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The nexus approach to water–energy–food security: an option for adaptation to climate change

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Developing countries face a difficult challenge in meeting the growing demands for food, water, and energy, which is further compounded by climate change. Effective adaptation to change requires the efficient use of land, water, energy, and other vital resources, and coordinated efforts to minimize trade-offs and maximize synergies. However, as in many developing countries, the policy process in South Asia generally follows a sectoral approach that does not take into account the interconnections and interdependence among the three sectors. Although the concept of a water–energy–food nexus is gaining currency, and adaptation to climate change has become an urgent need, little effort has been made so far to understand the linkages between the nexus perspective and adaptation to climate change. Using the Hindu Kush Himalayan region as an example, this article seeks to increase understanding of the interlinkages in the water, energy, and food nexus, explains why it is important to consider this nexus in the context of adaptation responses, and argues that focusing on trade-offs and synergies using a nexus approach could facilitate greater climate change adaptation and help ensure food, water, and energy security by enhancing resource use efficiency and encouraging greater policy coherence. It concludes that a nexus-based adaption approach – which integrates a nexus perspective into climate change adaptation plans and an adaptation perspective into development plans – is crucial for effective adaptation. The article provides a conceptual framework for considering the nexus approach in relation to climate change adaptation, discusses the potential synergies, trade-offs, and offers a broader framework for making adaptation responses more effective.

Policy relevance

This article draws attention to the importance of the interlinkages in the water, energy, and food nexus, and the implications for sustainable development and adaptation. The potential synergies and complementarities among the sectors should be used to guide formulation of effective adaptation options. The issues highlight the need for a shift in policy approaches from a sectoral focus, which can result in competing and counterproductive actions, to an integrated approach with policy coherence among the sectors that uses knowledge of the interlinkages to maximize gain, optimize trade-offs, and avoid negative impacts.

Keywords: adaptation to climate change; Hindu Kush Himalayan region; policy coherence; synergies; trade-offs; water–food–energy nexus

1. Introduction

The global community is looking for new approaches and solutions to adaptation to climate change and development challenges such as water, energy, and food security. The Rio + 20 Declaration 'The Future We Want' stresses the need for a balanced integration of economic, social, and environmental concerns into economic development, and also highlights the need to address food, water,

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and energy security in such a manner as to reduce the adverse impacts on nature (on water, biodiversity, air, and climate). One of the greatest challenges facing humanity is how to manage global warming and mitigate its adverse effects on human and natural systems. Meeting this challenge has emerged as a top priority in the national and international development agendas. Adaptation to climate change is a global priority and is critically important for developing countries, where large numbers of people depend on climate-sensitive sectors such as agriculture, forestry, and fisheries, have limited resources and capacity, and live in climate-vulnerable settings such as mountains and coastal areas (WRI, 2011). The goal of adaptation is to reduce vulnerability to both climatic and non-climatic changes, so it is closely linked to achieving the sustainable use and management of water, energy, and food, which are vital for sustainable development, by harmoniously addressing water, energy, and food security challenges.

Although interest in adaptation to climate change impacts has surged in recent years, the focus has remained sectoral. The role of the water–food–energy nexus in addressing the competing demands of – and facilitating – adaptation and development has not yet been fully recognized. Historically, most adaptation plans, including the National Adaptation Programmes of Action (NAPAs), have been prepared to meet sectoral goals. They generally focus on sectoral and project-based activities, without adequate consideration or coordination of cross-sectoral interactions among key climate-sensitive sectors such as water, energy, and food.

Sectoral adaptation strategies can increase vulnerability or undermine net resilience by decreasing capacity or increasing risks in another place or sector, resulting in maladaptation (Barnett & O'Neill, 2010; Lele, Klousia-Marquis, & Goswami, 2013; Urwin & Jordon, 2008; Walker, Salt, & Reid, 2006). In China, for example, excessive use of pesticides in food production has had a negative impact on health, costing an estimated US$1.4 billion per year, and has adversely affected farm and off-farm biodiversity (Norse, Li, Jin, & Zhang, 2001). This, in turn, has affected food production. Similarly, subsidies for groundwater extraction, provided by many countries in the Hindu Kush Himalayan (HKH) region to cope with surface-water shortages and uncertainty in water availability, have led to overexploitation of groundwater, wastage of scarce water resources, and increased demand for energy, ultimately undermining food and energy security. Balochistan, an arid region of Pakistan, is now growing apples and other fruit by using groundwater irrigation, which requires huge amounts of energy; meanwhile, the country is facing crippling shortages of energy (Khair, 2013; Mustafa & Qazi, 2007).

The prevailing approaches see adaptation largely as a local issue with a community or ecosystem focus (Huq & Reid, 2004) and ignore the role of the national, regional, and global policies and institutions that shape adaptation options and choices. Local adaptation approaches often prove unsustainable owing to inadequate institutional support (Agrawal, 2010).Climate change brings multiple stresses, and adaptation requires comprehensive and integrated approaches, with coordination between different sectors and at different scales (local, national, and regional). Water, energy, and food are critical for human survival and sustainable well-being. All three are subject to rapidly growing global demand, and all face resource constraints, with billions of people lacking access to them (Bazilian et al., 2011). Clearly, meeting these critical needs represents the most important challenge facing society today.

