ENVIRONMENTAL SCIENCE & POLICY 39 (2014) 35–48

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/envsci

Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region

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ARTICLE INFO

Article history:
Received 13 September 2013
Received in revised form
17 January 2014
Accepted 23 January 2014
Available online 15 March 2014

Keywords:
Food–water–energy nexus
Ecosystem services
Upstream–downstream linkages
Hindu Kush-Himalayan mountain systems
South Asia

ABSTRACT

With limited land resources, inadequate energy supply, and growing water stress, South Asia faces the challenge of providing enough water and energy to grow enough food for the burgeoning population. Using secondary data from diverse sources, this paper explores the food, water, and energy nexus from a regional dimension, emphasizing the role of Hindu Kush Himalayan (HKH) ecosystem services in sustaining food, water, and energy security downstream. The analysis reveals that the issues and challenges in the food, water, and energy sectors are interwoven in many complex ways and cannot be managed effectively without cross-sectoral integration. The most distinctive feature of the nexus in South Asia is the high degree of dependency of downstream communities on upstream ecosystem services for dry-season water for irrigation and hydropower, drinking water, and soil fertility and nutrients. This finding suggests that along with cross-sectoral integration to improve the resource-use efficiency and productivity of the three sectors, regional integration between upstream and downstream areas is critical in food, water, and energy security. Within the nexus approach in South Asia, equal attention should be paid to management of HKH ecosystems–especially the watersheds, catchments, and headwaters of river systems–and to tapping the potential of collaborative gains in water, hydropower, and other ecosystem services through coordination across HKH countries.

1. Introduction

Food and water are essential for human existence and energy is the key to human development. Access to these resources and their sustainable management are the basis for sustainable development. Recognizing that efficient use of these limited or declining resources is essential to sustainability, the global community has turned its attention to the concept of the food, water, and energy nexus. The World Economic Forum 2011, the Bonn2011 Nexus Conference, the sixth World Water Forum, and World Water Week 2012, to mention a few, have urged an integrated approach to food, water, and energy security. The Rio + 20 declaration 'The Future We Want', which stresses the need for a balanced integration of economic, social, and environmental issues in economic development, also stresses the need to address society's core issues of food, water, and energy security in a manner that reduces the adverse impacts on nature–water, biodiversity, air, and climate.

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1462-9011
http://dx.doi.org/10.1016/j.envsci.2014.01.010

The nexus approach recognizes the interdependencies of water, energy, and food production and aims to systemize the interconnections to provide a framework for assessing the use of all resources and to manage trade-offs and synergies (Hellegers et al., 2008; Bazilian et al., 2011; Scott et al., 2011; Hermann et al., 2012; Hussey and Pittock, 2012; Sharma and Bazaz, 2012).

The concept of the food, water, and energy nexus is extremely relevant to Asia as the region has to feed two-thirds of the world's population (4.14 billion people) and accounts for 59% of the planet's water consumption. Ensuring food security and providing access to safe drinking water and modern energy for all remains a key challenge for Asia's sustainable development. The challenge is especially great in the South Asian countries–Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka–where more than 40% of the world's poor live and some 51% of the population is food–energy deficient (Ahmed et al., 2007). With just 3% of the world's land, South Asia has about one-fourth of the world's population (1.6 billion people). Rice and wheat, the staple foods in the subregion, require huge amounts of water and energy. Freshwater, once abundant, is under growing stress due to the increased demand for competing uses, and climate change is creating additional uncertainties (Eriksson et al., 2009). About 20% of the population of South Asia lacks access to safe drinking water (Babel and Wahid, 2008). The increase in water stress and water demand raises questions about how to ensure enough water for growing food without losing hydropower for energy security. The energy required to make water available for crop production, for example through groundwater pumping, is in serious shortage (Shah, 2009); per capita energy consumption in this region is among the lowest in the world, only 300 kg of oil equivalent, which is just one-third of China's 2001 per capita consumption (USAID, n.d.). With a large and rising population, limited land resources, inadequate energy supply, and growing water stress, South Asian countries face a common challenge of how to produce more food with the same or less land, less water, and increased energy prices.

1.1. *Ecosystems — the missing link in the food, water, and energy nexus*

The nexus approach provides a framework for addressing competition for resources and enhancing resource use efficiency with a cross-sectoral focus. However, the nexus discourse has yet to appreciate the value of ecosystems, their functions, and their services in water, energy, and food production. Food and freshwater services critically depend on the flow and services from ecosystems (MA, 2005; Molden, 2007; Krchnak et al., 2011; Boelee, 2011). The ecosystem functions and services provided by mountains, for example – including freshwater, energy, biodiversity, forest products and services, food and medicinal products, and fish and other aquatic products – are central to food, water, and energy security (Molden et al., 2014; Rasul, 2010, 2012; López-Moreno et al., 2011).

The Hindu Kush Himalayas provide ecosystem services that are critical for water, energy, and agricultural sustainability and productivity in South Asia (Fig. 1). All of the subregion's major rivers and their numerous tributaries originate in the Himalayas. About 1.3 billion people in South Asia (the mainland population) rely on freshwater obtained directly or indirectly from the Hindu Kush Himalayan (HKH) mountain systems.

Failure to recognize the value of HKH ecosystems results in inadequate measures to manage the headwaters of the subregion's rivers, their catchments, watersheds, and vital natural resources, posing a serious threat to the sustained flow of ecosystem services critical for food, water, and energy security in the HKH and downstream (Rasul, 2010; Tiwari and Joshi, 2012).

1.2. *The regional dimension*

Many ecosystem resources such as water from transboundary rivers are used and managed at multiple scales – local, national, and regional – and governed by diverse stakeholders. Much of the food, water, and energy nexus debate so far has focused on intersectoral coordination for efficient use of competing resources; the emphasis has been on integrating policies, mainly for water pricing and withdrawing subsidies to reduce energy demand for water in agriculture or for construction of big infrastructure to store water to support the growing demand for water and energy for irrigation (Shah, 2009; Mukherji, 2007; Kumar et al., 2012). So far, few systematic efforts have been made to understand the spatial and regional dimensions of the nexus, in other words to examine the spatial patterns of resource availability and use, how resources flow, upstream–downstream linkages, and the potential benefits of addressing challenges through regional and river-basin approaches (Bach et al., 2012). The nexus approach has also paid little attention to the upstream–downstream linkages of ecosystem services, biophysical and socio-economic interdependencies, and the importance of cross-scale coordination in managing nexus challenges (Krchnak et al., 2011; Boelee, 2011; Scott et al., 2011). Since different countries have different resource endowments and face different challenges in managing the nexus, upstream–downstream coordination can tap the potential of synergies in transboundary river basins (Priscoli and Wolf, 2009; Bach et al., 2012; Rasul, 2014).

