Water Policy 10 Supplement 1 (2008) 23–36

Water–food–energy–environment synergies and tradeoffs: major issues and case studies

Peter G. McCornick[a,*], Seleshi B. Awulachew[b] and Michael Abebe[c]

[a]International Water Management Institute, P.O. Box 2075, Colombo, Sri Lanka.
[*]Corresponding author. E-mail: P.McCornick@cgiar.org

[b]International Water Management Institute, PO Box 5689, East Africa Office, Addis Ababa, Ethiopia

[c]Ministry of Water Resources, Government of Ethiopia, PO Box 17598, Addis Ababa, Ethiopia

Received 8 July 2007; accepted in revised form 2 September 2007

Abstract

The already complex interrelationships between water, food, energy and the environment are facing both challenges and opportunities. Rising fuel costs and increasing concerns over the effects of climate change are reinvigorating policymakers' interest in renewable energy sources such as hydropower and bio-energy—both from biofuels as well as biomass. Development of any of these sources has the potential to generate positive economic and environmental benefits, yet, at the same time, they can cause negative food and equity impacts. This obviously entails major tradeoffs between the food, energy and environmental goals of water and energy development, allocation and management. Using both a brief global overview as well as a closer review of four case studies from India, Ethiopia, Jordon and the USA, this paper tries to (i) a present the nature of the tradeoffs under different hydrological, energy, agricultural and environmental contexts and (ii) provide some anecdotal evidence and illustrative cases for the available policy options for minimizing conflicts but maximizing synergies between water, energy, food and environment.

Keywords: Biofuels; Energy; Environment; Ethiopia; Food; Hydropower; India; Jordan; Policy tradeoffs; USA

1. Introduction

The upward trend in energy costs and the worldwide concern over climate change have reinvigorated interest in alternative energy sources, including bio-energy and, more specifically, biofuels. Notably, this pursuit of increasing the share of biofuels and other bio-energy sources in the global energy supply is

doi: 10.2166/wp.2008.050

occurring within the broad context of complex inter-linkages between water, energy, food and the environment as well as their economic, social and ecological implications. Obviously, this new energy pursuit is likely to increase the stress on existing water resources and their current patterns of inter- and intra-sectoral water allocation. This stress is particularly serious in parts of Asia that are already water short or have difficulty in meeting existing water demand, and also in sub-Saharan Africa which is known for increasing population coupled with under-investment in water infrastructure. As a result, the water sector in these areas is likely to face major conflicts between its energy and environmental goals on the one hand and food and livelihood goals on the other. The issue of how to resolve these conflicts with acceptable tradeoffs is going to be, therefore, a major policy concern in the Asian and African regions in particular and other developing regions in general.

This paper is an attempt to address this policy issue based on both a general overview of the functional linkages between water, energy, food and the environment as well as a brief review of four case studies providing country and basin-specific experiences in managing the synergies and conflicts observed in one or more facets of these linkages. The four case studies come from Ethiopia, India, Jordan and the USA. The specific objectives of the paper are (i) to present a brief analytical overview of different facets of the water–energy–food–environment linkages and their economic, social and environmental implications, (ii) to describe the nature of the actual and potential conflicts and tradeoffs in different facets of the linkages as evident from each of the four case studies and (iii) to provide some anecdotal evidence for the available policy options for minimizing conflicts but maximizing synergies between water, energy, food and environment.

A general overview of the water–energy–food–environment interface is presented to set out the overall approach and scope of the paper and to put the issues in context and serve as the background for the case studies. Although the water–energy–food–environment interface is in reality vast and complex, for analytical convenience and focused analysis, only a few key facets of this interface are selected for illustration in each of the four case studies. They are water–energy–environment synergies (Ethiopia with a focus on the Awash Basin), water–energy–environment–food linkages (India with a focus on the Krishna Basin), energy–water–economy linkages (Jordan with a focus on the Jordan Valley) and energy–environment conflicts (the Snake River Basin in the USA). For each case study, the relevant national level problems and issues are discussed to provide context for the basin-specific experiences.

2. Water–energy–food–environment equation: layers and issues

Before dealing with few specific facets of the water–energy–food–environment interface in the context of the select basins and countries in greater detail, it will be instructive first to highlight some of the issues evident in different layers of this complex interface, particularly from a generic and global perspective. Taking first the water–energy part of the equation, water plays an important role in producing renewable energy sources both directly in the form of hydropower and indirectly in the form of biomass. At present, the share of renewable energy sources in total global energy supply is only about 13%. Of this, biomass accounts for the major share (10%) followed by hydropower (2.2%). Although the share of renewable energy sources including hydropower is only modest at present, many countries aim to increase this significantly. For instance, in China, where renewable sources account for only 8% of the present energy supply, the government aims to double this by 2020, particularly through the development of additional hydropower capacity. Much more important is the case of Africa, where there is tremendous untapped economically and technical feasible potential for hydropower development. While the total hydropower potential of the continent is estimated to be about 1,750 terrawatt-hour (TWh)/year, current use is just about 5% of this (BMZ, 2007). However, among other things concerns over the environmental and social impact of the required dams has constrained the availability of capital.

