those that were mentioned in all or the majority of reviewed sources covering specific sector connections. In contrast, “other interlinkages” refer to those that were only mentioned in few of the reviewed sources.

Similarly, challenges for the sustainable development of the water-energy-food nexus identified as “main” in this study are those that were covered in all or the majority of reviewed sources.

4. Results

4.1. Overview of nexus sectors

4.1.1. Water sector

Water sources

More than 52% of water withdrawn in India is surface water (water in lakes, ponds, streams, wetlands, rivers, and oceans). Groundwater (water in soil stored underground in aquifers) accounts for 33%, and agricultural drainage water accounts for 15% of total water withdrawal (Figure 4) (FAO, 2015). The volume of desalinated water is only 0.0006 km³ which is close to 0% of total withdrawal. Agricultural drainage water is the water withdrawn for agriculture that is not consumed and returned. While surface water and groundwater are called renewable freshwater resources, agricultural drainage water is considered as a secondary water source which can be recovered and reused. Agricultural drainage water, as well as wastewater and desalinated water, are among non-conventional water sources (FAO, 2020).



Figure 4. Water withdrawal by source in 2010. Adapted from FAO (2015, Figure 3, p.8).

India extracts around 25% of the world's groundwater annually, which is more than the United States and China combined (IEA, 2020).

Most of the groundwater resources come from the recharge of monsoon rainfall, which represents about 75–90% of the total annual rainfall in India (Government of India, 2020; Varikoden et al., 2019).

Surface water comes from monsoon runoff and summer snowmelt in the Himalayas that feed river systems, cyclonic rainfall, and runoff in neighboring countries that flows into transboundary rivers (Thatte, 2018).

Water use

Most of the water withdrawn in India is used for agriculture, which requires water for irrigation, livestock, and aquaculture. In 2010, 91% of water withdrawn was used by the agricultural sector. 7% and 2% were used by municipalities and industry, respectively (Figure 5). Water for the industrial processing of agricultural products and water for meat and dairy industries are included in the industrial water withdrawal.

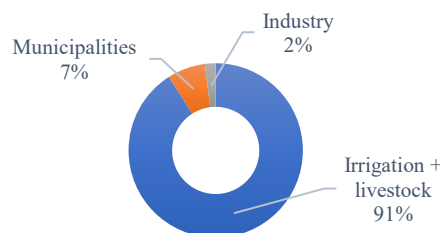


Figure 5. Water withdrawal by sector in 2010. Adapted from FAO (2015, Figure 2, p.8).

The main irrigation technique in India is flood irrigation which is highly inefficient (Barik et al., 2017). Under this type of irrigation, large amounts of water are lost through field runoff and evaporation (Kumar, 2018).

Water availability

Availability and demand for water differ across regions in India. Some regions suffer from groundwater depletion and the use and distribution of water which are inequitable and inefficient (Dhawan, 2017). The overall per capita water availability is now 1458 m³ per year, which is below the water stress threshold of 1667 m³ (Rasul et al., 2019).

Renewable internal per capita freshwater resources have declined over the last decades, from 3,082 m³ in 1962 to 1,444 m³ in 1997 and 1,155 m³ in 2014, falling by 65% between 1962 and 2014 (Beaton et al., 2020). This decline has been attributed to excessive withdrawal of water for irrigation and reduced monsoon season rainfall (Asoka et al., 2018).

According to a groundwater assessment of 2013, India's total groundwater availability was 411 billion m³ with the annual withdrawal of 253 billion m³ (Beaton et al., 2020).

In 2015, 94.1% of population had access to safe drinking water (92.6% of rural population and 97.1% of urban population) (FAO, 2016). The pipe water supply has been expanding in rural areas. The share of population getting safe and adequate drinking water within premises through the pipe water supply increased from 36.5% in 2017 to 40.5% in 2019 (Ministry of Statistics and Programme Implementation, 2020b).

Policies regulating the water sector

India's first National Water Policy (NWP) adopted in 1987 was mainly concerned with irrigation and food self-sufficiency, particularly in the event of extreme droughts and floods (Thatte, 2018). NWP was revised in 2002 and 2012, bringing in more policy aspects. In the revision of 2012, provision of drinking water was given top priority (Hirji et al., 2017; Kumar, 2018). The Policy points out a wide range of concerns related to the management of water resources, such as water stress caused by the growing demand, variation in water availability, climate change, issues with access to water, overexploitation, pollution, and others (Ministry of Water Resources, 2012). The Policy then proposes a framework for an action plan and sets the main principles for uses of water, enhancement of water availability, water supply and sanitation, management of water demand and water use efficiency, climate change adaptation, water pricing, conservation and management of water-related events, such as droughts and floods (Ministry of Water Resources, 2012).

In 2014, the Ministry of Water Resources published guidelines to lay out measures for improvement in the irrigation, domestic and industrial sectors.

However, at present, there are no clear incentives for farmers to use water in an efficient and sustainable way. Irrigation has been dominated by tube wells, which has led to an uncontrolled access to and overexploitation of water resources. In combination with energy subsidies for groundwater pumping, this allows farmers to continue pumping from the tube wells, while severely depleting groundwater resources (OECD & Indian Council for Research on International Economic Relations, 2018).

4.1.2. Energy sector

Energy production

The largest source of energy production in India is coal, which is mainly used for power generation. Oil is used for transport and industry, while biomass is used for residential heating and cooking. In 2017, coal accounted for around half of total energy production, while bioenergy and waste (biogases, biofuels, industrial and municipal waste) accounted for around one-third (Figure 6). The consumption of biomass fuels traditionally used for residential cooking and heating, such as fuelwood or animal dung, accounts for

around two-thirds of the bioenergy supply (IEA, 2020).

Around two-thirds of total primary energy supply are produced inside the country. Bioenergy and most of the coal supply are produced domestically, while most of the natural gas and oil are imported (IEA, 2020). At the same time, India is one of the largest producers of refined oil products in the world, exporting mainly transport fuels: diesel and gasoline (IEA, 2020).

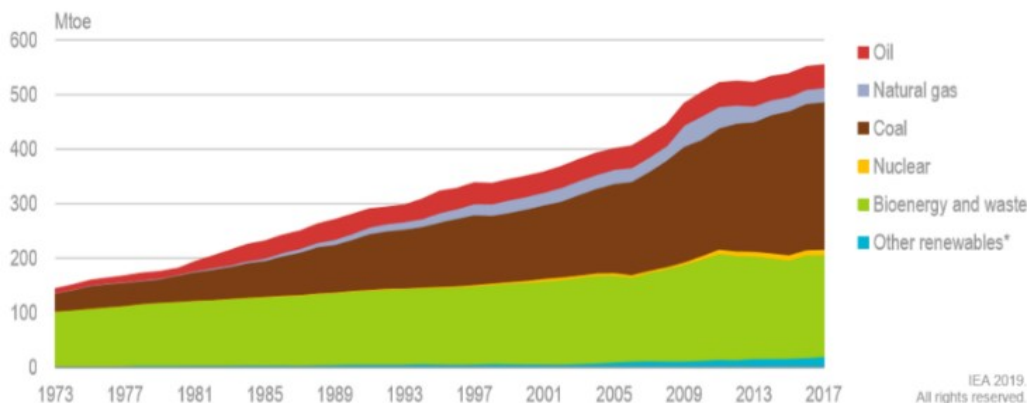


Figure 6. Energy production by source, 1973-2017 (IEA, 2020)

*Other renewables include hydro, solar, and wind.

Based on current policies, the share of coal in electricity generation is projected to reduce from the current 74% to 48% in 2040, while remaining the primary source of electricity generation. On the other hand, renewables are estimated to expand to 45% in 2040 from the current 18%, resulting in carbon-intensity reduction by 40%. At present, the largest source of renewable electricity is hydropower (9.3% of total electricity generation). However, wind power (3.3% of total electricity generation), solar power (1.7%), and bioenergy and renewable waste (2.9%) are expected to show a significant growth. Specifically, wind and solar photovoltaic (PV) power are expected to account for 36% of total installed capacity by 2030 (IEA, 2020).

Energy consumption

The major sources of energy consumed in India are coal and crude petroleum. In 2018-19, coal accounted for 45%, followed by crude petroleum (33%), renewable sources (13%), natural gas (7%), and lignite (2%) (Figure 7).