In South Asia the food, water, and energy nexus has a strong regional dimension, with upstream actions often having downstream effects. For instance, floods generated in Nepal also result in floods in India; glacial lake outburst floods in China can affect hydropower stations in Nepal; erosion in one country deposits sediment in another; and hydropower potential in one country serves markets in another (Tiwari, 2000). Approaching the food, water, and energy nexus from an ecosystem-based regional perspective, which takes into account the transboundary nature of HKH ecosystems and rivers, offers opportunities to enlarge planning horizons, increase economies of scale, identify trade-offs, and maximize synergies in food, water, and energy (Bach et al., 2012; Grey and Sadoff, 2007).

This paper explores the food, water and energy nexus in the Hindu Kush Himalayan region and South Asia from a regional dimension using an ecosystem perspective, focusing particularly on the role of HKH ecosystem services in sustaining food,

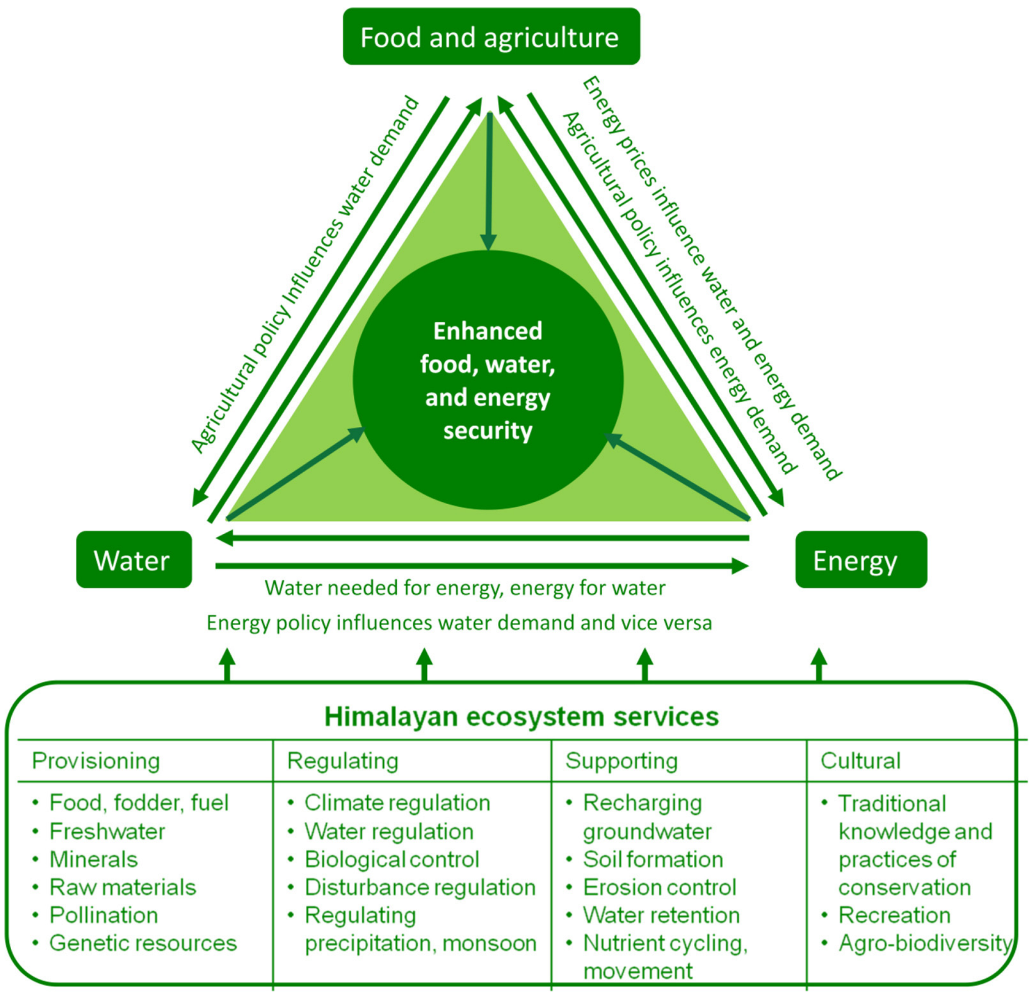

Fig. 1 – Interdependencies of food, water, energy, and ecosystem services.

water, and energy security in downstream areas. It begins by assessing the issues and challenges in food, water, and energy security in South Asia. Section 3 presents the contribution of HKH ecosystems to food, water, and energy security in South Asia, while the following section enumerates the challenges of sustaining these vital mountain ecosystems. The article concludes by suggesting some policy measures to promote food, water, and energy security in South Asia and the HKH region. This study relies predominantly on information drawn from secondary sources, including books, reports, and journal articles. Some information has been drawn from research by the authors and ICIMOD's research experience in the HKH region over the past 30 years.

2. Key challenges of the food, water, and energy nexus in South Asia

South Asia is one of the most dynamic regions of the world in terms of population growth, economic progress, urbanization, and industrialization (Table 1). The demographic, economic, and environmental changes in South Asia have increased the demand for natural resources and intensified their uses, which has serious implications for food, water, and energy security in the subregion. The key features and challenges of food, water and energy security and their interlinkages are presented in Table 2 and briefly described here.

2.1. *Increasing population and declining agricultural land*

In the half century from the late 1950s to 2010 the population of South Asia almost tripled from 588 million to 1621 million. With high population growth and industrial development, per capita agricultural land has been declining sharply over the years. Between 1980 and 2010, per capita arable land fell from 0.11 to 0.05 ha in Bangladesh, 0.23 to 0.13 ha in India, 0.15 to 0.08 ha in Nepal, and 0.24 to 0.12 ha in Pakistan (Kumar et al., 2012).