Climate change and anthropogenic pressures have exacerbated the pressure on water, energy, and food (Eriksson et al., 2009; Rockstrom et al., 2009; Shrestha & Aryal, 2011). All three sectors are both highly vulnerable to climate change and contribute heavily to that change through their GHG emissions (Calow et al., 2011; Howells et al., 2013). Adaptation is therefore intrinsically linked to water, energy, and food security. Although the likely impacts of climate change on water, energy, and food production have raised serious concerns and been emphasized in the pursuit of appropriate adaptation measures, the links among water, energy, and food, and the role of this nexus in effective adaptation, have not yet been well researched. Failure to consider the nexus of water, energy, and food in resource assessments and policy making has led to contradictory strategies and inefficient use of resources (Howells et al., 2013).

The HKH region provides a good example. With limited natural and financial resources and human capacity, this region faces difficult challenges in adaptation to the multiple effects of climate change, particularly in terms of ensuring adequate food, water, and energy for a burgeoning population. About half of the world's poor live in the eight countries of the HKH region, and more than 500 million people have no access to modern energy. To meet their nutritional requirements and provide energy and water access to all citizens, food production and energy generation need to increase substantially, and water availability needs to be enhanced (Rasul, 2014).These challenges are especially pronounced in mountainous regions, where the impacts of climate change are already visible and are likely to have serious implications for the availability of water, energy, and food unless appropriate measures are taken (Eriksson et al., 2009; Rasul, 2012; Shrestha & Aryal, 2011). With large populations, limited land resources, and growing water stress, the Himalayan countries face the common challenge of how to grow more food with the same or less land, less water, and increased energy prices. The cultivation of rice and wheat, the staple foods in the subregion, require huge amounts of water and energy. Efficient and coordinated management of water, energy, and food is critical for adaptation and the mitigation of climate change in the region (Rasul, 2014).

In the following, using the HKH region as an example, we suggest that focusing on the trade-offs and synergies of the water, energy, and food nexus is a potential strategy for integrated and efficient resource management and for adaptation to address future challenges in a systematic way. An outline for a broader framework is presented, and reform measures are suggested to make adaptation responses more effective and sustainable. The study relies predominantly on information drawn from secondary sources, including books, reports, and journal articles. Some information has been drawn from the research experience of the International Centre for Integrated Mountain Development (ICIMOD) over the past 30 years, as well as the authors' own research experience in the region.

2. Water, energy, and food nexus and adaptation to climate change: a conceptual framework

Although a growing body of literature is emerging on both adaptation to climate change and the water, energy, and food nexus, the linkage between the two is rarely explored.

2.1. Evolving approaches to adaptation to climate change

Development practitioners and academics have paid increasing attention in recent years to the question of adaptation, although different scholars define adaptation in different ways based on their professional interests. In terms of climate change, the Intergovernmental Panel on Climate Change (IPCC) Working Group 2 on Impacts, Adaptation and Vulnerability defines adaptation as 'the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC, 2007). The concept continues to evolve, however, and its focus is gradually changing from just responding to the impacts of climate change to addressing the underlying factors that cause vulnerability and addressing development challenges (Kok, Metz, Verhagen, & Van Rooijen, 2008).

More specifically, approaches to adaptation have evolved from the initial infrastructure-based interventions to a more development-oriented approach based on building a broader resilience to climate hazards by addressing the underlying causes of vulnerability rather than simply responding to the symptoms (Calow et al., 2011; Davies et al., 2013). Trans-sector and transboundary considerations, however, are only just emerging. Table 1 shows how adaptation approaches have evolved over the past two decades in terms of the assessment of risks, mainstreaming, focus, and scope. In the 1990s the focus was on the assessment of climate risks and aimed at reducing climate impacts using a locally specific sectoral

TABLE 1 Evolving approaches to adaptation

Feature	1990s	2000s	2010s
Overall objective	Reducing climate risks and impacts	Reducing climate risks and uncertainties	Reducing climate risks and impacts with socio-economic improvements Mainstreaming climate change adaptation into development
Scope	Sector-based approach, location specific	Sector-based approach, but adaptation mainstreamed into sectoral planning	Trans-sector and transboundary approaches started
Focus of activities	Protective: coping strategies, protection of those most vulnerable to climate risks and with low levels of adaptive capacity	Preventive: coping strategies, prevention of damaging strategies arising from risks to climate-sensitive livelihoods	Transformative: building adaptive capacity, transforming social relations to combat discrimination and underlying social and political vulnerability, improving livelihoods, building local institutions
Implementation	Activities seek to address impacts exclusively associated with climate change: provision of social services; social transfers (food/cash) including safety nets; social pension schemes; public works programmes	Managing climate risks: activities seek to incorporate climate-related information into decision making	Building response capacities: activities seek to build robust systems for problem solving, improving livelihoods Addressing the drivers of vulnerability: activities seek to reduce poverty and other non-climatic stressors that make people vulnerable; promotion of minority rights; proactive challenging of discriminatory behaviour

Sources: adapted from Davies et al. (2013) and Calow et al. (2011).

approach. In the 2000s the concept of adaptation, including the notion of mainstreaming, gained momentum faster than policy and practice, although the sector-based approach still dominated in mainstreaming. In the current decade the emphasis has shifted, with adaptation linked more to sustainable development. There has been a shift away from sectoral approaches and an emerging emphasis on cross-sectoral and transboundary approaches, for example, focusing on river basins.

Broadly, there are two distinct perspectives on how to approach adaptation in developing-country contexts. The first focuses on reducing climate change impacts, and the second on reducing vulnerability and building resilience by addressing not only climate change but also other drivers of vulnerability and poverty such as gender and social equity, as well as other structural factors hindering long-term sustainable development. In practice, most interventions fall somewhere between these two extremes. The development-oriented approach emerged based on the underlying premise that people are vulnerable not only to climate change but also to a range of other stresses, depending on access to resources and other socio-environmental circumstances shaped by political and economic processes (Kelly & Adger, 2000; O'Brien et al., 2004). Technological measures designed to help people adapt to specific changes in climate may fail to address the issues local people consider most urgent, such as access to water, food, and energy and livelihood security.