Particularly in the African context, besides its energy role, hydropower development also has the potential not only to contribute to tremendous economic, livelihood and food benefits but also to promote natural resources and environmental conservation. As will be demonstrated by the case of Ethiopia, in a condition where the total energy supply is dominated by biomass, the increasing share of hydropower could considerably reduce the pressure on local natural resources and forests. Water is also now becoming a significant factor in the development of yet another clean energy source, that is, biofuels. However, since the water use for biofuel is likely to affect existing allocations both across sectors as well as within agriculture, serious tradeoffs are involved between the energy, environment, food and livelihood roles of water, especially in the context of the developing countries of Asia and Africa. These tradeoffs can be resolved by judicious planning in the development of biofuel crops. For instance, if biofuel crops such as Jatropha and sweet sorghum are grown under rainfed conditions, their pressure on existing water allocation and cropping pattern may not be as much as expected. In contrast, biofuel crops can contribute to a more economically beneficial land use and better income and livelihood options for small and marginal farmers. Although biofuel production in rainfed regions is economically beneficial and has no pressure on existing water allocation, they do use "green water" more intensively than otherwise with the potential to disturb the normal process of "blue water" generation in the long-run. They are also likely to displace food production in rainfed regions. Moreover, unlike rainfed biofuels, sugarcane is another biofuel crop, which generally requires irrigation and can, therefore, divert water from food crops as well as other downstream uses, including hydropower and the environment.

Apart from the significant economic tradeoffs between different biofuel sources, there are also major policy tradeoffs between different energy production mechanisms (biofuels, hydropower, biomass and fossil fuels) themselves because of their diverse effects on energy, food, livelihood and the environment. Such tradeoffs also exist between the two water-based energy production mechanisms because of their differential stress on water and effects on environment. The extensive use of biomass in regions such as Africa is a major cause of watershed deterioration and the resultant environmental damage and hydrological disturbance. That said, the water-energy linkage goes beyond the hydropower and biofuels connection to cover the role of energy in groundwater withdrawal, surface water lifting and pressurization as well. The livelihood and resource implications of energy supply on groundwater are brought out clearly by the case studies of South Asia and China reported elsewhere in this special issue. But the economic and resource effects of energy used in lifting/moving surface water to upland urban and agricultural areas are equally serious. While this problem is present in most countries, as will be shown later in this paper, its severity is stark in countries like Jordan, where water supply is dependent on energy rather than producing it.

The significant and most sensitive component of the water–energy–food–environment equation relates to the food and livelihood linkages of water, especially considering how these linkages are affected by energy and environmental roles. Understandably, the issue is particularly serious for the water scarce developing countries of Asia and Africa where the food and livelihood roles of water have to be balanced with the emerging demand of water for energy and environmental needs. Considering the water needs for food and livelihoods, the Comprehensive Assessment on Water

Management in Agriculture (CA, 2007) has concluded that the world will be able to feed itself now and in the future, but this will require the use of at least 20% more water resources[1]. Besides the potential effects of biofuel crops on crop pattern and food production, the increasing urban and environmental demand for water is also posing a serious threat to food production. In addition to the agricultural and food implications of environmental water needs, there is also the age-old conflict between environment and dam development. This conflict is often viewed from the perspective of land submergence and forest loss, but there are also other contexts where environmental concerns such as fish migration and biodiversity preservation remain a major constraint for both water and energy development. This is actually the case in the Snake River in the USA, where the need to secure the migration of wild salmon is at odds with several existing dams involved in producing hydropower. The environmental benefits of clean energy from hydropower and biofuels should be placed and evaluated in this larger context.

3. Analytical framework and case study setting

Admittedly, the water–energy–food–environment interface is vast and complex with many layers with different sets of policy tradeoff issues. While the discussion in the previous section is more generic, there is need to see more closely some of these layers in the practical context of specific countries and river basins. To perform this task in a more analytically focused manner, we select only four key layers or facets of the larger process of interaction between water, energy, food and environment. They are (i) the water–energy–environment synergies, (ii) the water–energy–environment conflicts, (iii) the energy–water–economy linkages and (iv) the energy–environment conflicts. These four aspects will be illustrated respectively by case studies from Ethiopia (with a focus on the Awash Basin), India (with a focus on the Krishna Basin), Jordan (with a focus on the Jordan Valley and Dead Sea) and the USA (with a focus on the Snake River Basin). As these countries differ vastly in terms of their resource supply, economic conditions and decision-making environment, they provide an interesting context for illustrating some of the major issues and tradeoffs involved in the four selected facets of the interactions.