It is estimated that in 2025 there will be 2.2 billion people in South Asia, and with the increased population cereal demand will rise to 476 million tonnes as compared to 241 million tonnes in 2000 (FAO, 2012) (Table 1). The projected cereal demand rises to 550 million tonnes if higher incomes are taken into account (Dyson, 1999).

Table 1 – Key indicators related to agriculture, water, and energy security in South Asia.

Indicators	2007[a]	2050 projection
Population (millions)	1520	2242
Population density (per km^2)	352	–
Annual population growth rate (%)	1.5	0.53
Population below USD 1.25 a day (million)	596 (2005)	14.1
Poverty ratio (below USD 1.25 a day)	40.3 (2005)	–
Per capita GDP growth (%)	3.6 (1995–1997)	–
Undernourished people (millions)	331	93
Undernourished population (%)	21.8	4.2
Population without access to safe water (millions)	269	–
Total land area (million km^2)	4.47	–
Cultivable land area (million km^2)	2.19	–
Cultivated area (million km^2)	2.04	–
Arable land (million ha)	204	213
Irrigated area (million ha)	104.3 (2000)	135.2
Total rainfed area	98 (2000)	110
Annual growth rate in irrigated area (%)	1.6	0.1
Cultivated area (% of total area)	93	–
Cultivated land (ha per person)	0.12	0.08
Cultivated land irrigated (%)	39	–
Contribution of irrigated agriculture in total food production (%)	60–80	–
Fertilizer consumptions (millions tonnes)	27	59
Fertilizer consumption (kg/ha)	210	256
Agriculture growth rate (%)	2.4	1.3
Crop production growth rate (%)	2.1	0.9
Cereal production growth rate (%)	1.9 (1997)	–
Irrigated cereal yields (tonnes/ha)	2.7 (2000)	4.1
Per capita cereal consumption (kg/person/year)	169 (1997)	–
Cereal demand (million metric tonnes)	241 (2000)	476
Livestock production growth (%)	3.2 (2007)	2.2
Milk and dairy products growth rate (production)	4.1	2.0
Milk and dairy products growth rate (consumption)	4.1	2.0
Total water withdrawal (km^3)	1023.40	–
Annual water withdrawal by sector (%)		
Agriculture	91	–
Municipalities	7	–
Industry	2	–
Total water consumption in agriculture sector (km^3)	1479 (2000)	1922
Total water withdrawal for irrigation(km^3)	1095 (2000)	1817
Per capita water withdrawal (m^3)	631	–
Agricultural use (% of total withdrawal)	82.30	–
Total irrigated area (million ha)	88. 60	–
Total irrigated area (%)	47.48	–
Irrigation		
Surface water contribution	36.7 (2009)	–
Groundwater contribution	54.7 (2009)	–
Energy use per capita (kg of oil equivalent)	515 (2009)	–
Household with no access to electricity (%)	63	–
Households using traditional biomass for cooking (%)	65	–
Electricity consumption in agriculture sector per tube well (kWh)	8100 (2001)	–

Sources: FAO, 2012; de Fraiture and Wichelns, 2007; Lal, 2007. Sources: FAO, 2012; de Fraiture and Wichelns, 2007; Lal, 2007.

[a] All data are for 2007 unless otherwise specified.

2.2. *Stagnating or declining food production*

Although total food production is increasing because of additional area brought under irrigation, the growth rate of food production has slowed down in many parts of South Asia, and per capita food consumption has remained stagnant even though per capita incomes have registered impressive growth in recent years (Alagh 2010). Climate change may further exacerbate the situation. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), crop yields in South Asia may decrease by up to 30% by 2050 without changes in practices.

Low levels of consumption have contributed to persistent hunger and malnutrition (Kumar et al., 2012). Despite impressive economic growth in the last decade, South Asia is home to over 40% of the world's poor (living on less than USD 1.25 a day) and 35% of the world's undernourished (Ghani, 2010). More than 56 percent of the world's low-birth-weight babies are born in South Asia (Ahmed et al., 2007) (Table 1).

Table 2 – Key features and challenges in food, water and energy security in South Asia.

Key features	Socio-economic, environmental, and developmental implications and challenges	Interdependence of food, water, and energy resources
Food security		
Huge chronically undernourished population About half of the world's poor (46%) live in South Asia	To meet the nutritional needs of all, food production needs to double in next 25 years	Provision of food, water, and energy to large malnourished population without degrading natural resource base and environment
Burgeoning human population About 25% of the world population (projected to reach 2.3 billion by 2050) living on 3% of the world's land area	Increased pressure on land, water, and energy to meet increased demand	70% increase in agricultural production and 40% increase in energy needed to feed the growing population
Declining cropland per person Very low per capita arable land area, declining continually owing to population growth, urbanization, and growing biomass cultivation for fuel to meet energy demand	Limited options for growing more food grain by expanding crop area Growing demand for land and water for biofuel production	Further intensification of food production needed with more external inputs (water, energy, fertilizers) Competing demand for land for food and bioenergy production and for ecosystem services
Land degradation and declining soil fertility Over 104 million hectares of land degraded due to water erosion, soil erosion, waterlogging, salinization, and fertility decline Diversion of biomass to fuel use causing deterioration of soil fertility and soil structure	Increased use of chemical and inorganic fertilizers to keep productivity	Increased energy intensity in food production
Increasingly water and energy intensive food production Increased electricity consumption in agriculture because of increased use of groundwater for irrigation	High dependency on irrigated agriculture which supplies 60–80% of staple food	Agricultural growth constrained by shortage of energy and water
Changing food preferences towards meat	Production requires more energy and water: about 7 kg of grain equivalent energy is required to produce 1 kg of meat	Increased pressure on water for meeting food requirement
Sensitivity to climate change Food production highly sensitive and vulnerable to climate changes (temperature rise, accelerated glacial melting, increased evapo-transpiration, erratic rainfall)	Uncertainty of water availability owing to rapid glacier melting in the Himalayas	Climate change likely to be a critical factor in increasing water and energy demand for food production and land demand for bio-fuel production
Water security		
Growing water stress Growing water demand for agriculture, energy, industry, and human and livestock use: Annual water demand predicted to increase by 55% from 2005 to 2030 Only 0.03 ha of irrigated land area per capita in several countries in the region Uneven endowment of water resources over time and space	About 20% of the population without access to safe drinking water Increased water pollution and water-borne diseases, high child mortality, poor human health	Providing access to safe drinking water with increasingly variable water supply Balancing water demand for food production, energy, industrial growth, urbanization, and environment
Upstream–downstream linkage High dependency of downstream communities on water from upstream to grow food and generate hydropower	Need for enhanced upstream–downstream coordination and cooperation for sustainable development of HKH water resources	Irrigation, hydropower, and major economic activities depend on HKH rivers for dry season water
Increased dependency on groundwater for food production About 70–80% of agricultural production depends on groundwater irrigation	Decline in water tables, posing threats to the sustainability of agriculture, food production, health, and environment Saline soils already affecting almost 20% of irrigated areas in Pakistan Environmental stress and ecological insecurity Growing pressure on water resources	Increased electricity demand for groundwater pumping for irrigation
Energy security		

