

## WATER ENERGY FOOD NEXUS IN PRACTICE : EXAMPLES FROM SOUTH ASIA

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### Abstract

The Nexus among Water, Energy and Food (WEF) in three potential investment projects in South Asia were studied to understand how these three resources interact and affect the project outcomes. The Projects considered are (1) Ara Canal Water Productivity Improvement Project (ACWPIP), Bihar, India, (2) Mechanized Innovation Irrigation Project (MIIP), Nepal and (3) Rural High Voltage Distribution System (HVDS), Maharashtra, India. All of them aim to provide adequate and reliable access to water or electricity in an equitable manner. Only the linkages between water and food, and water and energy are assessed. Linkages between energy and food are not discussed.

In the ACWPIP, there's no significant change in surface water required for irrigation, groundwater pumping is expected to decrease, and the cropping intensity is expected to increase. Increase in cropping intensity will increase beneficial consumption due evapotranspiration. In MIIP, despite an increase in groundwater withdrawal, monsoon rains are expected to sufficiently recharge the aquifers and reduce flooding. In Maharashtra, it is possible that energy supply feeders may traverse through semi/critical or dark blocks. Hence there's a possibility that the increase in food production may be at the expense of depleting groundwater resources.

In the ACWPIP, there's no evidence of competition for water between hydropower generation and irrigation. Releases from reservoirs appear to be based on water stored rather than the demand for either hydropower or irrigation. There appears a willingness between State Agencies responsible for water and electricity to ensure enough electricity is available to support the Buried Pressure Piped System proposed.

Optimal use of any of the three resources is often constrained by other factors such as the land holding, land fragmentation and availability of capital. Despite the lack of consultation among the three sectoral agencies when project concepts were formulated, there appears enough consultation among them during project planning. Sectoral agencies are often focussed on protecting their own mandates as well as heeding to National Agenda, such as poverty alleviation and increased rural incomes. This prevents them focussing on WEF Nexus to guide their investments. Proponents of WEF analysis to influence policy formulation need to recognise these ground realities.

**Keywords:** Reliability, Adequacy, Equity, Inter-agency cooperation, National Agenda

### 1. INTRODUCTION

Within a Nexus framework, we explore linkages between three or more resources, and the potential for improving the efficient use of one resource to produce another. We seek to understand trade-offs due to the linkages among them and attempt to find and operationalize efficiency measures simultaneously. We hope to maximise economic and environmental outcomes from near optimal use of the resources. The Water

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Energy Food Nexus (WEF) addresses the interconnection between the three vital resources to enhance daily livelihoods and promote socio-economic development. The Nexus recognizes that the availability of one enhances the availability of another, as in the case of an increased supply of water in water deficit areas can increase food or energy production. There is hardly any situation, where one of the three can be secured independently of the other. Among the three, water is a unique resource that is finite, recyclable but has no substitute, while energy and food production have numerous alternative sources for their production.

South Asian countries have increased secure supplies of water, energy and food remarkably in recent years through investments in infrastructure and policy interventions. However, many challenges persist in eradicating hunger, ensuring nutritional security while safeguarding environmental sustainability. More importantly, Governments envision increased food production with an increase in access to water and energy as the means to uplift the rural population out of poverty. Towards this goal, South Asian countries have subsidized water and energy for rural populations, which may lead to inefficient use and degradation of resources. While respecting National Agendas for socio-economic development in rural areas by subsidizing water and energy, care needs to be taken to ensure that the resource base is not degraded, greenhouse gas emissions are restrained, and water-borne diseases are checked.

This paper confines the WEF Nexus to freshwater, non-renewable energy and food as *input* to the production of each other. For example, the WEF Nexus includes freshwater used for irrigation to produce food, not the seawater used in greenhouses to produce freshwater with solar, and then to produce vegetables. Exclusion of seawater and solar energy is due to their abundance, which is not the case with freshwater and fossil sources of energy. Use of freshwater to produce hydropower is part of this nexus because hydropower, a renewable form of energy, is closely linked to the availability of fresh water as input.