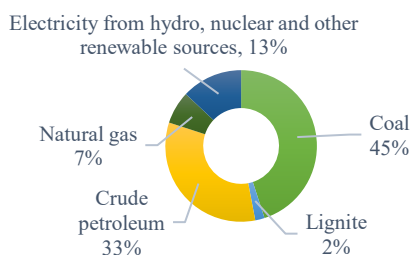


Figure 7. Source-wise consumption of energy during 2018-19. Adapted from National Statistical Office (2020, Fig 6.5, p.52)

As for energy consumption by sector, in 2017 industry accounted for around 42% of total final consumption (TFC), coming from oil, natural gas, coal, electricity, and biofuels (Figure 8). The transport sector consumed 17% of TFC, dominated by oil fuels, while the residential sector and the services/other sector accounted for 29% and 12% of TFC, respectively. The services/other sector includes public services, non-residential

buildings, agriculture, fishing, and forestry. In 2017, 42% of TFC in the service sector was attributed to agriculture and forestry (IEA, 2020).

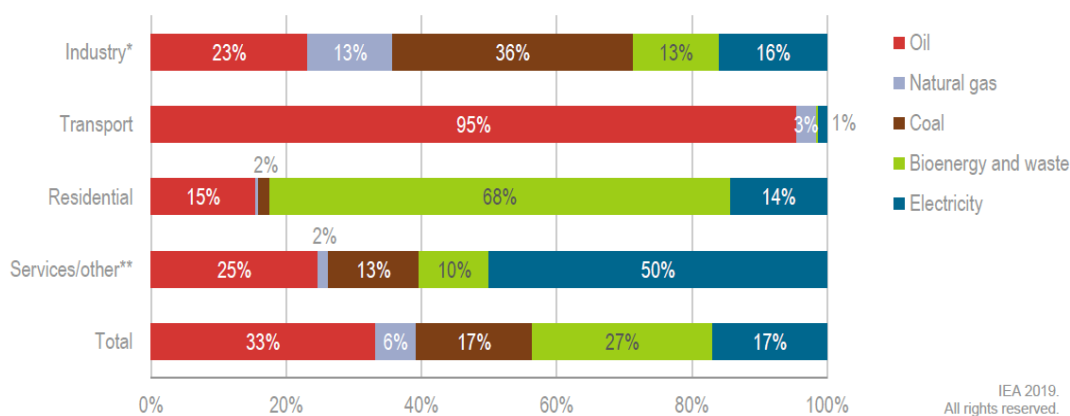


Figure 8. Total final consumption (TFC) of energy by source and sector, 2017 (IEA, 2020)

* *Industry* includes non-energy consumption.

In the period 2011 to 2018, per-capita energy consumption (PEC), which is the ratio of total energy consumption to population, has been increasing. The PEC in 2017-2018 was 18.9% higher than in 2011-2012 (Central Statistics Office, 2019). However, India’s per-capita energy consumption is still only 30% of the global average (IEA, 2020).

Energy availability

The proportion of population with access to electricity grew from 67.4% in 2005 to 95.2% in 2018 (Figure 9). However, there is a gap of nearly 7 percentage points between urban (99.7%) and rural population (92.9%) who had access to electricity (World Bank, 2020).

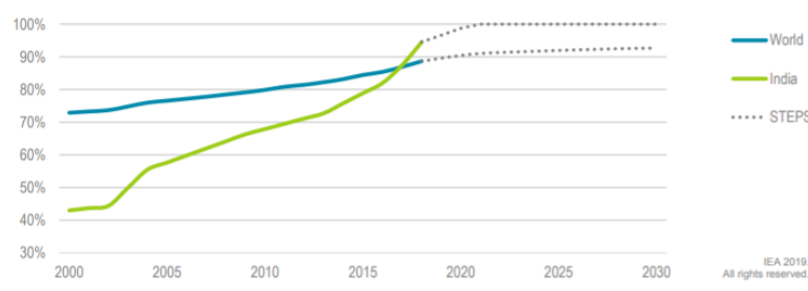


Figure 9. Proportion of population with access to electricity (IEA, 2020)

Policies regulating the energy sector

One of the main policies regulating the energy sector in India is the Electricity Act of 2003 which has seen continuous amendments, with the latest amendment added in 2013 (Ministry of Power, 2014; Abbas et al., 2018). The Electricity Act was enacted to reform the power sector by consolidating “the laws relating to generation, transmission, distribution, trading and use of electricity and generally for taking measures conducive to development of electricity industry, promoting competition therein, protecting interest of consumers and supply of electricity to all areas, rationalisation of electricity tariff, ensuring transparent policies regarding subsidies, promotion of efficient and environmentally benign policies” (Ministry of Statistics and Programme Implementation, 2019).

4.1.3. Food sector

The food and agricultural sector is an important contributor to India's economy, although its share in the Gross Domestic Product (GDP) has continued to decline over the last two decades – from 27% in 1995 to 17% in 2016 (Table 2). Despite this decline, agriculture still plays an important role in maintaining the country's food security (Barik et al., 2017). Agricultural sector is also the main source of employment in India, accounting for about 50% (NITI Aayog, 2018).

Table 2. Agriculture-related indicators. Adapted from OECD & Indian Council for Research on International Economic Relations (2018, Table 1.1, p. 23) which is based on information from the UN, World Bank, and Ministry of Labour and Employment.

	1995	2016 ¹
Agriculture in GDP (%)	27	17
Agriculture share in employment (%)	61	47
Agro-food exports (% of total exports)	20	13
Agro-food imports (% of total imports)	6	7

¹ Or latest available year.

Food production

A wide range of crops are cultivated in India in its diverse natural regions and climatic conditions. The production of several major crops, such as food grains, pulses, and oil seeds, have increased in the past decade (Table 3).

Table 3. Production of major crops (million tons). Adapted from (Ministry of Agriculture & Farmers Welfare (2019, Table 5.3(a), p. 48)

Crop	2011-12	2013-14	2015-16	2017-18¹
Foodgrains	259	265	252	285
Rice	105	107	104	113
Wheat	95	96	92	100
Maize	22	24	23	29
Nutri Cereals	42	43	39	47
Pulses	17	19	16	25
Gram	8	10	7	11
Tur (Arhar)	3	3	3	4
Oilseeds	30	33	25	31
Groundnut	7	10	7	9
Rapeseed & Mustard	7	8	7	8
Soybean	12	12	9	11
Cotton²	35	36	30	35
Jute & Mesta³	11	12	11	10
Sugarcane	361	352	348	377

¹ 4th Advance Estimates ² Million bales of 170 kg. each ³ Million bales of 180 kg. each

India has also become one of the major exporters of several agricultural commodities, such as high value pulses, fruits and vegetables, and livestock products (OECD, 2019). Total agro-food exports constitute 13% of India's total exports (Table 2).

In 2016, India was the largest producer of pulses with the 21.75% share in the global production, jute (57.31% of global production), buffaloes (56.46% of global production), and milk (20.42 % of global production) (Ministry of Agriculture & Farmers Welfare, 2019). India also ranks second in aquaculture and fish production in the world, accounting for about 6% of global production (OECD & FAO, 2014; FAO, 2020).

Food consumption

As the economic growth has been progressing and incomes have been increasing, the share of consumer spending on food in total households' expenditures declined for all income groups by about 10 percentage points for rural households and by about 16 percentage points in urban households from the end of 1990s to 2010. In 2011-12, food accounted for 42.6% for urban households and 52.9% of rural households' expenditures (OECD & Indian Council for Research on International Economic Relations, 2018).

However, there is still a lack of adequate access to food, with 14.8% of the population estimated to have been undernourished in the period 2015–17 (Beaton et al., 2020).

Food availability

Food availability per capita in India has increased to 179.6 kg per person per year in 2019 from 169.8 kg per person per year in 2015 (Ministry of Statistics and Programme Implementation, 2020b). Per capita availability of several important products, such as edible oils, sugar, tea, coffee and cotton cloth, has been improving over the past decades (Ministry of Agriculture & Farmers Welfare, 2019).

Policies regulating the food sector

The National Agricultural Policy (NAP) was formulated in 2000 with a priority on improving cropping intensity, developing infrastructure that would also support all other rural activities, developing and disseminating agricultural technologies, and reconsidering trade rules and regulations (OECD & Indian Council for Research on International Economic Relations, 2018).

The National Policy for Farmers (NPF) of 2007 emphasized the need to put focus on farmers' economic well-being by providing assets and technologies, empowerment, and support services (OECD & Indian Council for Research on International Economic Relations, 2018).

The National Food Security Act adopted in 2013 addressed the need to provide welfare schemes that would better target the poor and be more specific (OECD & Indian Council for Research on International Economic Relations, 2018).