Table 2 (*Continued*)

Key features	Socio-economic, environmental, and developmental implications and challenges	Interdependence of food, water, and energy resources
High energy poverty About 63% of population without access to electricity and 65% dependent on biomass for cooking Supply insufficient to meet demand; demand-supply gap widening Energy demands expected to triple in next two decades.	Inadequate and unreliable energy supply limiting opportunities for increased food production and water supply Economic growth could be accelerated by 2–3% if quality energy can be provided Access to modern energy required for rural people at affordable cost	Growing water and land demand for energy production Increased water demand to meet energy demand: India's water demand expected to grow from 20 to 70 billion m^3 between 2010 and 2050
Intensification of energy use in food production Greatly increased electricity consumption in irrigation due to ground water pumping (e.g., in India, sixfold increase of electricity consumption per 1,000 ha cultivated from 1980/81 to 1999/2000)	Reliability and quality of energy not keeping pace with increased demand and use, with huge private and social losses in terms of foregone agricultural production and frequent burn-out of transformers and motors	Reliable and quality energy required for agriculture, water, industry and other economic activities
High dependency on traditional fuel sources, fossil fuels, and imported energy Wood, crop residues, animal dung, and other biomass used as prime source of energy for cooking in rural areas	Serious health, socio-economic, and environmental implications of traditional biofuel use including emission of black carbon Soil fertility and thus crop productivity reduced by use of crop residues and animal dung for cooking	Reduced soil fertility challenging food production Black carbon emissions accelerating melting of glaciers, affecting water availability and hydropower
Underutilized potentials for hydropower and clean energy Promotion of hydropower and clean energy needed to reduce carbon intensity in energy production	Energy diversification needed to meet the demands of a rapidly growing economy	Clean energy a means of reducing glacial melting and associated risks in hydropower development and helping to ensure water availability

2.3. *Increasingly water- and energy-intensive food production*

About 39% of the cropland in South Asia is irrigated, and irrigated agriculture accounts for 60–80% of food production (World Bank, 2013). Agriculture consumes about 90% of the water and about 20% of the energy used in South Asia. Although in the early 1960s the major source of irrigation was surface water, the contribution of groundwater has been increasing steadily and has now overtaken surface-water irrigation in some countries. At present groundwater's contribution in irrigation is 79% in Bangladesh, 63% in India, 19% in Nepal, and 21% in Pakistan (FAO, 2012). In total about three-fifths of the region's irrigation water comes from groundwater (Shah, 2009).

2.4. *Water and energy scarcity*

Water, once considered abundant, has become increasingly scarce. Per capita water availability in Pakistan, for example, fell from 5000 m^3 per annum in 1951 to 1100 m^3 per annum in 2006 and is predicted to drop closer to 1000 m^3 by 2010. Water stress is also growing in India, with per capita water availability falling from 1986 m^3 in 1998 to 1731 m^3 in 2005 and projected to decline to 1140 m^3 in 2050 (Gupta and Deshpande, 2004). India is already extracting groundwater 56% faster than it can be replenished. Climate change is likely to have serious implications for water availability in the dry season (IPCC, 2007; Eriksson et al., 2009; Shrestha and Aryal, 2011). As about 70% of South Asia's cereal production comes from irrigated agriculture, water scarcity may affect food production unless appropriate measures are taken (Aggarwal et al., 2004; Rasul, 2012).

Increased extraction of groundwater has increased demand for energy and lowered the groundwater table in many parts of the HKH region, especially the northwestern Himalayas. This has created a serious concern for the entire region as the shortage of water and energy has severely constrained not only agriculture but also overall economic growth and human wellbeing. For instance, energy shortage in Pakistan is causing a loss of about USD 1 billion per annum along with a loss of 400,000 jobs (GoP, 2013). The situation is similar in Bangladesh, India, and Nepal and is challenging overall macroeconomic stability. It is estimated that in 2011–2012 about 50% of India's export earnings were spent to import crude oil to meet the energy demand (ASSOCHAM, 2012). Similarly, about 35% of export earnings in Pakistan are needed for the import of petroleum products (Ghauri et al., 2011).

2.5. *Impacts of burning biomass for energy*

Inadequate access to modern energy and the prevalent practice of burning biomass for cooking and heating also has impacts on the food, water, and energy nexus in South Asia. About 70% of the population in South Asia uses biomass such as fuelwood, crop residues, and animal dung as the main source of energy for cooking and heating. In traditional burning practices, incomplete combustion of biomass contributes to emissions of atmospheric black carbon – aerosol particles that absorb solar radiation and release the energy as heat, contributing to atmospheric warming (Venkataraman et al., 2005). When black carbon is deposited on ice and snow it reduces the albedo of these surfaces, increasing the absorption of heat; it is thus thought to be accelerating melting of Himalayan glaciers (Ramanathan et al., 2005; NAS, 2012). Black carbon particles also influence cloud formation. Scientific studies suggest that the haze referred to as the atmospheric brown cloud might have a significant effect on rice and wheat yields in South Asia through reduction of solar energy to the surface and change in rainfall (Ramanathan et al., 2005). Thus, by accelerating the melting of the Himalayan glaciers and influencing light and rain, black carbon could affect water availability and food and energy security in South Asia.