Table 1 provides a few key parameters for water and energy use in the four sample countries. The USA produces and consumes significantly more energy per capita than many other countries in the world. Of the four countries, USA consumption is nearly eight times more than that of Jordan, which has the next highest energy per capita. Ethiopia, in contrast, has meager energy use most of which is based on biomass typically in the form of dung, crop residue and fuel wood. Notably, although biomass has only a marginal share in the USA, in absolute terms, biomass-based energy is more than double the total energy in Ethiopia. Obviously, the USA is also rich in water resources with a very high freshwater per capita. While Ethiopia is often referred to as the water tower of Africa, its water per capita is lower than both the USA and India. Jordan, by contrast, is extremely short of both water and energy and, unlike the others, water is a net user of energy (mostly oil-based). Although its economic conditions are rather unusual, the relationship between water and energy under such conditions will be still insightful. Notably, despite the variations in water availability, in all four cases, hydropower represents only a tiny share of about 1% or less.

[1] The additional water demand of agriculture is projected even to even double the present use (even without considering biofuels), if the necessary political will is not feasible to break away from the "business-as-usual" scenario (Fraiture *et al*., 2008).

Table 1. Key parameters for water and energy use in the sample countries[a].

Particulars	Ethiopia	India	Jordan	USA
Water per capita (m^3/capita)	1,539	1,694	150	10,135
Energy per capita (kgoe)	278	512	1,022	7,795
Total energy (kgoe)[b]	20,509	548,661	5,533	2,280,881
Biomass (kgoe)[b]	18,709	211,201	3	47,341
Biomass (%)	91.20	38.50	0.10	2.10
Hydro (%)	1.00	1.20	0.10	1.10
Oil & petroleum (%)	7.80	22.60	93.30	40.40

Source: World Resources Institute (2007).
[a] Data pertain to 2003.
[b] 'Kgoe' denotes kilograms of oil equivalent.

4. Water–energy–environment synergies: the case of Ethiopia

Ethiopia is one of the largest countries of Africa with an area of 1.13 million km^2 and a population of over 80 million. The country has 12 basins with a total surface water potential of 122 km^3 and groundwater potential of 2.6 km^3 (Ministry of Water Resources, 2002). Despite an overall water abundance, water insecurity remains a major problem both for the population and agriculture. Indeed, most of the problems of the country—ranging from poor farm productivity and high poverty levels to the low level of overall economic growth—can be traced to under-investment in water and energy infrastructure. Without this investment, Ethiopia cannot build the basic platform necessary to absorb the shocks of periodic droughts and to enhance long-term economic growth (World Bank, 2006).

As shown already in Table 1, Ethiopia not only has a very low energy per capita but also most of this is in the form of biomass[2]. Notably, such a low per capita energy with an extreme dependence on biomass occurs despite the vast energy potential in the country. The economically exploitable hydropower potential is reckoned at 30,000 MW whereas actually developed capacity so far is only 667 MW (Beyene & Abebe, 2006). As a result, only 17% of the population, mainly in urban areas, has access to electricity. Low coverage and poor quality of power also cause heavy economic losses. For instance, during the drought of 2002/03, it is estimated that each day of lost service reduced the GDP for that day by up to 15% (World Bank, 2006). Equally serious are also the environmental consequences of the present energy composition. Owing to intensive biomass exploitation, it is reported that less than 3% of the natural forest remains at present. Siltation from land degradations has led to the storage loss of Koka reservoir (World Bank, 2006) and, to date, more than 30% of the total volume has been lost to sedimentation (Michael, 2004). Degraded catchments, on the other hand, have exacerbated the risk for extreme events (droughts and floods) and biodiversity loss (Taddesse *et al*., 2004).

Both from the energy and environmental perspective, the major development challenge in Ethiopia is the rapid development of clean energy sources. The economic and environmental consequences of the current pattern of energy use in the country suggests the potential synergies between water and energy development and environmental and livelihood protection. There are now notable efforts to realize such

[2] The composition of energy consumption is as follows: 73% of the energy comes from woody biomass, 16% from non-woody biomass (dung and crop residue), bagasse 0.4%, hydrocarbons 10% and hydropower at less than 1% (Halcrow & Partners & Metaferia Consulting Engineers, 2006).

synergies. The government has recently launched the Universal Electricity and Access Program and started three projects with a combined capacity of 1,180 MW, effectively increasing the national generating capacity by 150% to a total of 1971 MW on completion[3]. There are also ambitious plans to develop hydropower (and other energy sources) both to meet these domestic needs and to export electricity to Djibouti, Kenya, Sudan and Egypt (World Bank, 2006). Besides efforts to develop other energy sources such as natural gas, geothermal and coal and shale, there are also initiatives to promote rainfed biofuel production in over 200,000 ha[4].

Against the potential for synergies and tradeoffs at the national level, let us also see the related conditions at the basin level taking the Awash Basin (see Figure 1) as an example case. This basin has an area of 110,000 km^2 and has population of around 10.5 million. It has a mean annual surface water resource of 4,900 million m^3, of which 2,250 million m^3 is diverted for irrigation (Taddesse *et al*., 2004). The basin is the most intensively utilized basins of Ethiopia owing to its relative abundance of water and land resources, strategic location with access roads and absence of transboundary issues. As with much of the highlands of Ethiopia, the basin has mixed crop–livestock farming in its upper reach, a mix of crop, livestock and pastoral production in its middle section and a nomadic pastoral system with some irrigation in its lower segment. The basin has an irrigable land area in the range of 150,000–175,000 ha excluding the additional potential for medium and small-scale irrigation in the highlands and in isolated riverine areas (Halcrow & Partners, 1989). This basin is also important for hydropower generation with a total of 110 MW at three stations, representing 14% of the national capacity.