4.2. Current interlinkages between nexus sectors

This section provides answers to Research Question 1: *What are the main interlinkages between water, energy, and food in India?*

Findings of this section and section 4.3 are shown schematically for visualization (Figure 10).

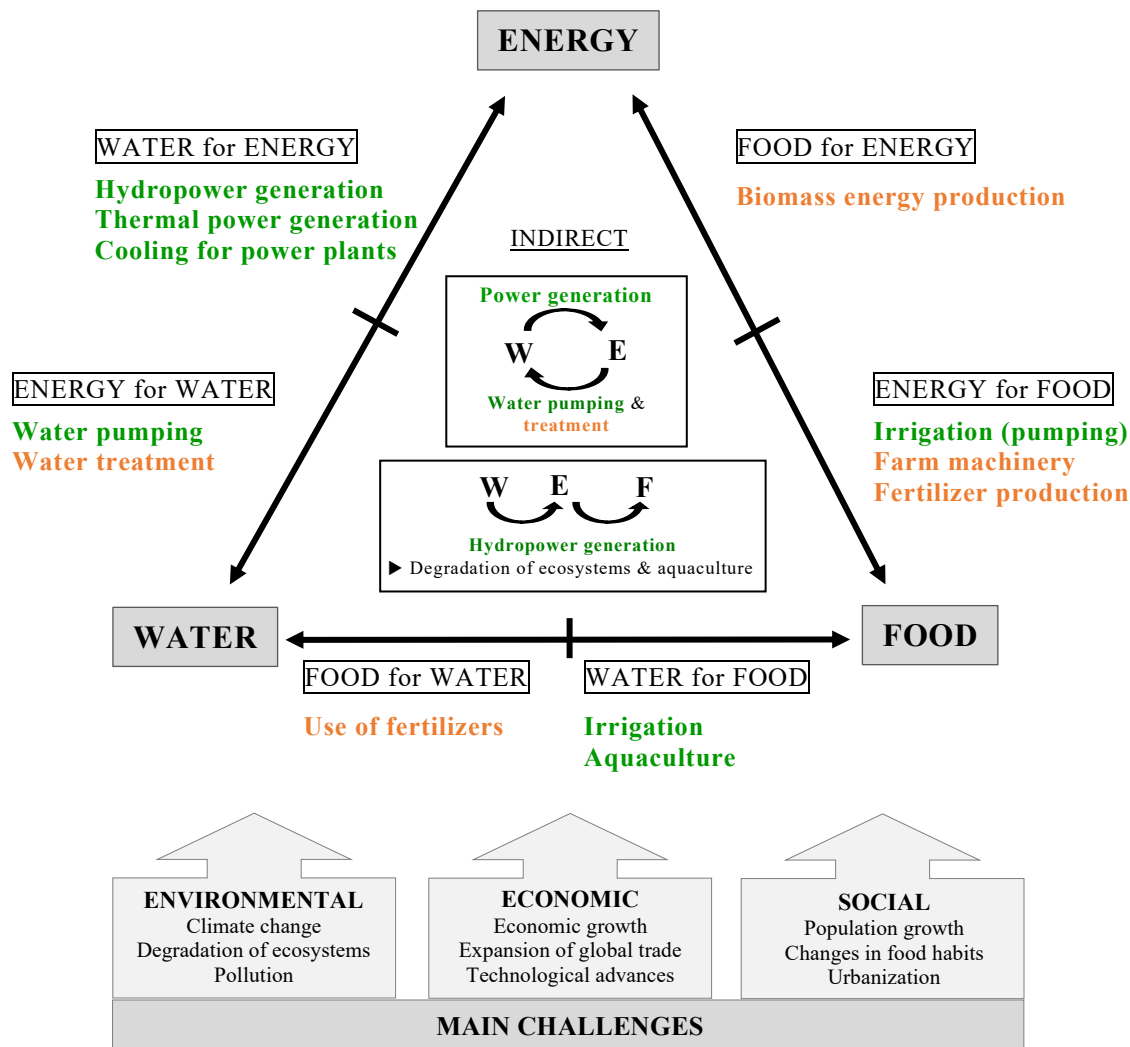


Figure 10. The interlinkages and main challenges for the sustainable development of the water-energy-food nexus in India. The main interlinkages are shown in green, while other interlinkages are shown in orange. Indirect interlinkages are placed inside the triangle.

4.2.1. Direct interlinkages

4.2.1.1. Water-food nexus

Food production can depend on water availability in different ways. First, production of food and livestock fodder in terrestrial ecosystems requires irrigation. Second, food is also produced in aquatic ecosystems, or the water itself. (D’Odorico et al., 2018).

The main interlinkages between water and food identified through the literature review are related to

irrigation and livestock fodder, as well as aquaculture (green in Figure 10). Another identified interlinkage is related to the use of agricultural fertilizers (orange in Figure 10).

Irrigation and livestock fodder

Food production in India is highly dependent on groundwater resources (Beaton et al., 2020). Around 83% of all available water resources and 91% of the groundwater withdrawn are used for agriculture (irrigation for crops and livestock fodder) and aquaculture (Barik et al., 2017). Irrigation includes water used in growing fodder crops which occupy 4.6% of total cropped area (Ministry of Agriculture & Farmers Welfare, 2019).

The most water-intensive crops - rice, wheat and sugarcane – are among the most important crops as they account for around 90% of India's crop production (Barik et al., 2017; Dhawan, 2017). In 2016, India was the second largest producer of rice, wheat and sugarcane in the world, with rice also being an important export crop (Ministry of Agriculture & Farmers Welfare, 2019). The production of one kilogram of rice requires around 3,500 liters of water (Dhawan, 2017).

As mentioned in the previous section, the main irrigation technique in India, flood irrigation, is highly inefficient (Barik et al., 2017). The use of such traditional methods leads to the loss of water through field runoff and evaporation (Kumar, 2018). More water- and energy-saving practices, such as micro-irrigation including sprinkler and drip irrigation, have been expanding in recent years (OECD & Indian Council for Research on International Economic Relations, 2018). For example, the area covered under sprinkler irrigation increased almost fourfold between 2004 and 2018 (FAO, 2015; Ministry of Agriculture & Farmers Welfare, 2019). Negative impacts of climate change on water availability and water demand are expected to further affect the use of irrigation practices, as well as time of cultivation and crop selection (Dhawan, 2017).

Aquaculture

Efficient water use in aquaculture and fishing is becoming increasingly important as this sector is constantly growing and contributing to India's food security. The gross value added (GVA) of fishing and aquaculture at constant (2011-12) prices increased by 23% between 2015 and 2017 and 63% between 2011 and 2017. This growth rate was one of the highest among all economic activities in all sectors (Ministry of Agriculture & Farmers Welfare, 2019). The annual growth in fisheries and aquaculture in the GDP has been around 9-10% in recent years (Ministry of Statistics and Programme Implementation, 2020b).

While inland waters are the origin of around 60% of the fish and the rest originates from marine waters, around 90% of aquaculture is produced in freshwater (OECD & FAO, 2014).

Fish production and aquaculture in India are expected to grow further (FAO, 2020), which will require large amounts of freshwater. That growth will also depend on external factors such as climate change, pollution and degradation of land and habitats (OECD & FAO, 2014).

Use of agricultural fertilizers

The quality of water resources in India is likely to be affected by practices that include discharges of phosphorous, nitrogen and other substances (OECD & FAO, 2014), as the consumption and production of such fertilizers have substantially increased in the 2010s compared to the 1980s and 1990s (Table 4).

Table 4. Consumption, production and imports of fertilizers (nitrogen (N), phosphorous (P) and potassium (K)), 1981-2018 (Ministry of Agriculture & Farmers Welfare, 2019)

(million tons)

	Consumption				Production		
	N	P	K	Total	N	P	Total
1981-82	4.1	1.3	0.7	6.1	3.1	0.9	4.1
1990-91	8.0	3.2	1.3	12.5	7.0	2.1	9.0
2000-01	10.9	4.2	1.6	16.7	11.0	3.7	14.7
2010-11	16.6	8.1	3.5	28.1	12.2	4.2	16.4
2014-15	16.9	6.1	2.5	25.6	12.4	4.1	16.5
2017-18	17.0	6.9	2.8	26.6	13.4	4.7	18.1

4.2.1.2. Water-energy nexus

Water and energy sectors are closely connected, as water can be used in fuel production and power generation, and energy can be used for the supply of water.