Moreover, diversion of animal wastes from fertilizers to fuel use has serious implications in the food, energy, and water nexus. Cattle dung, rich in organic matter, was used traditionally as manure in agriculture and also provides food for a wide range of animal and fungus species which are recycled into the food chain. Its increasing use as fuel for cooking in rural areas leads to loss of soil nutrients, affecting crop production. In India, about 30% of rural energy consumption is derived from animal wastes; annually, 300 to 400 million tonnes of cattle dung are used as fuel for cooking (GoI 2002). In Bangladesh, where 60% of rural energy comes from biomass, household consumption of biomass fuel is 219 kg per month, of which 42 kg is cow dung (Hassan et al., 2012). In Pakistan about 50% of cattle dung is used as fuel (Khurshid, 2009). Biomass is also the main source of fuel in Afghanistan and Nepal, and cattle dung is increasingly being diverted from manure to fuel (Pant, 2010). South Asian soils are very poor in organic matter, and with the reduced use of cattle dung in crop fields and the increased use of inorganic fertilizers, the organic matter content in soil is declining (Lal, 2007). In Bangladesh, for instance, the average organic matter content of topsoils has gone down from about 2% to 1% over the past 20 years (BARC, 1999). In Pakistan, soil carbon ranges from 0.52% to 1.38% and most soil series have less than 1% carbon (Ijaz, 2013). In India, the use of dung as fuel has resulted in an estimated loss of nitrogen to crops of 3 kg per hectare per year (Ravindranath and Hall, 1995). About 11 million hectares of South Asian cropland suffer from nutrient depletion and land degradation, which has led to stagnation or even decline in the productivity of the rice–wheat system (Lal, 2007). Finally, the diversion of cattle dung from farm manure to fuel has accelerated the use of chemical fertilizers, whose production is highly energy intensive – again, having an impact in the food, energy, and water nexus.

3. The role of the Hindu Kush Himalayas

From a nexus perspective the essential question is whether water and energy constraints can be overcome to grow adequate food for the growing population without degrading the natural resource base.

3.1. *Water*

Rice and wheat are the staple foods in South Asia; about 50% of dietary energy comes from these two crops. But these crops require huge amounts of water – about 1000 tonnes to produce 1 tonne of grain (Brown, 2009). Their production depends on the availability of water in the dry season and on irrigation facilities, which depend on water from the Hindu Kush Himalayas. These mountains are the source of Asia's 10 largest rivers including the Brahmaputra, Ganges, Indus, Mekong, Yangtze, and Yellow Rivers, which are a lifeline for more than a billion people, almost half of humanity (Beniston, 2013). These rivers and their numerous tributaries are the main sources of freshwater in South Asia. They provide water for drinking, irrigation, fisheries, navigation, and hydropower and support terrestrial and aquatic ecosystems.

The world's largest irrigation concentration is in the Indo-Gangetic plain. In Pakistan, food, water, and energy security depends heavily on the state of the Indus River. The Indus irrigation system, the world's largest contiguous irrigation system, irrigates about 14.3 million hectares of farmland, representing about 76% of the cultivated area in Pakistan; it enables the production of more than 80% of the food grains of Pakistan and cash crops, in particular cotton (GoP, 2010). Agricultural water withdrawal in Pakistan is 170 billion cubic metres per year.

Similarly, the Ganges River system is the main source of freshwater for half the population of India and Bangladesh and nearly the entire population of Nepal. The Ganges and Yamuna canal systems irrigate vast areas of India by using surface and groundwater received from the Himalayas. Almost 60% of India's irrigated area of 546,820 km^2 is in the Ganges basin (National Ganga River Basin Authority, 2011). Water use for irrigation in the Ganges basin is about 100 billion cubic metres per year.

The Brahmaputra River supports irrigation, hydropower, and fisheries for a vast part of Bangladesh, Bhutan, and India. Almost 6000 km^2 are irrigated using 1.4 billion cubic metres of water per year. Afghanistan's food and water security heavily depends on the Amu Darya. More than 5 billion cubic metres of water per year are drawn from this river and its tributaries in northern Afghanistan to irrigate 385,000 ha of farmland (NAS, 2012).

Himalayan freshwater resources: The Hindu Kush Himalayan mountain system is often called the 'third pole' or 'water tower of Asia' because it contains the largest area of glaciers and permafrost and the largest freshwater resources outside the North and South poles. About 30% of the world's total glaciated mountain area is in the HKH region. Estimates of glacier area vary considerably; one estimate suggests the glacier area in the HKH region is 114,800 km^2 (WGMS 2008, cited in NAS, 2012). A study conducted by ICIMOD inventoried 54,000 glaciers in the HKH covering 60,000 km^2 (Bajracharya and Shrestha, 2011). Himalayan ice reserves are estimated to be equivalent to about three times the annual precipitation over the entire HKH region (Bookhagen, 2012; Immerzeel and Bierkens, 2012). During summer and early autumn, meltwater released from glaciers, ice, and snow feeds the rivers reaching downstream, increasing their run-off and recharging river-fed aquifers. Glaciers provide a natural antidote for hydrological seasonality, providing water during the dry season when it is most needed.

However, the role of meltwater varies through the region: In the northwestern and far-eastern Himalayas more than 50% of the annual discharge comes from snow that falls during the winter westerlies. By contrast, the central Himalayan rivers generally receive less than about 25% of their annual discharge from snowmelt, and are instead fed mainly by summer monsoon rainfall. It is estimated that about 50–80% of the inflows in the Indus River system is fed by snow and glacier melt from the Hindu Kush Karakoram part of the HKH. With over 5000 glaciers, the upper Indus basin has a glaciated area of about 15,000 km^2, which corresponds to about 2700 km^3 of stored ice, equivalent to about 14 years of average Indus River system inflows (GoP, 2010). The Hindu Kush Karakoram and western Himalayas are the source of about 90% of the lowland flow of the Indus River and its tributaries (Liniger et al., 1998, cited in Winiger et al., 2005).

Groundwater: Although estimates of the Himalayan contribution to downstream groundwater recharge are limited, a recent study claims that it may be substantial (Bookhagen, 2012). Andermann et al. (2012) report that groundwater flow through bedrock is approximately six times the annual contribution from glacial ice melt and snowmelt to central Himalayan rivers. Groundwater is an invisible ecosystem service of the Himalayas; it is vital for irrigation in the entire agricultural landscape of HKH countries, in addition to serving other human uses and sustaining wetland ecosystems. Further study, therefore, is needed to determine the potential role of HKH watershed management in reducing runoff and increasing infiltration to ensure groundwater recharge downstream.