Operationalizing the WEF Nexus to improve resource use efficiency simultaneously has been the goal of many planners. There remain many challenges in research on the WEF nexus, while implementation as a management tool is just beginning. The challenges are primarily related to data, information and knowledge gaps in our understanding of the WEF inter-linkages. Our ability to untangle the WEF nexus is also limited by the lack of systematic tools that would address all the trade-offs involved in the nexus (Liu et al. 2017). Effective implementation of investment strategies based on Nexus analysis is often constrained by political and administrative responsibilities among Ministries. Frequently, different Ministries are responsible for each resource, with independent mandates. Respective mandates often ignore the mandate of other, often unintentionally. For example, an Energy Ministry may aim to provide an uninterrupted supply of electricity without necessarily paying attention to the sustainable use of groundwater for agriculture.

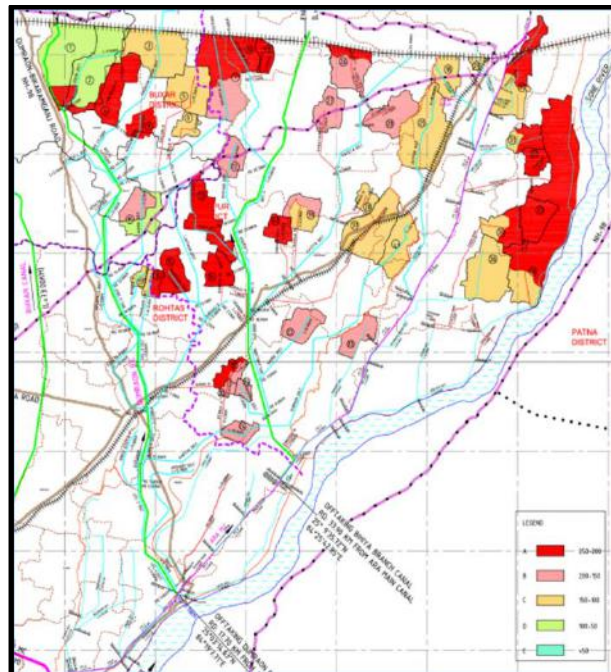
This paper discusses three potential investment projects in South Asia, in which an increase in water and energy productivity in agriculture is optimized through innovative use high-level-technologies. The Projects considered are (1) Ara Canal Water Productivity Improvement Project (ACWPIP), Bihar, India, (2) Mechanized Innovation Irrigation Project (MIIP), Nepal and (3) Rural High Voltage Distribution System (HVDS), Maharashtra, India. All aim to provide reliable access to a resource to meet demand equitably. The paper aims to assess how their main objectives impact availability of the other two resources.

## 2. PROJECT CONCEPTS

### 2.1 Ara Canal Water Productivity Improvement Project (AcwPIP), Bihar, India

The Ara Main Canal System in Bihar has a command area of 202,000 ha. It comprises the Ara Main canal, two Branches and 56 Distributaries and Minors. All the canals are unlined and seepage losses are high. The combined length of these canals is about 1,193 km, have about 3,740 ungated outlets, many of which have been tampered with. Due to its dilapidated condition, the system only services about half of the command area. Supply to the head of the system is sourced from Rihand and Bansagar Dams and averages 1629 MCM pa. Many farmers, especially in the middle and tail reaches of distributaries rely on groundwater extracted with diesel pumps from shallow tube wells due to inequity in surface water delivery. An average of 800 MCM/year of groundwater is pumped in the command area to supplement canal water. Rice and wheat are the major crops in Kharif and Rabi respectively. The annual cropping intensity is approximately 120%.