Around 35 billion cubic meters (bcm) of water was withdrawn in India for energy-related purposes in 2016. Such withdrawals, which are the amount of water removed from a source, are projected to almost double by 2040. Energy-related water consumption, which is the amount of water withdrawn from a source but not returned, was around 5 bcm out of 35 bcm in 2016 and is projected to increase almost fivefold by 2040. Such an increase is expected to come from the growth of nuclear power generation, in addition to the still remaining but decreasing coal-based power generation (IEA, 2020).

The main interlinkages between water and energy identified through the literature review are related to power generation and pumping (green in Figure 10). Other interlinkage is water treatment (orange in Figure 10).

Power generation

Water availability has a direct impact on all types of power plants to varying degrees (IRENA & WRI, 2018).

Hydropower, which currently accounts for 9.3% of India's power generation, is the largest source of renewable electricity in India (IEA, 2020).

Other renewable energy production can also be water-intensive (D'Odorico et al., 2018), while certain types of geothermal power generation, wind, and PV power generation have very low water requirements (UNESCO, 2020).

Around 85% of India's electricity is produced by fossil fuel and nuclear power plants, which are highly dependent on water resources for cooling purposes (IRENA & WRI, 2018). Coal-based power production also uses water resources intensively in other systems and processes, including the boiler and ash disposal. However, cooling systems have the highest water consumption among these processes.

Around 40% of thermal power plants in India are situated in high-water-stress areas. Those power plants are mostly coal-based. Water shortages between 2013 and 2016 led to shutdowns of India's 14 largest thermal power stations (OECD, 2019; IEA, 2020). An analysis by IRENA & WRI (2018) showed that around 14 TWh of thermal electricity generation was lost as a result of those shutdowns. This amount is equivalent to the annual power use in India's North-Eastern region.

Water treatment

Although water treatment technologies are not used on a large scale in India, there are a number of

desalination plants that produce freshwater from sea water. Such technologies require large amounts of energy (Manju & Sagar, 2017).

4.2.1.3. Energy-food nexus

Energy in the form of electricity is generally used in agriculture for pumping of groundwater for irrigation, while operation of farm machinery (tractors and other tools) uses energy in the form of diesel (Barik *et al.*, 2017; Ali *et al.*, 2019).

The main interlinkages between food and energy identified through the literature review are related to irrigation (water pumping) (green in Figure 10). Other interlinkages include biomass energy production, use of machinery in agriculture, and production of fertilizers (orange in Figure 10).

There has been a constant increase in electricity consumption for agricultural purposes in India over the past few decades (Table 5). In the past decade, the share of agricultural electricity consumption to total electricity consumption has been around 20-21%. It is estimated that electricity demand in India increased 12-fold from 1950 to 2010, while agriculture-related electricity consumption increased 25-fold (Mukherji, 2019).

Table 5. Consumption of electricity for agricultural purposes in India. Adapted from Ministry of Agriculture & Farmers Welfare (2019, Table 8.7, p. 90)

	Consumption for Agricultural Purposes (TWh)	Total Consumption (TWh)	Share of Agricultural Consumption to Total Consumption (%)
1982-83	18	96	18.6
1990-91	50	190	26.4
2000-01	85	317	26.8
2010-11	126	617	20.5
2012-13	147	709	20.8
2014-15	169	814	20.7
2016-17	191	914	20.9

Irrigation (water pumping)

This interlinkage is described in section 4.2.2 as an indirect interlinkage.

Machinery and production of fertilizers

There is no sufficient information on how much energy is used throughout the whole food production chain up to food processing and distribution. Calculations in a study by Rao *et al.* (2019) suggest that fertilizer production contributes up to 44% of energy used in agriculture, while irrigation and machinery account for 38% and 18%, respectively. However, these calculations exclude food processing, transport, and imports of fertilizers.

Biomass energy production

While traditional biomass fuels (e.g., wood or animal dung) have been an important energy source used in the residential sector, the use of food biomass, such as energy crops, in power generation is relatively new in India. In 2018, FAO stated that it would promote projects on biomass-based energy generation that are innovative and better utilize farm assets and agricultural products in India (FAO, 2018).

A study by Usmani (2020) on the potential for energy and biofuel from biomass in India showed that biomass from food grains, fibre crops and horticulture crops has a measurable potential to be used for biofuel production.

4.2.2. Indirect interlinkages between sectors

The above-described interlinkages between two sectors can be further expanded into chain reaction interlinkages among the three sectors.

One of the examples is irrigation which represents an energy-water-food interlinkage, or an indirect interlinkage between energy and food, where energy is used to pump water for irrigation. Agriculture-related electricity consumption can be used as a proxy for energy use in withdrawal of groundwater (Barik et al., 2017). In fiscal year 2017/18, agriculture-related consumption accounted for 18.1% of total electricity consumption in India (Beaton et al., 2020).

Another example that represents a three-sector interlinkage is related to aquaculture, where hydropower generation affects aquatic ecosystems which aquaculture depends on.

There are also indirect interlinkages where a sector is connected to one of the other sectors through a loop. One of the examples is a water-energy-water interlinkage, where water is used in the generation of energy which, in turn, is used for pumping, treatment and transportation of water.

4.3. Challenges for sustainable development of the water-energy-food nexus in India

This section provides answers to Research Question 2: *What are the main challenges for the sustainable development of the water-energy-food nexus in India from an environmental, economic, and social perspective?*

Findings of this section are shown schematically at the bottom of Figure 10 in section 4.2.

4.3.1. Environmental perspective

The main environmental issues that challenge the sustainable development of the water-energy-food nexus in India are climate change, degradation of ecosystems, and pollution.

Climate change

Quality and distribution of water resources in India are highly likely to be affected by climate change which brings more intense rains that are not evenly distributed in terms of space and time, melting glaciers, as well as changes in the generation of runoff and recharge of groundwater. Climate change will alter the ways water is used in all sectors – domestic, agricultural, industrial, and others, affecting water security, food security, biodiversity, and people's health (FAO, 2015).

It is projected that by 2080s the temperature will increase by at least 3.3°C on the Indian sub-continent, compared to preindustrial times. Increased temperature and more rare rains associated with the weakening of the Indian monsoon are already having a negative impact on particular crops in some areas (Barik et al., 2017; Srinivasa Rao et al., 2019). In the last four decades, India has experienced a major drought at least once every three years (Rasul et al., 2019). A climate change scenario for 2020-2039 projects a 4.5-9% reduction in crop yield (Srinivasa Rao et al., 2019). Among the most affected are rice, maize, wheat, cotton, vegetables, and sugarcane. Livestock, including milk production, will also be affected (OECD & Indian Council for Research on International Economic Relations, 2018).

According to a study by OECD (2017), India, the United States and China are expected to become water risk hotspots for agriculture. The problems with the water table and water quality in Northwest India caused by groundwater irrigation are expected to become even worse.

In Punjab, for example, the total water availability is twice lower than the water demand which mostly comes from the agricultural sector. This puts pressure on water resources and depletes groundwater rapidly (OECD & Indian Council for Research on International Economic Relations, 2018).

Hydropower generation in India is also extremely vulnerable to seasonal and temporal changes in water availability. Higher frequency and intensity of floods and droughts may alter patterns of water flow and affect the viability of hydropower generation (IEA, 2020). While droughts may negatively affect hydropower generation, there may be the opposite effect during periods of intense rains. According to a recent study, the rainfall at the sites of seven largest hydropower projects in India is expected to increase, resulting in a rise in hydropower electricity production (IEA, 2020).

Thus, the water-energy-food nexus in India is likely to be significantly affected by climate change.

Degradation of ecosystems and pollution

Terrestrial and aquatic ecosystems provide vital services such as water supplies, food production or purification. Ecosystem degradation is mainly caused by water depletion and pollution from various activities, untreated waste, or toxic dumping (UNESCO, 2020). Degradation of ecosystems may lead to changes in runoff, disruption of groundwater discharge, water quality and availability, as well as

destruction of the aquatic habitat, which may affect fisheries and aquaculture (Bonn 2011 Conference, 2012; D’Odorico et al., 2018).

River pollution and groundwater pollution caused by municipal and industrial wastewater discharges have become a serious issue across India (Narwaria, 2019; Schellenberg et al., 2020). The potential impact of fertilizers used in agriculture on water resources is described in section 4.2.1.1.

4.3.2. Economic perspective

As for economic aspects, further economic growth, expansion of global trade, and technological advances represent the main challenges.