3.2. *Energy*

From a nexus perspective, the major challenges facing South Asian countries relate to supplying enough energy for increased food production and other economic activities as well as domestic use without increasing carbon intensity. Hydropower from the HKH mountain systems can enhance energy security in South Asia, provide quality energy for agriculture and food production, reduce to some extent the vulnerability and impacts of fluctuations in supply and prices of fossil fuels (especially imports), and provide local, national, and global environmental benefits through the reduction in consumption of fuelwood and fossil fuels. Harnessing the huge untapped hydropower resources in the region could fuel industrialization and economic growth as well as strengthen food security.

Hydropower and clean energy potential in Himalayan rivers: The Himalayan topography and rivers with abundant rainfed and snowfed water resources provide an opportunity for generating an enormous amount of hydropower. The hydropower potential of the HKH region is more than 500 GW (Vaidya, 2012). The contribution of hydroelectricity to total commercial energy is about 50% in Bhutan, 17% in Nepal, 13% in Pakistan, 6% in India, and 4% in Afghanistan (ADB, 2011); and to the total electricity supply is about 100% in Bhutan, 92% in Nepal, 74% in Myanmar, 33% in Pakistan, 17% in India, and 16% in China (Molden et al., 2014).

The hydropower potential of the Brahmaputra River is one of the largest among the world's rivers – more than 296.8 TWh (Cathcart, 1999). The location where it drops 2300 m from the Tibet Autonomous Region of China to Assam in India has immense potential. The Brahmaputra's theoretical hydropower potential is estimated to be about 83,000 MW in Nepal, 21,000 MW in Bhutan, and almost 59,000 MW in northeast India. The Ganges–Brahmaputra–Meghna river system is estimated to have about 200,000 MW of hydropower potential, of which half or more is considered to be feasible for harnessing (Chalise et al., 2003). Nepal has identified 28 potential reservoir sites with an aggregate gross storage capacity of 110 billion cubic metres. Biswas (2004) notes that Nepal and Bhutan could harness this hydropower potential at a relatively low cost compared to alternative energy sources. The 1986 Brahmaputra Master Plan of India identified 18 storage sites in northeast India, five classified as large, with a total gross storage capacity of 80 billion cubic metres. Several multipurpose projects with large reservoir storage capacities have been identified in India in the Brahmaputra and Meghna basins (Sharma and Awal, 2013; Rahaman and Varis, 2009; Sharma, 1997; Rao, 2006). One large storage site (Tipaimukh) has been identified in the Meghna (Barak) system with a gross storage potential of 15 billion cubic metres (Mohile, 2001).

In the Indus River system in Pakistan, 800 potential sites have been identified. The collective potential of hydropower in the Indus River system is about 60 GW, but only 6720 MW (11%) have been realized (Siddiqi et al., 2012).

The Ganges and its tributaries also have huge potential for hydropower development and trade. A recent study conducted by the World Bank suggests that about 25,000 MW of electricity could be generated in the Ganges basin through upstream storage of water in 23 dams, and that this could provide benefits worth of USD 5 billion per year with little trade-off (Sadoff and Rao, 2011).

Of the total hydropower potential in India, 79% (117,329 MW) is in the Himalayan region. However, only 12,543 MW has been developed, with another 12,375 MW in development (GoI, 2010).

In Afghanistan, hydropower contributes more than 54% of the total power supply. The upper Amu Darya and Panj Rivers in Afghanistan are estimated to have about 20,000 MW of hydropower potential. Ten hydro projects with a total capacity of more than 10,000 MW have been identified. However, present utilization is only 256 MW (Ahmadi, 2012).

Micro-hydropower: In addition to the potential on a large scale, Himalayan streams and rivers also offer ample opportunity for generating hydropower at small and medium scales. Nepal and Pakistan have good experience with micro-hydropower plants (less than 100 kW capacity), especially in relation to community involvement in planning, construction, and operation. These countries also have a significant industrial base that produces the required electro-mechanical equipment. In northern Pakistan, under an initiative of the Aga Khan Rural Support Programme, communities in remote mountain valleys built 240 micro hydro plants between 1990 and 2005, with a total capacity of more than 10,000 kW. A

Clean Development Mechanism (CDM) project was registered with the CDM Executive Board in October 2009 to develop 103 new micro and mini hydropower plants in Pakistan with a total capacity of 15 MW at a cost of USD 18 million (Molden et al., 2014).

India has also initiated small and micro-hydropower development in its Himalayan region. By 2006, 3,434 MW had been installed in Himachal Pradesh, Uttaranchal, Assam, West Bengal, Sikkim, and Bihar, contributing about 13.2% of renewable power (Reddy et al., 2006).

3.3. *Other ecosystem services*

Climate regulation: The Himalayan mountain system creates conditions conducive to agriculture by regulating microclimate as well as wind and monsoon circulation in the Himalayan region. Because of their altitude and location, the Himalayas block moisture-laden monsoon winds from travelling further northward and thus facilitate timely and heavy precipitation (snow and rain), saving South Asia from the gradual desiccation that afflicts Central Asia (NAS, 2012). During winter, the mountains pose a barrier to storms coming from the west, and as a consequence receive snow at higher elevations and rainfall at lower elevations and in the adjacent plains of northern India (GoI, 2010). The Himalayan ranges also prevent frigid and dry arctic winds from blowing south into the subcontinent, keeping South Asia much warmer than other regions at corresponding latitudes around the globe.

Soil fertility: In addition to providing surface and groundwater, Himalayan rivers carry soil and nutrients to downstream areas, making floodplains in South Asia, particularly the Indo-Gangetic plain, fertile and contributing substantially to productivity of agriculture and aquatic resources (Aggarwal et al., 2004; Prasad and Kar, 2005; Sharma et al., 2007).

Agro-biodiversity: The Himalayas are important storehouses of agro-biodiversity, which is fundamental for agricultural sustainability and human wellbeing in South Asia and beyond. Over 675 edible plants and nearly 1743 species of medicinal value are found in the Indian Himalayan region alone (Singh, 2006).