It is increasingly recognized that successful adaptation will require interventions that address the full spectrum of challenges, including the underlying causes of vulnerability, managing climate risks, and building response capacity, in the context of other theories of risk and development. As highlighted by Schipper (2007), adaptation will not be effective unless it is integrated into development policy, and development processes have been aligned to create the necessary enabling conditions.

2.1.1. Principles of sustainable adaptation

Although the need to adapt to a changing climate is now widely acknowledged, the 'hows' of effective adaptation remain far from clear. Debates on climate change adaptation have taken place largely outside the broader discourse on sustainable development (Bizikova, Roy, Swanson, Venema, & McCandless, 2013; Skea, Hourcade, & Lechtenboehmer, 2013). The IPCC has only included sustainable development as a theme since its third assessment (Munasinghe & Swart, 2000; Yohe et al., 2007), and little attention has been paid to identifying principles for creating synergies between sustainable development and adaptation.

Climate change adaptation can be made more relevant to policy by contextualizing it within a sustainable development framework (Burch, Shaw, Dale, & Robinson, 2014; Robinson & Herbert, 2001). Eriksen et al. (2011) define sustainable adaptation as

> a set of actions that contribute to socially and environmentally sustainable development pathways, including social justice and environmental integrity. It considers the wider effects of adaptive responses on other groups, places, and socio-ecological systems, both in the present and in the future.

According to Doria, Boyd, Tompkins, and Adger (2009, p. 815), 'Successful adaptation is that adaptation that generates net benefits for the adapting party, in both the short- and long-term, without causing net loss of welfare for the wider society.' Climate change influences the availability and demand for water, energy, and food, the underlying drivers, and the resource base on which the livelihoods and adaptation options of the poor depend, so sustainable use of natural resources is thus critical for effective adaptation (Burch et al., 2014; Scott et al., 2013). Efficient and rational use of natural resources can relieve the pressure on natural resources and support adaptation (Nilsson & Persson, 2012; Stewart & Raes, 2007). A sustainable adaptation process requires adjustments in policies, institutions, and attitudes that promote a comprehensive and integrated approach for reducing poverty and vulnerability and enhancing resilience and in a sustainable manner (Jerneck & Olsson, 2008; Kok et al., 2008).

Although, as yet, there is no framework or set of principles for sustainable adaptation that has been agreed by all stakeholders, certain key principles can be discerned:

- Adaptation entails measures that reduce poverty and vulnerability and enhance long-term resilience in a changing climate.
- Adaptation comprises actions that strengthen the adaptive capacities of the poor, including the management of the natural resources on which their livelihoods depend; manages risks; and uses resources in an efficient and sustainable manner to meet the needs of present and future generations.
- Adaptation in one sector or by one community does not undermine the resilience of others.
- Adaptation responses and mechanisms do not undermine long-term sustainability.

2.2. Interlinking actions: concept of the food, water, and energy nexus

The discourse on food, water, and energy security is driven by growing pressure on natural resources. The demand for food, water, and energy is growing steadily, but the resources required to generate them are limited and in many cases dwindling (Rockström et al., 2009; State of the Planet Declaration, 2012). The interdependencies among water, energy, and food are numerous and multidimensional, and their relationship is often called the food, water, and energy nexus (although the order of the components may vary). Although the discourse on this nexus has been gaining currency (Hoff, 2011; Hussey & Pittock, 2012; Marsh & Sharma, 2007), it is not yet clearly understood how the concept can be applied to ensure food, water, and energy security, although understanding the different interfaces in the food, water, and energy nexus will be critical for taking action.

One of the important interfaces in this nexus is that of water with food and energy. Water plays a vital role in both food and energy production, and in sustaining the ecosystems that support agriculture and other economic activities that are critical for achieving food security (Hellegers, Zilberman, Steduto, & McCornick, 2008; Molden et al., 2007). A second important interface is that of energy with food and water. Energy is required for food production (especially irrigation) and for water supply, including the extraction, purification, and distribution of water (Bach et al., 2012; Bazilian et al., 2011; Mukherji & Shah, 2005). Food production as a consumer of land, energy, and water is the third interface in the nexus. Agriculture, responsible for growing food, is a major user of water (more than 70% of all water use globally) and energy. Agriculture and food production further affect the water sector through land degradation, changes in runoff, and disruption of groundwater discharge (Alauddin & Quiggin, 2008). Sustainable agricultural practices, such as those designed to prevent land degradation, save water and energy by increasing water storage in the soil and groundwater recharge and by reducing the use of energy-intensive fertilizers.

The relationships among food, energy, and water are dynamic. Actions in one area usually have impacts in one or both of the others, with profound economic, environmental, and social implications. Indeed, the security of one sector often cannot be achieved without undermining another sector (Lele et al., 2013; Newell, Phillips, & Purohit, 2011; Ringler, Bhaduri, & Lawford, 2013). The environmental footprints associated with increased water and energy use for food production impose external costs to water and ecosystems, thus threatening the sustainability and resilience of global water and food systems and demonstrating the need for integrated solutions (Khan & Hanjra, 2009).