Since available water is not sufficient to meet the full needs of irrigation and power generation, the basin faces major issues on the energy, livelihood and food fronts. Water use and livelihood issues are particularly serious. In an effort to benefit the local communities who lost their access to farm and grazing land when the system was first developed, the government in the 1990s transferred the ownership of 11 schemes with a total irrigated area of nearly 25,000 ha (Halcrow & Partners & Metaferia Consulting Engineer, 2006). But, owing to water shortage, technical capacity or other problems, the communities, in most cases, have either abandoned the schemes or leased them to investors for cotton and other crops.

There are now additional complications for the ongoing extensive replacement of cotton by sugarcane and irrigation expansion in sugarcane areas[5]. The expansion of sugarcane has two major effects on the water and livelihood fronts. First is the increase in the consumptive use of water and its effects on the water availability for other food crops. Second is the loss of farm and non-farm employment and livelihoods owing to the loss of cotton production. Apart from the problems for Ethiopia's nascent textile industry, declining cotton areas also reduce the grazing options for the pastoralists. Expanding sugarcane

[3] These projects are: Tekeze, Gilgel Gibe-II and Tana Beles. In addition, there are six committed sites with an aggregate capacity of 3,281 MW and a further seven sites with a combined capacity of 6,693 MW under pre-feasibility and feasibility study stages, respectively. Notably, four of the latter are in the Nile Basin and supported by Nile Basin Initiative regional projects.

[4] The include the 10,500 ha offered by the Ormoia regional estates to a German investor (Biopact, 2007) and the 80,000 ha set aside by the state government of Benshangul Gumuz for another investor. More areas are also planned for similar investments in other western areas and in the south of the country, where rainfall levels are relatively high.

[5] For instance, the new irrigation developments—either ongoing or planned—in the sugarcane estates of Wonji-Shoa, Metahara, Kessem and Tendaho are expected to add 18,000, 12,000, 20,000 and 60,000 ha of irrigation, respectively.

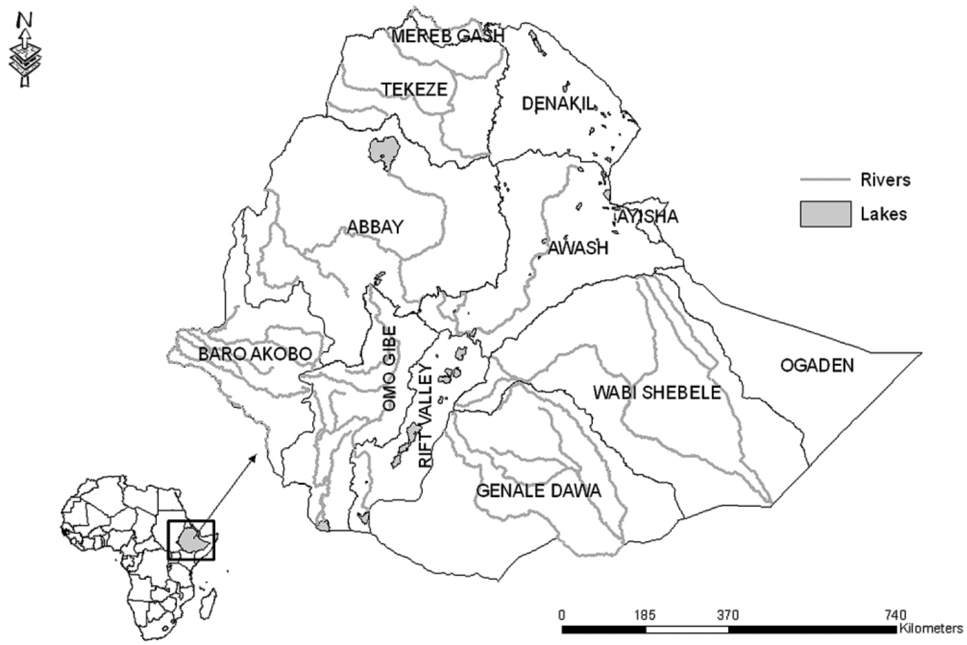

Fig. 1. Major river basins of Ethiopia.

production, however, contributes to energy in the form of both bagasse and ethanol[6]. Sugar estates are net generators of power, but sugarcane expansion affects food and livelihood. One option to resolve the conflict is to expand small scale irrigation and water supply systems from surface and groundwater sources in the basin.