Recognising that shortage of canal water is constraining cropped areas and yields, a project is being developed for modernisation of the command area. Under this proposal, the modernised canal system will include a SCADA with flow measurement and remote gate operation and selected canals will be lined with minimal change to the section. Also, a Buried Pressure Pipe System (BPPS) will be distributed over 60,000 ha, mostly at the tail of distributaries at 41 locations, as identified in coloured polygons (Figure 1). The BPPS will be supplied with canal and ground water. Polygon colour represents the volume of groundwater in mm/y, to be extracted to compliment canal water to meet the irrigation demand. A 'Water-Accounting' analysis has been completed for the project area and demand for non-beneficial consumption has been estimated.

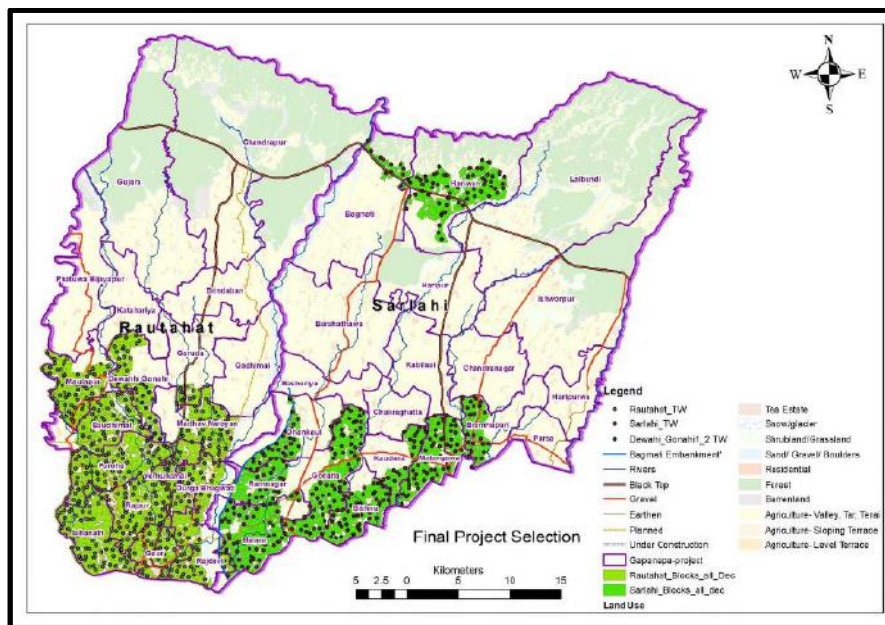


**Figure 1:** Ara Canal Command, Bihar, India. Proposed BPPS areas are in coloured polygons.  
Mechanized Irrigation Innovation Project (Miip), Terai Component, Nepal

In the Terai of Nepal, irrigation in the dry season is often constrained by the need for costly investments in storage dams and inter-basin transfers with significant social and environmental impacts. However, year-round irrigation can be achieved by tapping available groundwater resources. Three crucial conditions must be satisfied: (i) availability of affordable and reliable energy, (ii) sustainable financing mechanism to meet the higher operational cost, and (iii) availability of extra groundwater without detriment to other users.

The MIIP proposes to provide long-term sustainable solutions to increase year-round access to irrigation water. The project aims to address this challenge by focusing on areas where groundwater can be economically and sustainably exploited. The project proposes to construct a large-scale network of public-owned tube wells and a grid-tied solar photovoltaic power plant, with dedicated electricity distribution networks linked to tube wells. The management of the project is expected to involve the private sector, under a Design Build Operate (DBO) business model.

A 'Water-Accounting' analysis has been completed for the project area and demand for non-beneficial consumption has been estimated. On-demand irrigation services will be available to farmers for a fee. Specifically, the project will be developing 40,000 ha of irrigated area (Figure 2) by constructing: (a) 1,000 tube wells with pumps, prepaid meters and buried pipe distribution systems; (b) a 30-megawatt solar power plant constructed and connected to NEA national grid; and (c) a dedicated 500-kilometre low voltage network connected to each project tube well.