The need for an integrated approach in development has been recognized at different stages of development planning. An integrated approach to rural development was introduced in the 1970s in many developing countries. The aim was to reduce poverty through the integration of public services and the promotion of synergy and complementarity among different agencies at the local level, focusing on health, social welfare, agriculture, and income generation. The approach raised huge aspirations for improving the delivery of public services and reducing poverty. For example, India introduced an integrated programme in the sixth and seventh five-year plans (1980–1990). Among other actions, subsidized loans were distributed to over 15 million families to promote income-generating activities (Copestake, 1996). The programme failed to meet expectations, however. Although described as integrated, it mainly focused on credit delivery and there was little integration of the other public services actually required for poverty reduction. Moreover, political influence in credit delivery and weak support from the central ministries undermined the effectiveness of implementation.

Another integrated approach that has gained currency involves managing water and land in an integrated way by realigning sectoral organization along hydrological boundaries to enable integrated water resource management (IWRM) (Saravanan, Geoffrey, & Mollinga, 2009). However, although the concept is widely acclaimed, the focus remains on water and hydrological boundaries, with the risk of prioritizing water-related development goals over others and thereby reinforcing the traditional sectoral approach (Bach et al., 2012; Benson, Gain, & Rouillard, 2015). The approach is very different to the nexus approach. Although IWRM attempts to involve all sectors from the water management perspective, the nexus approach treats water, energy, and food equally and recognizes the interdependencies of the three sectors (Bach et al., 2012).

The nexus approach aims to systematize the interconnections and provide tools to assess the use of all resources (Hermann et al., 2012). It is a system-wise approach, and recognizes the inherent interdependencies of the food, water, and energy sectors for resource use, seeks to optimize trade-offs and synergies, and recognizes social and environmental consequences (Bazilian et al., 2011; Prasad, Stone, Hughes, & Stewart, 2012). Understanding the linkages within the food, energy, and water nexus can provide opportunities to increase resource use efficiency and enhance cooperation and policy coherence among the three sectors. The nexus perspective should help to promote interdisciplinary and mutually beneficial actions (Scott et al., 2011). It can contribute to meeting the future needs of the global population, particularly those who do not have access to safe drinking water and modern energy (Marsh, 2008). From this perspective, the identification of crucial interactions, conflicting demands, and potential synergies in the water, energy, and food nexus can be a powerful entry point for achieving sustainable adaptation.

2.2.1. Key principles of the nexus approach
The nexus approach can be summarized as follows:

- Understand the interdependence of subsystems within a system across space and time and focus on system efficiency rather than the productivity of individual sectors to provide integrated solutions that contribute to water, energy, and food policy objectives.
- Recognize the interdependence between water, energy, and food and promote economically rational decision making and efficient use of these resources in an environmentally responsible manner.
- Identify integrated policy solutions to minimize trade-offs and maximize synergies across sectors, and encourage mutually beneficial responses that enhance the potential for cooperation between and among all sectors, and public–private partnership at multiple scales.
- Ensure policy coherence and coordination across sectors and stakeholders to build synergies and generate co-benefits to produce more with less and contribute to long-term sustainability with limited environmental impact.
- Value the natural capital of land, water, energy, and ecosystems and encourage business to support the transition to sustainability.

2.3. Interfaces between the water, energy, and food nexus and adaptation strategies
The water, energy, and food nexus and adaptation responses are interlinked in numerous ways. The main elements of the nexus and links with adaptation are shown in Figure 1. It is critically important for policy makers to understand the linkages between the water, energy, and food nexus and adaptation when devising sustainable adaptation strategies.

3. Key challenges of food, water, and energy security and adaptation to climate change in HKH countries

South Asia is one of the most dynamic regions of the world in terms of population growth, economic progress, urbanization, and industrialization. The demographic, economic, and environmental changes in South Asia have increased the demand for resources, including food, water, and energy, and intensified their use, which has serious implications for adaptation strategies to ensure food, water, and energy security in the region. Within South Asia the HKH region is particularly vulnerable to climate change impact, with the vast majority of the population increasingly exposed to growing physical, social, and economic risks and vulnerability in the face of looming water, food, and energy security challenges.

3.1. Increasing population and declining agricultural land
The population of South Asia almost tripled, from 588 million to 1.6 billion, in the half century from the late 1950s to 2010, and is expected to reach 2.2 billion by 2025. With high population growth and industrial development, cereal demand is projected to rise to 476 million tonnes by 2025, compared to 241 million tonnes in 2000 (FAO, 2011). However, this higher agricultural production has to come from the same amount of land, or maybe even less land because of the competing uses related to