5. Water–energy–environmental conflicts: the case of India

In contrast to the Ethiopian case, the water–energy–environmental interaction in the case of India presents a picture of both serious conflicts as well as potential synergies. This can only be expected in a country with a vast size and varied resource potential[7]. India has enough water and produces enough food at present. Irrigation development played a major role in achieving food security and, at present, irrigated agriculture accounts for about 66% of total grain production. But water scarcity and allocation conflicts, which are becoming serious now, can be a major future constraint on farm production and rural livelihoods, especially in basins where water is already fully allocated. This is also true in the groundwater regions as well as in the rainfed regions which are now being upgraded with various forms

[6] In fact, many sugarcane estates located in the Blue Nile area generate their own electricity using bagasse. In some cases, ethanol is produced for developing K50—a blend of 50% kerosene and 50% ethanol—which is used in factories and households (IWMI, 2007).

[7] Of the 19 major basins in India, the per capita renewable freshwater supply varies from 240 m^3 in the Sabarmati Basin in the north-west to 17,000 m^3 in the Brahmaputra Basin in the north east (Amarasinghe *et al*., 2005). Similarly, per capital water withdrawals also range from 243 m^3 in the north east to 1,700 m^3 in the Indus basin (Amarasinghe *et al*., 2005).

of small scale irrigation and water harvesting (Velpuri *et al*., 2007). As seen in the Ethiopian case, while the expansion of sugarcane area in irrigated regions and other biofuel crops in rainfed areas could contribute to energy production and farm income, at the same time they present some serious consequences for water use and food production.

For a dynamic and fast growing country like India with relatively low oil reserves and a heavy dependence on oil importation, energy is also a major issue owing to the increasing demand and heavy cost of oil imports. While there is a major thrust in expanding hydropower capacity and developing new sources such as nuclear and biofuels, economic, political and environmental concerns remain as major constraints. Currently, at the national level, 40% of the rural population lacks access to power and to meet the full power need of the country, the government estimates an additional requirement of 100,000 MW of capacity by 2012 (World Bank, 2007). Hydropower now accounts for 22 GW of installed capacity, which represents only 30% of the total hydropower potential of the country (Ministry of Renewable Energy, 2007). The exploitation of the full potential is constrained not only by controversy over the ecological damage and displacement of people but also by investment and institutional bottlenecks (Briscoe & Malik, 2006). The role of hydropower and diesel supply for groundwater withdrawal and policy issues such as energy supply and pricing add, therefore, another important dimension to the water–energy linkages in India.

The Krishna Basin (see Figure 2)[8], an inter-state river system with three riparian states, that is Andhra Pradesh, Karnataka and Maharashtra, located in the southern part of India, illustrates both the challenges and options of a basin where water resources are nearing full allocation. The basin has an area of 259,000 km^2 with a population of 70 million of which 68% are rural based. It has a per capita renewable water availability of 1,130 m^3, which is lower than the all-India figure. There are 24 large to medium dams with a total installed hydropower capacity of about 3,000 MW[9]. Since all the major dams in the basin also serve irrigation, there is a potential for conflict between irrigation and hydropower. Since water releases for power generation are made to coincide with irrigation needs, such conflicts are generally absent in the lower part of the basin (Venot *et al*., 2007). However, in the upper part, there are cases of conflict as dams are often drawn down to meet hydropower with less carry over for agriculture (Guar *et al*., 2007).

Even these limited tensions in terms of water release need to be looked at from the larger context of the synergy between agriculture and hydropower as more than half the hydropower is used for groundwater pumping for agriculture (Venot *et al*., 2007). But, the major problem that affects both irrigation and hydropower relates to the long-term decline and temporal variation in the total water supply of the basin[10]. Besides, the growth of small dams and tanks for irrigation, groundwater recharge and domestic purposes also squeeze the water that will be available for power generation[11]. This means

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[8] This figure is adapted from Biggs *et al*. (2007).

[9] Only a few of the dams are very important for hydropower generation. For instance, two dams, i.e. Sri Sailam and Nagarjuna, located in the lower part of the basin and managed by the state of Andhra Pradesh account for 88% the state's hydropower and 16% of the state's total power supply.

[10] For instance, flow into the lower Krishna basin has almost halved over the past 50 years (i.e. 38 km^3 per annum during 1996–2000). During the recent drought (2001–04), power generation was at an all time low owing to lack of water in reservoirs.

[11] There are over 6,100 tanks and other small storages in the basin, which irrigate about the same area as the medium to large scale irrigation schemes in the basin (Velpuri *et al*., 2007). But, since this storage reduces the water flow to downstream reservoirs, it is no longer available for hydropower generation.