Aquatic resources: Both tropical and Himalayan coldwater fish are important sources of nutrition and food security in the HKH region and downstream. The Himalayan river systems harbour some of the richest fish biodiversity resources in the world. Connecting Himalayan headwaters with the sea, they serve as biological corridors for migration of fish and other aquatic species, thus supporting biological diversity and livelihoods. The Ganges river system alone hosts around 265 species of fish. Because of the perennial water from mountain snow and ice in the Ganges and the Brahmaputra, India and Bangladesh stand second and third respectively in the world in terms of inland fisheries production (Hussain, 2010). Subsistence and semi-intensive fisheries also support the livelihoods of a huge population. A total of 2.5 and 0.4 million fishers in India and Bangladesh respectively rely on fishing in Himalayan rivers for income, food security, and nutrition (FAO, 2012). The Koshi River, a major tributary of the Ganges, has 103 fish species and contributes about half of Nepal's total fish production of 33,000 tonnes per year; more than 30,000 people depend on fishing in the Koshi and other rivers in Nepal for their livelihoods (Sharma, 2008).

4. Challenges of sustaining Himalayan ecosystems for food, water, and energy security

Throughout the Himalayas, the growing demand for resources, widespread poverty, and the strong profit motive of commercial enterprises, and inadequate incentives for sustainable management have led to unsustainable use of resources (Singh, 2006). Rapid population growth – with South Asia's population projected to increase from 1.36 billion in 2000 to 2.31 billion in 2050 (Lal, 2007) – has increased demand for food, fodder, grazing land, water, and other natural resources in the mountains and downstream. Rapid urbanization – at an annual rate of 2.87%, as compared to 2.34% worldwide (Sardar, 2012) – is also increasing the demand for water, energy, and food. The urban population of South Asia has grown from 73.95 million in the 1950s to 485.79 million in 2010. Urbanization has resulted in changed food preferences and higher demand for meat and other water and energy intensive foods. These demographic pressures and higher demands, along with increased connectivity and other socioeconomic factors, are resulting in changes in land use and land cover and intensified resource use patterns in the upland areas (Tiwari and Joshi, 2012; Postel and Thompson, 2005; Wasson et al., 2008).

The HKH region suffers severe land degradation, in particular deforestation and forest degradation, erosion, landslides, overgrazing, biodiversity loss, declining productivity, and desertification (Tiwari and Joshi, 2012; Semwal et al., 2004; Pandit and Kumar, 2013). Rangelands have been converted to rainfed farming, marginal lands have been used for quick-return commercial farming, and minerals have been extracted without adequate environmental protection (Singh, 2006; Tiwari and Joshi, 2012).

Forests have an important role in replenishing groundwater and maintaining the volume of river water in the dry season, sequestering carbon, and supporting agriculture (Singh, 2006; Singh and Sharma, 2009). Most of the forests in the central Himalayas were heavily degraded during the last century as a result of the growing demand for timber and fuelwood and inadequate management (Haigh et al., 1990). The southeastern Tibetan plateau, once covered by coniferous forest, was denuded of forest by the middle of the twentieth century (Cui et al., 2007). Similarly, most of the forest lands in the Indus basin have been converted to other uses for short-term gains (, 98). Forest degradation poses significant challenges to local people's livelihoods and food and energy security as they depend heavily on forest for fuelwood, fodder, and other non-timber forest products (Rasul et al., 2008).

Forest degradation and the loss of vegetation have made the Himalayan watersheds more vulnerable to erosion, which has led to loss of soil and nutrients, siltation of rivers and reservoirs, and increases in the incidence and severity of flooding. The Koshi River in Nepal carries an annual load of 119 million cubic metres of silt, which is equivalent to 2 mm of topsoil depth over its entire catchment (Laban, 1979). Siltation is not only causing river beds to rise; it is also affecting the water infrastructure, reducing the life of reservoirs and dams for hydropower, irrigation, and flood control, thus affecting energy and food production (Tiwari, 2000). Watershed degradation is also resulting in decreased groundwater recharge and consequent drying up of springs, streams, and other water sources (Haigh et al., 1990; Tiwari, 2000; Tiwari and Joshi, 2012). This has caused shortage of water for drinking, irrigation, and other livelihood activities in the Himalayas.

The changes in the headwater regions also have downstream impacts in the Indo-Gangetic plain in terms of silting of river beds, increased incidence of floods, and decreased water discharge in rivers (Wasson et al., 2008; Semwal et al., 2004; Tiwari, 2000; Tiwari and Joshi, 2012). It is estimated that 2400 million tonnes of silt are being transported to Bangladesh every year (Tejwani 1990, cited in Tiwari, 2000).

So far adequate measures have not been taken to protect the vital Himalayan ecosystem resources through coordination between upstream and downstream stakeholders. Although mountain communities bear the cost of conservation in foregoing more productive alternatives, their efforts bring them few benefits because of a lack of institutional mechanisms and policy arrangements for sharing the benefits and costs of conservation (Thapa, 2001; Singh, 2006).

These challenges highlight the importance of urgent action to protect and sustainably manage Himalayan ecosystems to ensure food, water, and energy security in the HKH region and South Asia.

5. Discussion

With limited land resources, growing water stress, increasing energy demand, unstable energy prices, and poor socioeconomic conditions, South Asian countries face serious challenges as to how to provide adequate food and nutrition, access to modern energy, and safe water and sanitation to a burgeoning population without degrading the natural resource base. The nexus approach provides a framework for better understanding of the interdependencies of the food, water, and energy sectors and linkages between upstream and downstream countries as well as better insights into how to address such challenges by maximizing synergies and managing trade-offs.

As shown in the above analysis of the role of Himalayan ecosystem services in ensuring food, water, and energy security in South Asia, one of the key characteristics of the nexus in South Asia is that food production in the region has become increasingly water and energy intensive. While the demand for food, water, and energy is growing tremendously, land, water, and other natural and environmental resources are in decline, so that increased food production in South Asia will have to come from the same or even less land. Another distinctive feature of the food, water, and energy nexus in South Asia is the high economic and environmental dependence on upstream resources. The Himalayan ecosystems are critical for ensuring food, water, and energy security not only in the HKH region but also in downstream river basins. As water, nutrients, and other ecosystem services flow downstream from the Himalayas, the land use and management practices at the headwaters and in Himalayan watersheds affect the quantity and quality of water, energy, and other resources critical for sustaining agriculture and food security downstream.

The widespread burning of biomass for fuel could also affect water availability and food and energy security in South Asia. Although the causes of accelerated melting of snow, ice, and glaciers in the Himalayas are not fully understood, growing evidence suggests that black carbon could be one of the factors responsible for this phenomenon.