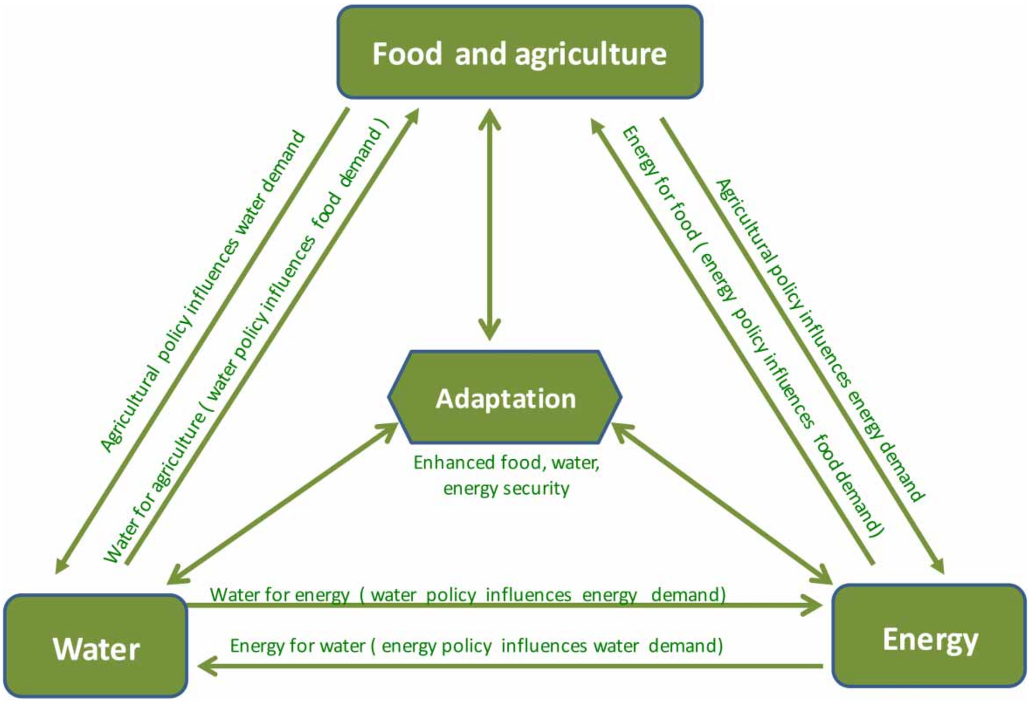

FIGURE 1 The interfaces among water, energy, food, and adaptation

population growth, urbanization, and industrialization. Economic growth will also influence this dynamic. For example, in China, which feeds 23% of the world's population with only 7% of the world's cultivated land area (Gu & Zhang, 2009), economic growth has resulted in a change in dietary preferences towards meat and other energy-intensive foods, further intensifying the demand for water, energy, and grain to feed livestock (Liu et al., 2007). The problems are compounded in the mountains of the HKH, where the land is steep and fragile, and farming and grazing have already been extended to marginal areas. Intensification of agriculture and land use can lead to rapid degradation of land resources and a reduction in production potential.

3.2. Stagnating or declining food production

Although total food production is increasing because of the additional area brought under irrigation, per capita food consumption has remained stagnant in many parts of South Asia in recent years (Alagh, 2010). Estimates indicate that climate change will result in a decrease in crop yields in South Asia by up to 30% by 2050 if there are no changes in the practices used (IPCC, 2007) and appropriate adaptation measures are not taken (Beddington et al., 2012). Low levels of consumption have contributed to persistent hunger and malnutrition (Dev & Sharma, 2010) in South Asia, which is home to more than 40% of the world's extreme poor (living on less than $1.25 a day) and 35% of the world's undernourished (Rasul, 2014).

3.3. Increasingly water- and energy-intensive food production in the face of water and energy scarcity

Around 39% of the cropland in South Asia is under irrigation, and irrigated land accounts for 60–80% of food production (Rasul, 2014). As a result, agriculture consumes about 90% of the water and 20% of the total energy used in the region. Water, once considered abundant, has become increasingly scarce. Per capita water availability in Pakistan, for example, dropped to close to 1000 m^3 per annum in 2010 from 5000 m^3 in 1951, while that in India is projected to drop to 1140 m^3 per annum by 2050 from 1986 m^3 in 1998 (Gupta & Deshpande, 2004). Water scarcity has also become a growing concern for food security in China (Liu et al., 2007). About three-fifths of the irrigation water in the region comes from groundwater (Shah, Gulati, Pullabhotla, Shreedhar, & Jain, 2009), with about 60% of the population in India and 65% in Pakistan relying on groundwater for irrigation (Qureshi, McCornick, Sarwar, & Sharma, 2010). India and China are already extracting groundwater 56% and 25% faster than it can be replenished, respectively. The increased extraction of groundwater has increased demand for energy and lowered the groundwater table in many parts of the HKH region, especially in the northwestern Himalayas. This has created a serious concern for the entire region, as the shortage of water and energy severely constrains not only agriculture, but also overall economic growth and human well-being.

3.4. Key challenges

The key features and challenges of food, water, and energy security, and their interlinkages in HKH countries are summarized in Table 2.

Despite the complex interdependency of food, water, and energy among competing uses, each country in the HKH region has put forward a NAPA to address the adverse impacts of climate change using a sectoral adaptation approach, with little or no attention being paid to a nexus-based systemwise adaptation approach to deal with the vulnerability to climatic and non-climatic changes. Considering that water, energy, and food are vital resources for poverty and vulnerability reduction, it is critically important to prioritize and devise an integrated adaptation option based on a nexus assessment that reduces vulnerability to both climate and non-climate changes.

4. Synergies and trade-offs in the water–energy–food nexus and adaptation strategies

As water, energy, and food are vital resources for poverty and vulnerability reduction, understanding the linkages among them is critical for adaptation planning. Understanding trade-offs and synergies or complementarities in the water, energy, and food nexus can provide new insights for developing effective adaptation strategies. Given the complex interplay of water, energy, and food demand and supply, numerous challenges and opportunities exist to minimize trade-offs and promote synergies to formulate effective adaptation options. The nexus approach provides a framework for addressing competition for resources and enhancing resource use efficiency. The goals and principles of the nexus approach and of climate change adaptation are closely linked and interconnected, as are the focus and strategies. Effective adaptation and nexus approaches share many common features (Table 3). Management of water, energy, and food security has an impact on adaptation, and the strategies and policies aimed at climate mitigation and adaptation have significant implications for nexus challenges.