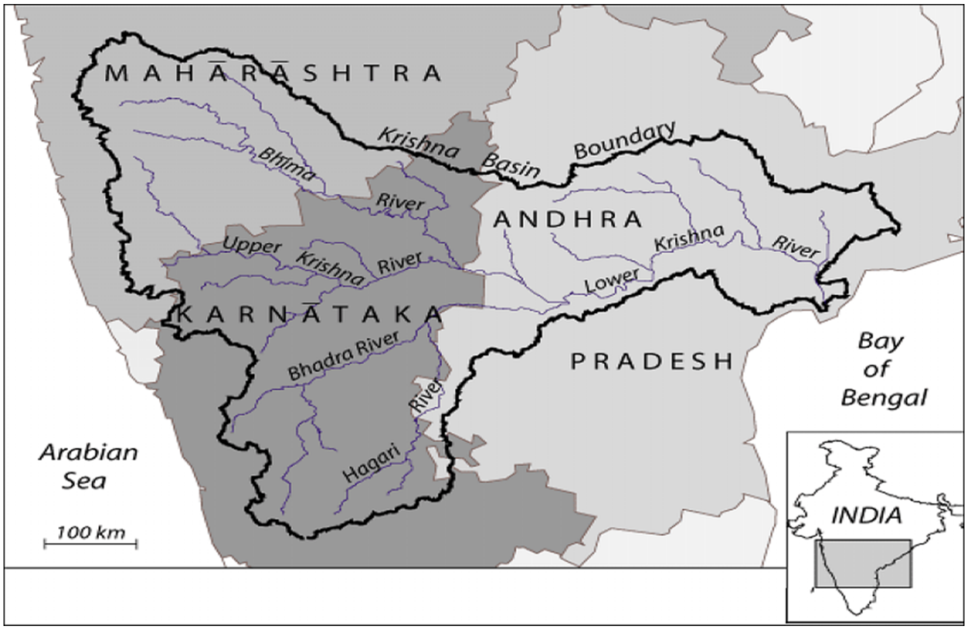

Fig. 2. The Krishna Basin, India.

that irrigation and domestic uses have an implicit conflict with power generation and this fact has to be taken into account along with the synergy between hydropower and groundwater use.

Another issue of increasing concern in the basin is the effect of expanding sugarcane cultivation on water use, energy supply and crop pattern. In fact, the three riparian states of the basin are among the top six sugar producing states in India. Although India is the world's second largest producer of sugar next to Brazil, it is not always able to produce enough to meet domestic demand. Given this fact, plus the highly water productive (in US dollars per cubic meter) nature of the crop (Gaur *et al*., 2007), the economic importance of sugarcane is understandable. Besides the pressure this crop places on the already stressed basin, its perennial nature limits the extent to which both the basin and crop pattern can adjust to changing water supplies in a drought (Gaur *et al*., 2007). Most sugarcane cultivation is presently based on groundwater, but when it expands into the surface irrigated areas, its water and food implications will be still more serious. Despite these negative effects, sugarcane can significantly contribute to energy through ethanol production. But this energy potential is only just being explored. From an environmental angle, major conflicts are emerging between economic water withdrawal and environmental needs[12]. While there remains an opportunity to improve the overall productivity of water used in the basin and thereby provide allocations for the environment, increasing demand from all sectors, including biofuels, will make this increasingly difficult to achieve.

[12] For instance, the environmental flow requirements of the basin are estimated to be in the range of 6.5–14 km^3/year (Smakhtin & Anputhas, 2007). But, owing to increasing water withdrawals and declining water supply, environmental water needs are rarely met, especially during drought periods.

6. Energy–water–economy linkages: the case of Jordan

Jordan is at the other end of the water–energy spectrum, where water is extremely scarce and energy use is intensive. The country relies on the limited water from the Jordan River and a few other river systems (see Figure 3). Energy is needed for lifting, moving and treating surface water, especially from the Jordan Valley. Since almost all of this energy is from imported oil, there are major consequences extending far beyond the water sector. With few opportunities for alternative sources of both water and energy, energy imports come at significant cost, both financially and also from a foreign policy perspective (Scott *et al*., 2003). Thus, the water–energy challenge in Jordan relates to both securing energy for water lifting, conveying and treatment and to meeting the increasing water needs of an expanding population, including the mass influx of refugees. Energy and water pricing is another major issue. Even prior to the recent increases in energy prices, it is estimated that Jordan used 25% of its electricity, primarily generated from oil imports, to manage its limited water resources (Scott *et al*., 2003).

The primary water source for Amman, the capital city and major population center, is the Yarmook River in the Jordan Valley, which is pumped from the King Abdullah canal (KAC) 1300 m up to the city (see Figure 3). The system was upgraded in the late 1990s so that up to 80 million m^3 per year could be transferred to the city, but at the moment, the actual transfers are only around 50 million m^3. Since Amman remains water short, a new source of water was developed at Zara-Ma'in near the Dead Sea to help address this. It is expected to provide an additional 45 million m^3 per annum when it comes on line later this year. The pumping lift is similar to the KAC, but the raw water is brackish, requiring desalination to make fit for domestic purposes. As a result, the new source will be the most energy intensive water source in the country. Ironically, a similar volume of water from the Yarmook continues