Economic growth

India’s GDP and GDP per capita have been steadily growing in the recent decades (Figure 11).

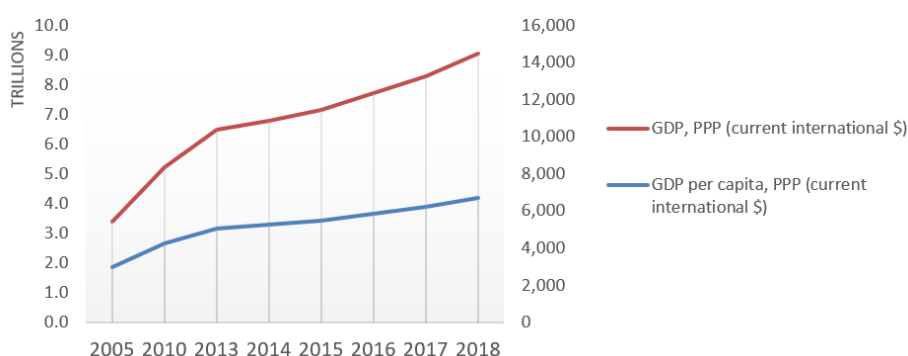


Figure 11. India’s GDP and GDP per capita, 2005-2018 (World Bank)

As an emerging economy with the annual growth target of 9%, India’s rising incomes and consumption will also lead to increasing demand for water, food, and energy resources and systems, as well as infrastructure (IEA, 2020). Water requirements are estimated to reach 1,180 billion m³ by 2050 with a total availability of 1,137 billion m³ (Beaton et al., 2020).

Global trade

The share of agro-food trade in India’s agricultural GDP rose to 16% in 2016 from 5% in 1990, at the start of the economic reforms. India’s agriculture is integrating into the global market. 13% of the country’s total exports is agro-food exports, and 7% of total imports is agro-food imports (Table 2) (OECD & Indian Council for Research on International Economic Relations, 2018).

India is one of the major exporters of cotton, rice, meat, fish, vegetable extracts and other products (OECD & Indian Council for Research on International Economic Relations, 2018). In 2017, the export of vegetables, foodstuffs and wood accounted for 9% of India’s gross export (Figure 12).

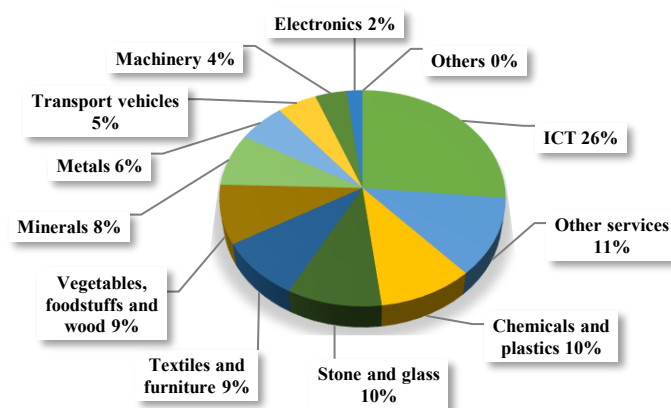


Fig. 12. Export of goods and services per sector: Percentage of gross export flows, 2017. Adapted from OECD & Indian Council for Research on International Economic Relations (2018, Figure 7A, p.23)

Further increase in production of agricultural products for export will continue to put pressure on water resources.

Technological advances

Production of electronics and IT (hardware and software) in India in monetary terms has been rapidly growing between 2000 and 2017 (Table 6). Information & Communications Technologies (ICT) now represent 26% of India's gross export flows (Figure 12), playing a significant role in India's economy.

Table 6. Electronics and IT Production in India (Ministry of Statistics and Program Implementation, 2018)

Item	(billion rupees)				
	2000-01	2005-06	2010-11	2015-16	2016-17
Consumer Electronics	120	180	320	558	648
Industrial Electronics	40	88	170	451	622
Computer Hardware	34	108	150	199	209
Mobile Handsets	45	70	354	540	940
Strategic Electronics	18	32	77	181	208
Electronics Components (LED)	5	88	218	454 (51)	521 (71)
Sub-Total (Hardware)	311	566	1,289	2,433	3,218
Software for Exports	284	1,041	2,686	7,000	7,792
Domestic Software	94	296	787	1,405	1,608
Sub-Total (Software)	378	1,337	3,473	8,405	9,400
Total	689	1,903	4,762	10,837	12,618

However, the development of technologies that are energy-intensive will pose a challenge for the country as it will need to address an increase in associated energy demands.

4.3.3. Social perspective

From a social perspective, the main issues that the water-energy-food nexus in India must face are population growth, changes in food habits, and urbanization.

Population growth

South Asia's population has been growing at the annual rate of about 1.5%. By 2030, it is projected to grow from 1.6 billion to 2.1 billion which will lead to increases in food, water, and energy demand. This will result in further shrinking of land per capita that has already reduced from 0.4 hectares per capita in 1960 to 0.12 hectares per capita in 2013. Intensification of food production will be needed to address such pressure on arable land, which will require even more water and energy (Rasul et al., 2019).

Population of India has also been steadily growing (Figure 13). It is estimated that between 2019 and 2050 the population of India will increase by around 273 million people and India will become the most populous country in the world, surpassing China around year 2027 (United Nations, 2019).

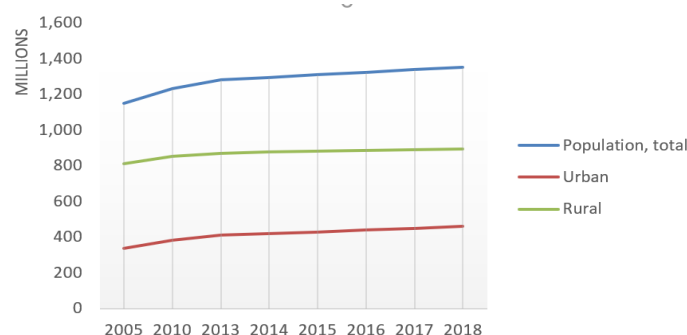


Figure 13. Population in India, 2005-2018 (World Bank)

India will need to face the challenges of growing food, water, and energy demands following the population growth, as well as reduced availability of agricultural land and overexploitation of groundwater resources.

The increase in food production with the aim to meet the growing food demand in India has been possible thanks to intensified irrigation. However, per-capita food availability has declined during the recent decade, because the increase in food production was insufficient to meet the growing demand (Barik et al., 2017).

Groundwater resources get overexploited to meet the food demand. Lack of restrictions on pumping, as well as low agricultural electricity tariffs in India that have been kept so for the farmers to easily afford groundwater pumping, are leading to uncontrolled drilling with no consideration of the impact on water availability (Barik et al., 2017).

The per capita land availability may fall to 0.14 hectares by 2050 from 0.9 hectares 50 years ago. 47% of India's geographical area is cultivated, 23% is covered with forests, 7% is used for non-agricultural purposes, and 23% is wasteland. 37% of the cultivated area is irrigated and produces 55% of food in India. The rest is rain-fed and produces 45% of food. As production and consumption needs will be increasing, the land productivity will need to be substantially improved (Thatte, 2018).

Changes in food habits

India will need to address the challenge of rising food, water, and energy demands brought by changes in food habits of its population.

The middle class as a percentage of total population, as well as overall consumption, has been rapidly increasing in India. It is projected that the middle class could account for two thirds of the total population by the end of 2020s if India continues to grow at the current pace (OECD & Indian Council for Research on International Economic Relations, 2018).

While the diet in India is largely vegetarian, the economic development will bring higher consumption of non-vegetarian food which has a bigger water footprint (Thatte, 2018). With the growth of the middle class, diet preferences will shift to animal-based from plant-based. Water and energy demand will increase as a result of increased meat and dairy production, as well as production of processed food (Rasul et al., 2019).

With the increased consumption of dairy products, the demand for feed/fodder and water will also increase (Thatte, 2018).

Urbanization

While two thirds of India's population still live in rural areas (Fig. 12), the level of urbanization has increased from 27.8% to 31.1% over the past decade (Rasul et al., 2019). The National Commission on Integrated Water Resources Development had estimated the urban population in India to be 603 million people by 2025 and 971 by 2050 (in case of a high urbanization rate) and 476 million people in 2025 and 646 million people by 2050 (in case of a low urbanization rate) (Kumar, 2018).

Further urbanization will create additional demand for water and energy and also alter the land use pattern, leading to a decline in availability of agricultural land (Rasul et al., 2019; Sinha et al., 2020).