TABLE 2 Key features and challenges of food, water, and energy security in South Asia

Key characteristics	Adaptation challenges	Interface among food, water, and energy resources, and adaptation to climate change
Food security		
Huge chronically undernourished population About half of the world's poor (46%) and 35% of the world's under-nourished live in South Asia	Provision of food, water, and energy to a large malnourished population without degrading the natural resource base and environment	To meet the nutritional needs of all, food production needs to double in the next 25 years
Burgeoning human population About 25% of the world's population (projected to reach 2.3 billion by 2050) lives in just 3% of the world's land area	To feed the growing population, agricultural production will have to increase by 70%, energy by 40%, and water by 57%	Increased pressure on land, water, and energy to meet the increased demand
Declining cropland Per capita arable land continually declining due to population growth, urbanization, and increasing bio-fuel cultivation to meet the energy demand	Limited options for growing more food grain by expanding crop area	Competing demand for land for food, bio-energy production, and ecosystem services
Intensive food production Food production becoming increasingly water- and energy-intensive	Adapting to the declining groundwater table	Agricultural growth is constrained due to shortage of energy and water
Changing food preferences towards meat The meat production process requires more energy and water	About 7 kg of grain equivalent energy is required to produce 1 kg of meat	Increased pressure on water to meet the food requirement
Sensitivity to climate change Food production is highly vulnerable to climate change due to rising temperatures, accelerated glacial melting, increased evapotranspiration, and erratic rainfall.	Uncertainty in water availability due to rapid glacier melt and changes in monsoon pattern in the Himalayas	Climate change is 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 is predicted to increase by 55% by 2030 compared to 2005	Providing access to safe drinking water in the face of increasing variability in the water supply	Water intensive adaptation practices leading to increased water pollution and water-borne diseases, high child mortality, poor human health
Upstream–downstream dependence on water High dependence of downstream communities on the upstream for water to grow food and generate hydropower	Need for enhanced upstream–downstream coordination and cooperation for sustainable development of HKH water resources	HKH rivers are the lifeline for dry season water for irrigation, hydropower, and major economic activities

Continued

TABLE 2 Continued

Key characteristics	Adaptation challenges	Interface among food, water, and energy resources, and adaptation to climate change
Increased dependence on groundwater for food production About 70–80% of agricultural production depends on groundwater irrigation	Adapting to declining water tables	Groundwater pumping for irrigation requires excessive energy, which further increases electricity demand
Energy security		
High energy poverty About 63% of the population without access to electricity; 65% use biomass for cooking	Providing adequate and reliable energy to a large population without increasing pollution	Growing demand for water and land for energy production
Under-utilized potential for hydropower and clean energy	Adaptation options are restricted	Energy diversification to meet the growing demands of food, water, and economic growth

While some adaptation measures such as water-use efficiency, renewable energy, and growing biofuels on wasteland might have positive implications for water, energy, and food resources, other measures for adaptation and mitigation such as extensive groundwater pumping, desalination plants, inter-basin transfers of water to deal with water scarcity, and growing biofuels to deal with fuel scarcity, may increase nexus challenges (Bazilian et al., 2011). For example, micro-irrigation technologies such as drip and sprinkler irrigation reduce water demand by increasing efficiency, but increase energy demand. Similarly, growing biofuels on wasteland can enhance the energy supply and reduce dependence on fossil fuels, but diverting cultivable land for biofuels can threaten food security and lead to social impacts in terms of higher food prices. Promoting large-scale bioenergy production is a prime example of a policy in which trade-offs have to be made between food security, biodiversity, and climate change (Scott, Kurian, & Wescoat, 2015). The higher costs of clean energy systems generally have to be weighed against social and economic benefits. These trade-offs are strongest in developing countries where a large section of the population do not have access to adequate food, nutrition, drinking water, and energy, as in the HKH region. Trade-offs may also arise between efficiency of resource use and equity of access. Policy makers have to make choices between food and energy, and efficiency and equity. Managing trade-offs across the three sectors of water, energy, and food is a daunting task and significant challenges remain. The following section provides some examples of promising approaches to managing trade-offs.

4.1. Promises of a nexus-oriented approach for sustainable adaptation: potential for synergy

Some sector-specific adaptation measures have the potential to provide synergistic ‘win–win’ opportunities to enhance climate mitigation or adaptation objectives across one or more of the other sectors in the nexus, while other measures may have negative impacts on mitigation or adaptation

TABLE 3 Complementarities and co-benefits from nexus-based adaptation

Key characteristic	Nexus approach	Climate change adaptation	Complementarities and co-benefits from nexus-based adaptation
Goal	Achieving water, energy, and food security objectives and sustaining resources through efficient use of available resources	Build resilience and enhance adaptive capacities against climate and other risks	Understanding adaptation to climate change is critical for addressing nexus challenges, and efficient use of resources is critical for effective adaptation
Core principles	Minimize resource waste and maximize economic efficiency, while accelerating the sustainable supply	Reduce vulnerability by managing climate risks and building response capacity	Since resource scarcity often increases people's vulnerability, the nexus approach may contribute to facilitating adaptation and vice versa
Main focus	Provide integrated solutions at multiple scales	Minimize shock, risks, and vulnerability and address impacts and risks associated with climate change	Understanding vulnerability to climate change is crucial for assessing nexus challenges; equally, integrated nexus solutions can contribute to reducing vulnerability and poverty
Broad strategies	Policy integration, harmonization, and governance to build synergies and generate co-benefits across sectors by engaging multiple stakeholders, public–private partnership	Addressing the drivers of vulnerability to climate change in specific sectors through building adaptive capacity and resilience	Cross-sectoral nexus analysis identifies trade-offs and synergies and integrates policy implementation; diversification increases resilience; nexus strategy is critical for integration of climate adaptation and mitigation, while broadening the scope to address poverty–vulnerability linkages

potential in other sectors (Table 4). Increasing the efficiency of freshwater use as an adaptation measure has the potential for synergy across sectors, as it increases the availability of water for energy, agriculture, and industry while reducing emissions per capita. For example, the Chinese government has been able to meet the increased demand for water in industry by increasing irrigation efficiency. Agricultural water use has been reduced by 20% in northern China in comparison to 1990, while food production increased by 30%,which has freed up water for industrial and urban users and helped to meet the increasing water demand for industry and economic growth (Doczi, Calow, & d'Alançon, 2014; Shen, 2014).