The interdependencies in food, water, and energy security in South Asia thus highlight the need for intersectorally integrated solutions, while the crucial role of the Himalayas underlines the need to address the issues from an ecosystem perspective.

Mountain communities are the custodians of vital resources and their actions have important implications for the condition of the headwaters and watersheds. So far, however, no effective mechanisms have been developed to provide adequate incentives for communities to conserve mountain natural resources. Lack of appropriate incentives or other policy and institutional mechanisms has resulted in increased degradation of headwaters and emissions of black carbon along with declining agricultural productivity, with serious implications for downstream communities. Ecosystem degradation in Himalayan headwaters and watersheds could jeopardize the food, water, and energy security in South Asia.

Despite the urgent need for clean energy to meet the growing demand for food, water, and energy, the hydropower potential of the Himalayan rivers has remained under tapped. Acute energy deficit in Bangladesh, India, and Pakistan and huge hydropower potential in Bhutan and Nepal suggest an opportunity for synergies that could be obtained by exploiting the hydropower potential of the Himalayan rivers in a collaborative and integrated manner. Optimal utilization of Himalayan water for energy, irrigation, navigation, and fisheries can contribute significantly in achieving food, water, and energy security in South Asia in the long run.

It may be argued that the exploitation of hydropower in upstream areas might affect water availability for irrigation downstream and thus intensify food – energy trade-offs. However, hydropower generation is a non-consumptive use, so it does not necessarily reduce water availability downstream; the water used for hydropower can also be used for irrigation if it is properly managed. Arguably, upstream storage of monsoon water for hydropower may augment downstream water availability in the dry season (Rasul, 2014). This perspective is supported by a detailed World Bank study in the Ganges basin which found that huge hydropower benefits can be obtained with a very small trade-off in irrigation (Sadoff and Rao, 2011). In harnessing hydropower potential, of course, it is essential to address any potential adverse impacts on the environment, ecology, and society (Biggs et al., 2013) and to ensure equitable benefit sharing following the framework set out by the World Commission on Dams (WCD, 2000).

The potentials cannot be realized without coordination and collaboration across countries, as most of the Himalayan rivers flow through more than one country. At present, cooperation between upstream and downstream countries is minimal, and its absence is a major constraint in addressing the nexus challenges (Rasul, 2014). To address the challenges of food, water, and energy security, it is therefore necessary to identify synergies across boundaries at the basin level (Crow and Singh, 2009). For example, the Aswan Dam on the Nile River not only contributes to mitigating drought and flood damage but also supplies electricity to half of the rural communities in Egypt, supports the fishing industry, and has created new livelihood opportunities (Lindström and Granit, 2012).

6. Conclusions and policy recommendations

The findings of this study suggest that ecosystem services and their upstream–downstream linkages, particularly in the region's transboundary river basins, are an integral part of the food, water, and energy nexus. In a transboundary river basin – where resource flows transcend national boundaries, and where management practices and conservation initiatives upstream have impact in downstream areas – the synergies and trade-offs in food, water, and energy cannot be optimally managed unless a basin-level approach is taken. The Himalayas are a regional public good, and it is the common interest and shared responsibility of all in South Asia to protect the Himalayan ecosystems for the benefits of the region. To address the nexus challenges, a two-pronged approach is needed: first, to enhance cross-sectoral coherence and second, to improve management of the Himalayan headwaters, watersheds, forests, rangelands, soils, and farmlands on which the sustainability and stability of flow of ecosystem services depend. The following are some broad recommendations.

- Harmonize policies among the three sectors, taking into account interdependencies of resources across both sectors and scales, upstream and downstream, as well as the role of Himalayan ecosystems in long-term security of water, energy, and food in the region.
- Integrate planning and management of water, energy, land, forest, ecosystems, agriculture, and food security to reduce intersectoral externalities, tap synergies and co-benefits across sectors and scales, enhance resource use efficiency, and reduce environmental impacts.
- Manage demand for water and energy through regulation and introduction of incentives for efficient use of water and energy for food production.
- Strengthen coordination mechanisms among upstream and downstream countries to maximize synergies and minimize trade-offs in resource use, and take a river basin approach to protect Himalayan ecosystems, catchments, watersheds, and headwaters and to harness the potential of water resources, as the benefits of sustainable watershed management transcend national boundaries.
- Develop appropriate incentives such as payments for ecosystem services and mechanisms for sharing the benefits and costs of conservation to encourage local communities to use and manage the headwaters sustainably.
- To sustain the ecosystem services of the Himalayan glaciers in providing fresh water to downstream areas, control black carbon emissions by providing clean energy options to rural people (such as as micro and macro hydropower, efficient stoves for burning biomass, and biogas) and by improving kiln efficiency in the brick making industry.
- In exploiting hydropower potential, take the ecological, environmental and social implications of hydropower development seriously into account. Detailed studies of technical and economic feasibility are required to identify potential hydropower areas and to demarcate fragile zones where heavy construction must be avoided, for example at high altitude and in vulnerable watersheds.
- Establish a cooperation framework for multiple uses of water (for irrigation, energy, navigation, fisheries, and domestic uses) and for appropriate benefit sharing.
- Finally, as knowledge and understanding of the dynamics of the food, water, and energy nexus and the possible areas of trade-offs and synergies are limited, support integrated modeling research and the development of a nexus knowledge base to support decision-making in addressing trade-offs and promoting synergies among the concerned sectors.

Acknowledgement

The author would like to offer his sincere thanks to the anonymous reviewers for their very helpful comments and suggestions. The author also benefitted from discussions and comments from David Molden, Philippus Wester, Gopal Rawat, Eklabya Sharma, and SM Wahid of ICIMOD and Gopal Thapa of AIT. He would also like to acknowledge Andrea Perlis for her valuable editorial inputs. This study was part of the Himalayan Climate Change Adaptation Programme (HICAP), is implemented jointly by ICIMOD, CICERO and Grid-Arendal and is funded by the Ministry of Foreign Affairs, Norway and Swedish International Development Agency (Sida) and the Koshi Basin Programme of ICIMOD funded by the Department of Foreign Affairs and Trade (DFAT) of Australia. The views expressed are those of the author's and do not necessarily reflect that of ICIMOD or any other organization mentioned above.

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