A study of Ganga Basin by Misra (2011) demonstrated that urbanization might cause high-concentration river pollution, changes in water habitats, pollution of reservoirs and wetlands, which will also affect ecosystems (Arora & Tiwari, 2018).

5. Discussion

The Results in this report aimed to provide answers to the two research questions that were set for the study. This section will discuss reflections on those answers.

1. What are the main interlinkages between water, energy, and food in India?

The most frequently described interlinkage is irrigation in the “water for food” connection, as around 90% of the water withdrawn in India is used for agriculture (FAO, 2015). The agricultural sector plays a significant role in India’s economy. Although its contribution in terms of percentage of the GDP has been declining (OECD, 2018), around 50% of the workforce is still engaged in the agricultural sector (NITI Aayog, 2018). Agricultural products for both domestic consumption and exports, such as rice, are water-intensive (Barik et al., 2017), which puts pressure on water resources. There is also an interlinkage between energy and food here, as a large amount of energy is used for water pumping to irrigate those crops (Barik et al., 2017).

Aquaculture and fish production in India is also a growing sector which requires large amounts of freshwater (FAO, 2020).

Other main interlinkages are related to the use of water for energy production. Around 9% of electricity generation in India comes from hydropower generation (IEA, 2020). Large amounts of water resources are used for cooling of fossil fuel and nuclear power plants which produce around 85% of total electricity (IRENA & WRI, 2018)

Interlinkages that were not identified as “main” include biomass energy production in the “food for energy” connection; the use of energy for farm machinery and production of fertilizers in the “energy for food” connection; the use of fertilizers in the “food for water” connection; and water treatment (desalination) in the “energy for water” connection.

There can also be interlinkages with a chain reaction (water is used for hydropower generation that affects aquatic ecosystems which aquaculture depends on) or a loop (water used for generation of power that is later used for pumping or water treatment).

Some potential interlinkages that were described in general literature, such as energy use for food processing and transportation of food, as well as energy use for transportation of water (Endo et al., 2015; Yillia, 2016; D’Odorico et al., 2018), were not covered in this study as there was no sufficient information for India.

2. What are the main challenges for the sustainable development of the water-energy-food nexus in India from an environmental, economic, and social perspective?

The sustainable development of the water-energy-food nexus in India is challenging mainly because of the impact of environmental factors such as climate change, degradation of ecosystems, and pollution; and the growing demand for water, energy, and food which is caused by economic and social factors such as population growth, economic growth, urbanization, change in food habits, expansion of global trade, and technological advances.

Although the challenges were divided into three categories – environmental, economic, and social, these challenges are connected and can cause a chain reaction. For example, the economic growth speeds up urbanization, which may further cause pollution of water resources and ecosystems.

The most frequently described environmental challenge is climate change. The southwest monsoon rainfall is the main source of water supply for energy production and agriculture and drinking water in India (Thatte, 2018; Varikoden et al., 2019). Therefore, the impact of climate change on the monsoon and rainfall patterns poses a significant threat to India’s water security. In addition, rising temperatures will bring a higher demand for water for irrigation (Barik et al., 2017). Livelihoods can be affected by expanding shortages of drinking water.

Another environmental challenge is degradation of ecosystems which affects runoff, groundwater discharge, water quality and availability. Pollution of water resources from fertilizers can be an issue in India as their

consumption and production have been increasing (Ministry of Agriculture & Farmers Welfare, 2019).

Economic factors such as economic growth, expansion of global trade, and technological advances are all leading to the growth in demand for water and energy. The rise of incomes and higher demand for products requires expanding production and higher use of energy, while food production both for domestic consumption and export requires more water (OECD, 2018; IEA, 2020).

Social factors such as population growth, changes in food habits, and urbanization also lead to a higher demand for water, energy, and food. In addition to the growing number of consumers, their diet and preferences are changing as a result of growing incomes (Rasul et al., 2019). More food needs to be produced, and food production can become more water-intensive because of the shift to animal-based diets (Thatte, 2018). These factors and urbanization may also affect availability of agricultural land (Sinha et al., 2020).

Other South Asian countries are facing similar challenges as they need to ensure availability of safe drinking water, food, and sustainable energy sources (Putra et al., 2020). While most of the region is water- and energy-deficient, water plays a crucial role in achieving food and energy security. Agriculture is dependent on intensive irrigation and consumes around 90% of water and 20% of energy in South Asia (Rasul, 2014; Keskinen et al., 2016). Annual water demand is expected to grow by 55% by 2030 compared to 2005 (Rasul, 2016). Water stress is growing, and the climate change adds to the issue (Rasul, 2014). Similar to India, other South Asian countries are densely populated, and industrialization and urbanization are progressing further. The factors affecting water, food, and energy security in South Asia also include the growing middle class, intensification of resource use in food production, land degradation, and deteriorating soil fertility (Keskinen et al., 2016; Rasul, 2016). This all puts additional pressure on water, energy and food resources and interlinkages among them. Therefore, understanding the water-energy-food nexus interlinkages is extremely important to address the challenges that the region is facing.

WEF Nexus and the Sustainable Development Goals

Achieving the Sustainable Development Goals (SDGs) adopted by the United Nations 2015 highly depends on how water, energy, and food are managed and used.

SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Sustainable Consumption and Production), SDG 14 (Life Below Water), and SDG 15 (Life on Land) are all closely connected. For example, water and energy security need to be achieved to ensure availability of water and energy for food production to end hunger. On the other hand, the ways of food production and processing, transportation and consumption influence the achievement of water and energy security (Rasul, 2016).

Fader et al. (2018) analyzed the targets of SDG 2 (food) SDG 6 (water), and SDG 7 (energy) and came to a conclusion that achieving water targets continuously makes the achievement of other targets easier, as SDG 6 has the highest potential for synergies. For example, sustainable management of water resources, improved access to water and its quality contribute to the achievement of SDG 2.

Stephan et al. (2018) argue that the WEF nexus approach can be used to achieve the SDGs with water as a catalyst, while the SDGs can be used in WEF development plans as the minimum development goals.

A study by Mitra et al. (2020) on interlinkages between SDG 2, SDG 6, and SDG 7 in India showed a large number of synergistic relationships (in 124 out of 182 identified interlinkages) which could potentially be used in solving the issue of inefficient resource allocation. The authors emphasize that the WEF nexus approach needs to be applied to identify and address the challenges and barriers to achieving the SDGs. India needs integrated strategic planning to utilize synergies and minimize trade-offs between the goals (Mitra et al. 2020).

India is a lower-middle income country whose water, energy and food security is facing various challenges. However, it is one of the most populous and biggest countries with one of the largest economies in the world.

Therefore, the country's ability to achieve the sustainable development of its water-energy-food nexus and ensure better wellbeing of its population will have significant implications for the world.

LIMITATIONS

The amount of literature and data initially collected for review was large and came from a wide variety of sources. There were sometimes discrepancies in the data from international organizations and from national governmental sources. Perhaps, this was due to the difference in used methods.

The most up-to-date data was not always available and a large amount of literature published in 2019 and 2020 was based on the data that was several years old. Therefore, the Results in this study presented as the current state of the nexus sectors and interlinkages within the nexus do not always contain the most recent data and may not reflect the most recent developments.

Interlinkages and challenges were defined as “main” based on how often they were mentioned in reviewed sources. The results could have been different to a certain degree with a different definition of “main interlinkages” and “main challenges.”

Regions within India differ in terms of climate, land types, water resources availability, and other characteristics. However, this report does not discuss spatial variability within India to a full extent because it is beyond the scope of the study.

6. Conclusion

In this study, a literature review was conducted to identify the main interlinkages of the water-energy-food nexus in India and the main challenges to its sustainable development.

The study clearly shows the interconnectedness of the three sectors – water, energy, and food - and the role that water resources play in energy and food security of India.

Climate change, which is one of the biggest challenges, coupled with the growing demand for water, energy and food, put enormous pressure on water resources in India. As energy and food sectors compete for water and land, it may be challenging to maintain energy, water, and food security at the same time. In order to improve water, food and energy security and enhance preparedness and resilience against future challenges, available resources need to be allocated in the most optimal way by utilizing synergies across various sectors and managing trade-offs.

As for further research, climate and ecosystems should be added to water, energy and food as components and studied together as a nexus. In addition, since all regions in India have their own climatic, hydrological, and other characteristics, the research on the water-energy-food nexus in specific regions is needed.