Benefit transfer has the potential to manage the nexus challenges. In the 1990s in Costa Rica, intensive agriculture and livestock raising to meet the growing demand for food accelerated soil erosion and led to increased sedimentation in hydropower reservoirs, which reduced reservoir capacity and power generation. To address this problem, the government established a 'National Fund for Forest Financing'. The hydropower companies contributed to the Fund, which paid upstream communities for tree plantation and other conservation programmes, thus reducing soil erosion and helping minimize

TABLE 4 Synergies between the climate change adaptation and nexus approaches

Sector-specific adaptation measures		Positive implications for the sector	Potential for synergies across the nexus
Water	Increasing water use efficiency	Reduces water use per capita	Increased availability of water for energy and agriculture
	Switching from use of freshwater to wastewater	Reduces freshwater use per capita	Increased availability of freshwater for food, energy, and other uses
	Switching from wet to dry cooling at thermoelectric power plants	Reduces water use and associated thermal pollution	Increased availability of water for energy and agriculture
	Desalinization	Increase in brackish and freshwater supplies	Increased availability of freshwater and overall water supply for energy, agriculture, and other uses
	New storage and conveyance of water to serve new demands	Increased water supplies to meet demand	Increased availability of freshwater and overall water supply for energy, agriculture, and other uses
	Watershed management	Increased water supplies to meet demand	Increased water supply for energy and other uses, improved water quality, reduction in flood potential
Land	Switching to drought-tolerant crops	Increased/maintained crop yield in drought areas	Reduced water demand
	Using waste or marginal land for biofuels	Increase in renewable energy	Reduced pressure on non-renewable energy as some fossil fuels are replaced with biofuels
Energy	Increasing transmission capacity	Reduced economic and social impacts	Potential for reduced emissions if new transmission and wind/solar power supplied to the grid
	Increasing renewable energy, e.g. solar, wind, biogas, bioenergy	Increased clean energy and reduced pressure on energy	Reduced GHG emissions, reduced water demand for cooling, thermal power

Source: adapted from Skaggs, Hibbard, Janetos, and Rice (2012).

the trade-offs between food and energy (Blackman & Woodward, 2010) Similarly, in China, downstream industries on the Yellow River invested in agricultural water efficiency technologies in upstream Inner Mongolia to relieve the pressure on water resources and free up water to help meet the downstream demand (Doczi et al., 2014).

The integrated governance mechanism has been able to reduce the tension between the food, water, and energy systems in Sacramento–San Joaquin Delta, California (Gray, Thompson, Hanak, Lund, & Mount, 2013). The Sacramento–San Joaquin Delta provides drinking water to 27 million people, irrigation water for 3 million acres of land, and is a source of fish and other nutrition. However, the competing demands for water for irrigation, fisheries, and industry have led to ecological degradation. In 2009, the government established the Delta Stewardship Council to reverse the trend. The Council established a framework and governance structure to achieve the twin goals of providing a more reliable water supply to California and restoring and enhancing the Delta ecosystem. This new mechanism could be potentially applied in other river basins to address nexus challenges.

The engagement of business community has contributed to decoupling resource use and minimizing trade-offs between water and food. For example, faced by a shortage of water due to drought in Australia, the Coca Cola company invested in water-use efficiency both in their operation and in the management of watershed and springs. This has considerably reduced the water required per unit of beverage production, and has improved the quality of watershed and springs and ensured a sustainable flow of water (Gerholdt & Pandya, no date). Promoting strong public–private partnerships thus offers an innovative solution for managing nexus challenges.

5. Towards a nexus-based framework for sustainable adaptation

Developing countries face a difficult challenge in meeting the growing demands of the population for food, water, and energy, and the problem is further compounded by climate change. Understanding the role of the water, energy, and food nexus in adaptation will be key to designing effective adaptation policies and strategies. The nexus approach is a system-wide approach that recognizes the inherent interdependencies of the food, water, and energy sectors for resource use and seeks to optimize the trade-offs and synergies, thus enabling adaptation responses to be made more effective and sustainable. The nexus outlook can also help to stimulate critical thinking on aligning the sustainable development goals (SDGs) with planetary boundaries in the post-2015 development agenda.

The complex interplay of food, energy, and water demand and supply requires a holistic approach and institutional mechanisms to coordinate the actions and strengthen complementarities and synergies among the three sectors of water, energy, and food. In most countries in the HKH region, this coordination would be the responsibility of the national planning commissions. The reasons why such coordination remains elusive still need to be analysed, but our discussions with a few senior officials in Bangladesh and Nepal indicate that planning commissions have multiple functions, with the primary focus on supporting ministries to achieve planned growth and sectoral goals. Insufficient attention has been given to cross-sectoral issues, particularly the harmonization of sectoral goals and systemization of decision making, taking into account cross-sectoral dimensions. Moreover, planning commissions have little control over the ministries or budgetary resource allocation. It is therefore critical to strengthen the nexus perspective in national planning and strengthen the capacity for diagnosing interlinkages among sectors and bringing them into planning decisions. The nexus approach may help in the systemization of planning and decision making at the national level to support sustainable adaptation by maximizing synergies and minimizing trade-offs in resource use, and enhancing policy coherence across the three sectors.