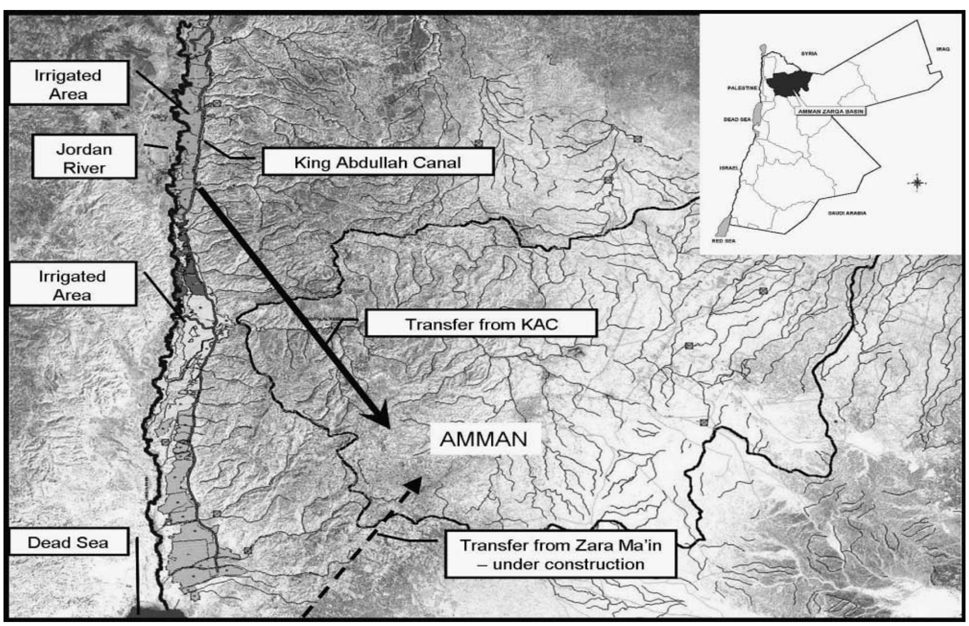

Fig. 3. The Jordan River and Amman-Zarqa Basin, Jordan.

to be utilized for relatively low-value orchard crops in the north of the Jordan Valley. While various observers lament the unrealized economic and energy savings from using this source, the political consequences of transferring this water are very significant (Courcier *et al.*, 2005). Needless to add, in such conditions of scarcity, allocating water for the environment will be much more difficult even compared to the issue of water reallocation from agriculture to urban uses.

As annual water per capita is projected to fall below 100 m^3 sometime before 2025, even without accounting for the influx of refugees from Iraq, the government continues to explore additional options to augment the limited resources further. Understandably, all options are both capital and energy intensive. This applies also to the next major project, which aims to transfer 100 million m^3/year of relatively freshwater from the Disi aquifer in the south. Although there is no need for desalinization and the pumping need is not as extreme as the case of Jordan valley, the transfer distance is 325 km. Energy and investment needs are also heavy for the proposed Red Sea–Dead Sea project, which is a regional project that aims to lift sea water from the Red Sea by 200 m and then letting it drop into the Dead Sea. This is to not only stabilize water levels in the Dead Sea but also to use the water pressure to generate hydropower and to add freshwater through desalinization[13]. While there is debate about the effect on the water quality and other environmental consequences and while a major objective is to stabilize the decline of the Dead Sea, the energy contributions and freshwater augmentation for Jordan are very important considerations. The intent is to begin the feasibility study later this year (World Bank, 2007). Overall, the Jordan case, which also reflects the conditions of other countries in the region, demonstrates the intricate nature of water–energy linkages. While there are synergies between water and energy, they are one sided (i.e. energy for water and not *vice versa*) and they also come at heavy economic and environmental costs.

7. Energy–environment conflicts: a USA case study

The Snake River Basin in the Pacific North West of the USA provides another extreme form of conflict, where the environmental concern to preserve wild salmon fish migration through rivers has become a constraint to hydropower generation. The Snake River Basin with an area of 280,000 km^2 and an annual discharge of around 52 km^3 has a number of large dams (see Figure 4) that were developed for irrigation, hydropower, flood control and navigation. The hydropower from these dams and those on the Columbia River has provided inexpensive energy that has been the bedrock of the regional economy. Besides their power and irrigation contribution, the series of dams and locks have allowed barge traffic to reach Lewiston in Idaho, an inland port for agricultural products, primarily grain, nearly all of which are then exported. Despite their economic contributions, there are now increasing concerns about the environmental impact of these dams, more specifically, the fate of the wild salmon, which is now protected under the Endangered Species Act.

Among the efforts to mitigate this impact, there are also serious proposals to dismantle the four lower dams on the river built between 1962 and 1975[14]. Notably, the combined generating capacity of

[13] As presently proposed, as the sea water drops into the Dead Sea, the pressure from the elevation difference will be used to pass the water through a series of hydropower plants to generate electricity. Also, the pressure will also be used for desalination by reverse osmosis (Harza Jordan Rift Valley Group, 1998). The fresh water would then be lifted to the respected urban centers of the three interested countries, including Jordan, using some of the power from the hydro plants.

[14] These dams are the Lower Granite, Little Goose, Lower Monumental and Ice Harbor, all of which are run-of-the-river systems with limited storage capacity. They are located immediately downstream (to the west) of Lewiston, Idaho.