7. Acknowledgement

I am extremely grateful to my supervisor Assistant Professor Claudia Teutschbein for her guidance, patience, and understanding. I would also like to thank my subject reviewer Associate Professor Thomas Grabs for his valuable feedback.

8. References

- Abulibdeh, A. & Zaidan, E. (2020). Managing the water-energy-food nexus on an integrated geographical scale. *Environmental Development*, 33, 100498.
<https://doi.org/10.1016/j.envdev.2020.100498>
- Ali, M., Geng, Y., Robins, D., Cooper, D. & Roberts, W. (2019). Impact assessment of energy utilization in agriculture for India and Pakistan. *Science of The Total Environment*, 648, 1520–1526.
<https://doi.org/10.1016/j.scitotenv.2018.08.265>
- de Amorim, W.S., Valduga, I.B., Ribeiro, J.M.P., Williamson, V.G., Krauser, G.E., Magtoto, M.K. & de Andrade Guerra, J.B.S.O. (2018). The nexus between water, energy, and food in the context of the global risks: An analysis of the interactions between food, water, and energy security. *Environmental Impact Assessment Review*, 72, 1–11. <https://doi.org/10.1016/j.eiar.2018.05.002>
- Arora, T. & Tiwari, V.M. (2018). Hydrological Studies in India During Last Decade: A Review. *Proceedings of the Indian National Science Academy*, 99 (0).
<https://doi.org/10.16943/ptinsa/2018/49512>
- Asoka, A., Wada, Y., Fishman, R. & Mishra, V. (2018). Strong Linkage Between Precipitation Intensity and Monsoon Season Groundwater Recharge in India. *Geophysical Research Letters*, 45 (11), 5536–5544. <https://doi.org/10.1029/2018GL078466>
- Barik, B., Ghosh, S., Sahana, A.S. & Pathak, A. (2017). Water–food–energy nexus with changing agricultural scenarios in India during recent decades. *Hydrology and Earth System Sciences*, 21 (6), 3041–3060. <https://doi.org/10.5194/hess-21-3041-2017>
- Beaton, C., Jain, P., Govindan, M., Garg, V., Murali, R., Roy, D., Bassi, A. & Pallaske, G. (2020). *Mapping Policy for Solar Irrigation Across the Water-Energy-Food (WEF) Nexus in India*. Manitoba: International Institute for Sustainable Development.
- Daher, B.T. & Mohtar, R.H. (2015). Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making. *Water International*, 40 (5–6), 748–771.
<https://doi.org/10.1080/02508060.2015.1074148>
- Dhawan, V. (2017). Water and Agriculture in India - Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture (GFFA) 2017. German Asia-Pacific Business Association. Available at:
https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf [Accessed May 2020]

D’Odorico, P., Davis, K.F., Rosa, L., Carr, J.A., Chiarelli, D., Dell’Angelo, J., Gephart, J., MacDonald, G.K., Seekell, D.A., Suweis, S. & Rulli, M.C. (2018). The Global Food-Energy-Water Nexus. *Reviews of Geophysics*, 56 (3), 456–531. <https://doi.org/10.1029/2017RG000591>

Endo, A., Burnett, K., Orencio, P.M. & Kumazawa, T. (2015). Methods of the Water-Energy-Food Nexus. *Water*, 7 (10), 5806–5830. <https://doi.org/10.3390/w7105806>

Endo, A., Yamada, M., Miyashita, Y. & Sugimoto, R. (2020). Dynamics of water–energy–food nexus methodology, methods, and tools. *Current Opinion in Environmental Science & Health*, 13, 46–60. <https://doi.org/10.1016/j.coesh.2019.10.004>

Fader, M., Cranmer, C., Lawford, R., & Engel-Cox, J. (2018). Toward an Understanding of Synergies and Trade-Offs Between Water, Energy, and Food SDG Targets. *Frontiers in Environmental Science*, 6, 112. <https://doi.org/10.3389/fenvs.2018.00112>

FAO (Food and Agriculture Organization of the United Nations) (2015). *FAO AQUASTAT Reports: Country Profile - India*. Rome: FAO. <http://www.fao.org/3/ca0394en/CA0394EN.pdf> [Accessed 12 May 2020]

FAO (Food and Agriculture Organization of the United Nations) (2016). *India - FAO Country Programming Framework 2016-2017*. New Delhi: FAO. http://www.fao.org/fileadmin/user_upload/FAO-countries/India/docs/INDIA_FAO_Country_Programming_Framework_2016_%E2%80%93_2017.pdf [Accessed 12 May 2020]

FAO (Food and Agriculture Organization of the United Nations) (2018). *Country Programming Framework for India*. New Delhi: FAO. <http://www.fao.org/3/I9066EN/i9066en.pdf> [Accessed 12 May 2020]

FAO (Food and Agriculture Organization of the United Nations) (2020). AQUASTAT Database. <http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en> [Accessed 12 May 2020]

FAO (Food and Agriculture Organization of the United Nations) (2020). *Fishery and Aquaculture Country Profiles - The Republic of India*. <http://www.fao.org/fishery/facp/IND/en#CountrySector-Statistics> [Accesses 17 May 2020]

Ghodsvalli, M., Krishnamurthy, S. & de Vries, B. (2019). Review of transdisciplinary approaches to food-water-energy nexus: A guide towards sustainable development. *Environmental Science & Policy*, 101, 266–278. <https://doi.org/10.1016/j.envsci.2019.09.003>

Ghosh, S., Vittal, H., Sharma, T., Karmakar, S., Kasiviswanathan, K.S., Dhanesh, Y., Sudheer, K.P.

& Gunthe, S.S. (2016). Indian Summer Monsoon Rainfall: Implications of Contrasting Trends in the Spatial Variability of Means and Extremes. *PLOS ONE*, 11 (7), e0158670. <https://doi.org/10.1371/journal.pone.0158670>

Hirji, R., Nicol, A. & Davis, R. (2017). *South Asia Climate Change Risks in Water Management - Climate Risks and Solutions: Adaptation Frameworks for Water Resources Planning, Development, and Management in South Asia*. Washington: World Bank. <https://doi.org/10.1596/29685>

IEA (International Energy Agency) (2020). *India 2020 - Energy Policy Review*. <https://www.iea.org/reports/india-2020> [Accessed May 2020]

IRENA & WRI (International Renewable Energy Agency & World Resources Institute) (2018). *Water Use in India's Power Generation: Impact of Renewables and Improved Cooling Technologies to 2030*.

<https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2018/pdf-2018-7956-2-IRENAIndiapowerwater2018pdf.pdf> [Accessed May 2020]

Jain, S.K. (2012). India's water balance and evapotranspiration. *CURRENT SCIENCE*, 102 (7), 5.

Keskinen, M., Guillaume, J., Kattelus, M., Porkka, M., Räsänen, T., & Varis, O. (2016). The Water-Energy-Food Nexus and the Transboundary Context: Insights from Large Asian Rivers. *Water*, 8 (5), 193. <https://doi.org/10.3390/w8050193>

Kumar, M.D. (2018). *Water Policy Science and Politics: An Indian Perspective*. Oxford: Elsevier Science & Technology.

Liu, J., Yang, H., Cudennec, C. & Gain, A.K. (2017). Challenges in operationalizing the water–energy–food nexus. *Hydrological Sciences Journal*, 62 (11), 1714–1720. <https://doi.org/10.1080/02626667.2017.1353695>

Manju, S. & Sagar, N. (2017). Renewable energy integrated desalination: A sustainable solution to overcome future fresh-water scarcity in India. *Renewable and Sustainable Energy Reviews*, 73, 594–609. <https://doi.org/10.1016/j.rser.2017.01.164>

Ministry of Agriculture & Farmers Welfare (2019). *Pocket Book of Agricultural Statistics 2018*. New Delhi: Government of India. <https://eands.dacnet.nic.in/PDF/Pocket%20Book%202018.pdf> [Accessed 11 May 2020]

Ministry of Home Affairs (2011). *Disaster Management in India*. New Delhi: Government of India. https://www.undp.org/content/dam/india/docs/disaster_management_in_india.pdf [Accessed 31 May 2020]

Ministry of Power (2014). *Electricity (Amendment) Bill, 2014*. New Delhi: Government of India. <https://powermin.nic.in/en/content/Electricity-Act-2003> [Accessed May 2020]

Ministry of Statistics and Programme Implementation (2018). *Statistical Year Book India 2018*. New Delhi: Government of India. <http://www.mospi.gov.in/statistical-year-book-india/2018/> [Accessed 14 May 2020]