To move from a sectoral approach to a holistic approach, an appropriate framework is required. Although the development of a detailed framework is beyond the scope of this article, a generic framework for a nexus-based approach to sustainable adaptation is outlined here (Figure 2). The framework is intended to stimulate critical thinking rather than provide definitive answers. Area A in the Venn diagram represents the situation of an integrated nexus-based response strategy for sustainable adaptation to ensure the security of all three sectors. The central area represents the core principles of a nexus smart policy and the associated outcomes that underpin the three sustainability dimensions:

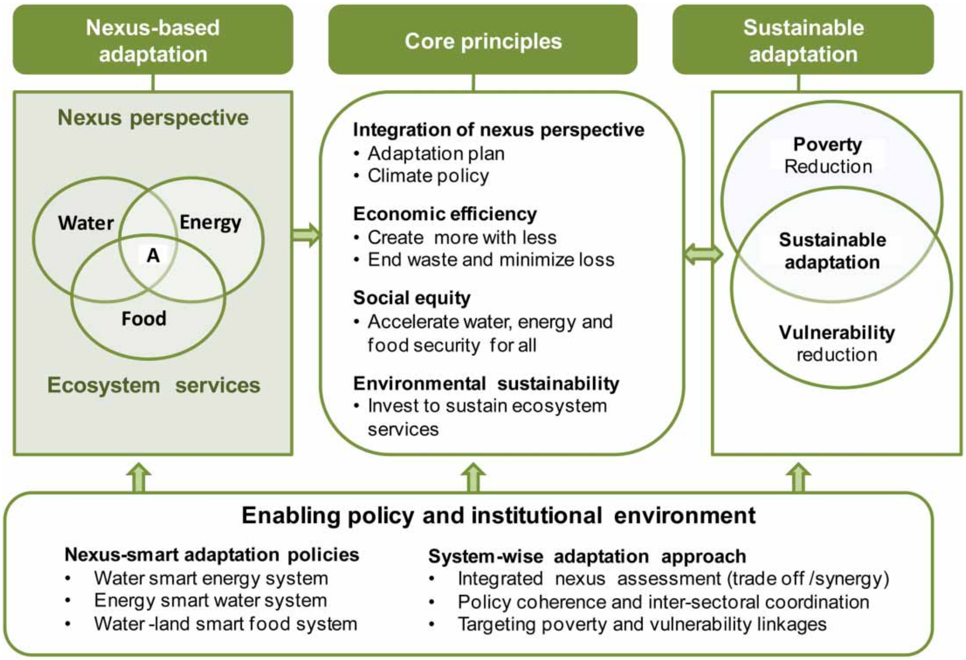

FIGURE 2 Outline for a nexus-based adaptation framework

economic (increasing resource efficiency), social (accelerating access for all), and environmental (investing to sustain ecosystem services). This means that we should devise a climate smart adaptation policy that not only improves the efficiency of resource use among the nexus sectors, but also takes a broader view of the impact of resource use on the overall environment and societal well-being. Finally, the third area stresses the need to target the vulnerability–poverty linkages (overlap between poverty eradication and vulnerability reduction) to reduce poverty and vulnerability concurrently, rather than treating them separately, in order to ensure that adaptation solutions are sustainable. All three areas must be underpinned by an enabling environment.

Since the adaptive capacity of those affected by climate change ultimately depends on their access to poverty reducing opportunities, adaptation plans can only be effective if they are built into the wider development agenda. This is necessary to ensure that adaptation policies do not work counter to development efforts – so-called ‘maladaptation’. The framework illustrates the need to understand how the context of vulnerability to both climate and non-climate change influences the development of poverty and how people adjust their adaptation strategies, before devising a nexus-based response strategy. It stresses the need to improve cross-sector and cross-border cooperation and coherence of efforts to properly tackle the nexus-based adaptation challenge. The following are some broad recommendations (Figure 2):

- *Integrate the nexus perspective into adaptation plans and the adaptation perspective into development plans for better policy integration*. For effective integration, it is critical to recognize the importance of the nexus perspective and to integrate multiple policy objectives and increase stakeholder collaboration in sustainable adaptation and development planning and decision making.

- *Deepen the nexus knowledge base and internalize it into development and adaptation plans*. Knowledge and understanding of the interlinkages between the nexus perspective and adaptation plans and responses are limited, so deepening the nexus knowledge base and developing mechanisms to strengthen institutions and internalize this knowledge in the planning process through nexus-based assessment and prioritization will be critical for effective adaptation.
- *Promote a system-wise adaptation approach*. Move from a sectoral to a trans-sectoral approach so that different adaptation responses and measures support each other, synergy is enhanced, and trade-offs are minimized.
- *Promote win–win options for nexus security and adaptation to climate change*. Enhance the efficiency and productivity of resource use and increase multiple uses of resources through economic incentives, governance, institutional and policy coherence, and the promotion of public–private partnerships to increase the benefit from productive ecosystems.
- *Create and support an enabling environment*. Strengthen policy integration between nexus and adaptation mechanisms across sectors at different scales and among the major actors (public–private–civil society partnerships) and strengthen institutional capacity for coordinating the water, energy, and food nexus and adaptation in a holistic way.
- *Invest in nexus smart infrastructure, multifunctional ecosystems, and innovative technologies and institutions*. Provide policy and institutional support for attracting investment in green infrastructure and design mechanisms to internalize externalities (environmental and social costs) into decision making by introducing appropriate incentives, regulations, and payments for ecosystem services.

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