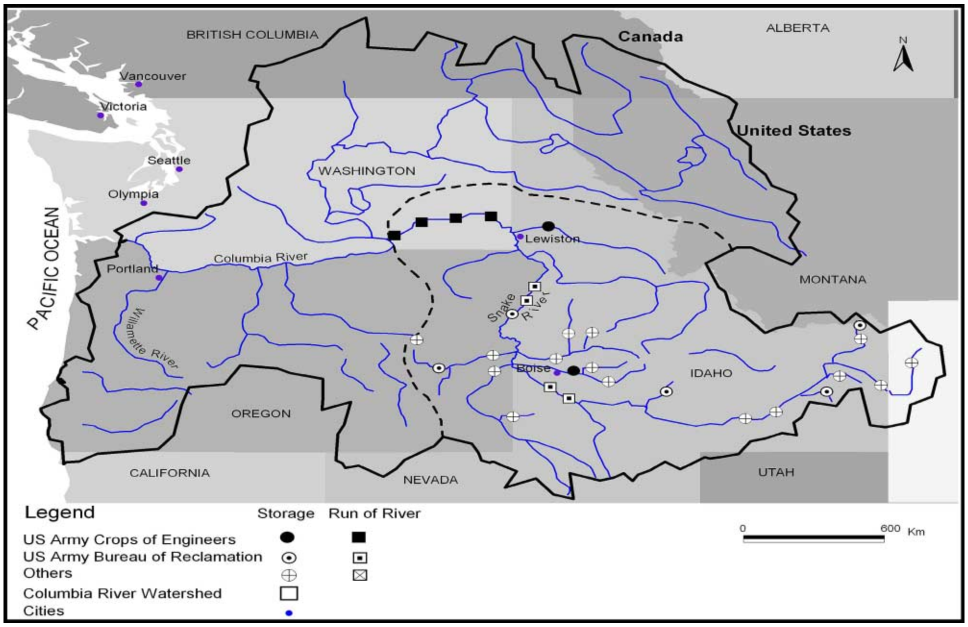

Fig. 4. Snake River basin with major dams.

these four dams is 3,000 MW (United States Army Corp of Engineers, 2002). Of the four dams, only the Lower Granite dam, which was completed in 1975, was constructed with by-pass facilities for the downstream migration of juvenile salmon. However, the other dams have had facilities retrofitted to benefit both the juvenile and adult salmon. Despite these efforts, the juveniles are significantly affected by the dams owing to slower water velocities, increased exposure to predators and mortality from turbines (USACE, 2002). But, the removal of dams to save the salmon will entail a major economic cost. The average net annual loss of breaching the dams was estimated to be approximately US$266 million/year (USACE, 2002)[15]. Considering these economic and environmental costs, the removal of these dams would be less likely and indeed incompatible with the global energy and environmental realities.

8. Conclusions and policy implications

The four case studies present some contrasting examples of the complex interrelationships between water, food, energy and the environment. There are both conflicts and synergies with considerable implication for policy. In the case of Ethiopia, with significant untapped potential, increasing the level of investments for water development and hydropower generation can tremendously enhance food

[15] There are benefits from breaching the dams but in economic terms these are overshadowed by the opportunity cost in terms of generating the lost hydropower from thermal sources, estimated to be US$271 million per year, the loss from irrigated agriculture and the additional pumping costs for urban and industrial users were estimated to be US$15 million/year and the replacement of the barge transport system would be about US$40 million. Furthermore, the increase of annual carbon emission would be around 3.6 million tonnes. (USACE, 2002).

production through irrigation, increase access to modern energy sources and improve the environment by reducing biomass use. While there are synergies between sugarcane and energy, there are also conflicts with food and livelihoods. Policy options to resolve these conflicts include expanding small scale irrigation and water supply systems from surface and groundwater sources in the basin, upgrading rainfed systems, development of multi-purpose systems and increasing smallholder access to markets throughout grower schemes.

In the Krishna Basin, although the conflict between hydropower and canal irrigation is minimal, there are serious conflicts between upstream water use through small surface facilities and groundwater pumping and downstream water needs for irrigation and hydropower generation. While there are strong synergies between hydropower and groundwater irrigation, the potential synergy between sugarcane cultivation and energy production are still to be explored. But, in view of declining water availability and increasing withdrawals for economic uses, the environmental water needs have suffered the most. While various policy options can be suggested to minimize the conflicts but maximize the benefits, the most important one relates to the improvement in water productivity, especially in agriculture. Similarly, the policy of promoting biofuel crops in rainfed rather than in irrigated regions could improve the economic returns of rainfed agriculture while minimizing the impact on food production, unless of course this results in rainfed food crops being displaced.

The Jordan case shows the indispensable role of energy in a water scarce environment and the effects this will have on the fiscal system. While there are options such as the reallocation of water from agriculture, they are not only politically difficult but also may not be adequate in the long run. The USA case represents one of the high profile examples of the extent to which environmental concerns can be constraint for water and energy development. It also illustrates the need to consider other environmental dimensions in addition to the impact on salmon migration. Interestingly, the environment–energy conflict seen here also provides a contrast not only to the forest-loss based argument dominant in Asia but also to the positive environmental contribution of hydropower from a global perspective. Overall, despite their brief nature, the four case studies are useful both to illustrate various synergies and conflicts between water, energy, food and environment and to indicate potential policy options to manage them.

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