Ministry of Statistics and Programme Implementation (2019). *Energy Statistics 2019 (Twenty Sixth Edition)*. New Delhi: Government of India. <http://mospi.nic.in/publication/energy-statistics-2019> [Accessed May 2020]

Ministry of Statistics and Programme Implementation (2020a). *Energy Statistics*. New Delhi: Government of India. http://www.mospi.gov.in/sites/default/files/publication_reports/ES_2020_240420m.pdf [Accessed May 2020]

Ministry of Statistics and Programme Implementation (2020b). *Sustainable Development Goals - National Indicator Framework Progress Report 2020*. New Delhi: Government of India. http://www.mospi.gov.in/sites/default/files/publication_reports/SDGProgressReport2020.pdf [Accessed 14 May 2020]

Ministry of Water Resources (2012). *National Water Policy*. New Delhi: Government of India. http://www.mowr.gov.in/sites/default/files/NWP2012Eng6495132651_1.pdf [Accesses 12 May 2020]

Ministry of Water Resources (2014). *Guidelines for Improving Water Use Efficiency in Irrigation, Domestic & Industrial Sectors. Government of India*. New Delhi: Government of India. http://mowr.gov.in/sites/default/files/Guidelines_for_improving_water_use_efficiency_1.pdf [Accessed 8 May 2020]

Mitra, B. K., Sharma, D., Kuyama, T., Pham, B. N., Islam, G. M. T., & Thao, P. T. M. (2020). Water-energy-food nexus perspective: Pathway for Sustainable Development Goals (SDGs) to country action in India. *APN Science Bulletin*, 10 (1), 34–40. <https://doi.org/10.30852/sb.2020.1067>

Mohtar, R.H. & Lawford, R. (2016). Present and future of the water-energy-food nexus and the role of the community of practice. *Journal of Environmental Studies and Sciences*, 6 (1), 192–199. <https://doi.org/10.1007/s13412-016-0378-5>

Mukherji, A. (2019). Circular food systems and solutions: addressing the nexus issues in South Asia. *The Crawford Fund 2019 Annual Conference*, 12-13 August 2019, Canberra, Australia.

<https://doi.org/10.22004/ag.econ.301981>

Narwaria, S.S. (2019). Conceptual aspect of environment security: evidence from India and Bangladesh. *Management of Environmental Quality: An International Journal*, 30 (1), 36–46. <https://doi.org/10.1108/MEQ-08-2017-0084>

NDMA (National Disaster Management Authority) (2020). *Vulnerability Profile of India* (2020). <https://ndma.gov.in/en/vulnerability-profile.html> [Accessed 31 May 2020]

NITI Aayog (National Institution for Transforming India) (2018). *Aspirational Districts - Unlocking Potentials*. New Delhi: NITI Aayog. <https://niti.gov.in/sites/default/files/2018-12/AspirationalDistricts-Book.pdf> [Accessed 10 May 2020]

OECD (2019). *OECD Economic Surveys: India 2019*. Paris: OECD Publishing. <https://doi.org/10.1787/554c1c22-en>

OECD & FAO (2014). *OECD-FAO Agricultural Outlook 2014-2023*. OECD Publishing. https://doi.org/10.1787/agr_outlook-2014-en

OECD & Indian Council for Research on International Economic Relations (2018). *Agricultural Policies in India*. (OECD Food and Agricultural Reviews). Paris: OECD Publishing. <https://doi.org/10.1787/9789264302334-en>

Pradhan, R., Singh, N. & Singh, R.P. (2019). Onset of summer monsoon in Northeast India is preceded by enhanced transpiration. *Scientific Reports*, 9 (1), 18646. <https://doi.org/10.1038/s41598-019-55186-8>

Putra, M. P. I. F., Pradhan, P., & Kropp, J. P. (2020). A systematic analysis of Water-Energy-Food security nexus: A South Asian case study. *Science of The Total Environment*, 728, 138451. <https://doi.org/10.1016/j.scitotenv.2020.138451>

Rao, N.D., Pobleto-Cazenave, M., Bhalerao, R., Davis, K.F. & Parkinson, S. (2019). Spatial analysis of energy use and GHG emissions from cereal production in India. *Science of The Total Environment*, 654, 841–849. <https://doi.org/10.1016/j.scitotenv.2018.11.073>

Rasul, G. (2014). Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. *Environmental Science & Policy*, 39, 35–48. <https://doi.org/10.1016/j.envsci.2014.01.010>

Rasul, G. (2016). Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environmental Development*, 18, 14–25.

<https://doi.org/10.1016/j.envdev.2015.12.001>

Rasul, G., Neupane, N., Hussain, A. & Pasakhala, B. (2019). Beyond hydropower: towards an integrated solution for water, energy and food security in South Asia. *International Journal of Water Resources Development*, 1–25. <https://doi.org/10.1080/07900627.2019.1579705>

Schellenberg, T., Subramanian, V., Ganeshan, G., Tompkins, D. & Pradeep, R. (2020). Wastewater Discharge Standards in the Evolving Context of Urban Sustainability—The Case of India. *Frontiers in Environmental Science*, 8, 30. <https://doi.org/10.3389/fenvs.2020.00030>

Sinha, J., Das, J., Jha, S. & Goyal, M.K. (2020). Analysing model disparity in diagnosing the climatic and human stresses on runoff variability over India. *Journal of Hydrology*, 581, 124407. <https://doi.org/10.1016/j.jhydrol.2019.124407>

Srinivasa Rao, Ch., Kareemulla, K., Krishnan, P., Murthy, G.R.K., Ramesh, P., Ananthan, P.S. & Joshi, P.K. (2019). Agro-ecosystem based sustainability indicators for climate resilient agriculture in India: A conceptual framework. *Ecological Indicators*, 105, 621–633. <https://doi.org/10.1016/j.ecolind.2018.06.038>

Staupe-Delgado, R. (2019). The water–energy–food–environmental security nexus: moving the debate forward. *Environment, Development and Sustainability* 22, 6131–6147. <https://doi.org/10.1007/s10668-019-00467-5>

Stephan, R. M., Mohtar, R. H., Daher, B., Embid Irujo, A., Hillers, A., Ganter, J. C., Karlberg, L., Martin, L., Nairizi, S., Rodriguez, D. J., & Sarni, W. (2018). Water–energy–food nexus: A platform for implementing the Sustainable Development Goals. *Water International*, 43 (3), 472–479. <https://doi.org/10.1080/02508060.2018.1446581>

Thatte, C.D. (2018). Water resources development in India. *International Journal of Water Resources Development*, 34 (1), 16–27. <https://doi.org/10.1080/07900627.2017.1364987>

The Water, Energy and Food Security Nexus – Solutions for the Green Economy. Conference Synopsis (2012). *Bonn 2011 Conference*, 16-18 November 2011, Bonn, Germany.

The World Economic Forum Water Initiative (2011). *Water Security*. Washington, DC: Island Press/Center for Resource Economics. <https://doi.org/10.5822/978-1-61091-026-2>

UNESCO (2020). *(UNESCO) United Nations World Water Development Report 2020: Water and Climate Change*. Paris: UNESCO. <https://en.unesco.org/themes/water-security/wwap/wwdr/2020> [Accessed May 2020]

United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019: Highlights*.

Usmani, R.A. (2020). Potential for energy and biofuel from biomass in India. *Renewable Energy*, 155, 921–930. <https://doi.org/10.1016/j.renene.2020.03.146>

Varikoden, H., Revadekar, J.V., Kuttippurath, J. & Babu, C.A. (2019). Contrasting trends in southwest monsoon rainfall over the Western Ghats region of India. *Climate Dynamics*, 52 (7–8), 4557–4566. <https://doi.org/10.1007/s00382-018-4397-7>

WMO (World Meteorological Organization) (2020). *Consensus Statement on the Forecast for the 2020 Southwest Monsoon Season (June – September) Rainfall over South Asia*. <http://www.fao.org/giews/country-analysis/en/> [Accessed 3 May 2020]

World Bank (2020). *World Development Indicators DataBank*.

<https://databank.worldbank.org/reports.aspx?source=world-development-indicators#> [Accessed 25 May 2020]

Yillia, P.T. (2016). Water-Energy-Food nexus: framing the opportunities, challenges and synergies for implementing the SDGs. *Österreichische Wasser- und Abfallwirtschaft*, 68 (3–4), 86–98. <https://doi.org/10.1007/s00506-016-0297-4>