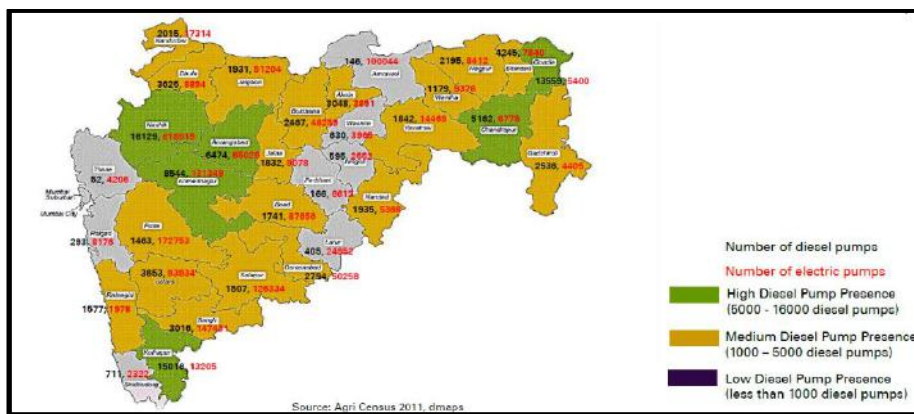
**Figure 2:** Sarlahi and Rautahat districts of Nepal Terai, with proposed sites for tube wells

Maharashtra Rural High Voltage Distribution System Program, Maharashtra, India

The Maharashtra State Electricity Distribution Company Limited (MSEDCL) has 4.2 million agricultural customers in rural areas. The number of pumps in the State is estimated to be 1.8 million in 2011, most of them connected to low voltage supplies. Due to low voltage and high losses, they are not efficiently supplied with electricity. Hence, there are over 100,000 diesel pumps, used in locations where electricity is unreliable or unavailable, which significantly impacts agricultural production costs. The

state is planning a program over the next 10 years to convert these to high voltage distribution systems (HVDS).

The “Power for All” program aims to achieve 24x7 reliable power to all non-agriculture customers and an assured supply of 8-10 hours for agriculture customers. The MSEDCL is focusing on improving its rural network through programs on (i) feeder segregation between agriculture and non-agriculture load; (ii) adoption of HVDS; (iii) increased metering; (iv) improving household electrification to 100%; (v) distributed generation through renewable energy; and (vi) widespread adoption of information technology. Key outputs of this intervention include 500 MW of distributed solar power generation in rural areas, transmission, distribution feeder separation, 100% electrification for households and high voltage distribution for agriculture consumers. The districts where diesel pumps use is high will benefit more from the project (Figure 3).



**Figure 3:** Distribution of electric and diesel pumps in Maharashtra in 2011  
Impact of Interventions on Water, Energy and Food Nexus

### 3. WATER FOR FOOD

In the ACWPIP, Bihar, India, the proposed modernisation will not increase the supply of water at AMC Headworks but will deliver more water to farms due to reduced seepage losses. Water available at headworks averaged 1629 MCM pa between 1997 till 2016, of which only an estimated 802 MCM was delivered to farms. Under the project, delivery to farms is expected to increase to 996 MCM. Due to an increase in on-farm canal water supply, groundwater requirement is anticipated to decrease. An estimated 718 million cubic meters (MCM), instead of 800 MCM pa at present, will still be required from groundwater to meet crop water requirements, especially in BPPS areas. The cropping intensity with the Project will be higher in the BPPS areas than in areas supplied only by canal water. Tentatively with-Project, cropping intensities of (i) 153% are expected for canal supply areas, and (ii) 195% for the BBPS areas due to conjunctive use. For the whole command area, this would result in an increase in the annual cropping intensity from 120% to 166%. Overall, without drawing on additional surface water and abstracting less groundwater, food production will be increased due to this project.

In the MIIP-Terai, 1000 tube wells are proposed, each supplying water to approximately 40 ha on demand. This will result in the pumping of additional 480 MCM or about five or six times of groundwater volume than what is pumped now. A pre-paid meter with Smart Cards and installation of underground pipes is expected to deliver water on demand in a financially sustainable manner. Cropping intensity is expected to increase,

cropping pattern may shift to high-value crops, resulting in net farm income increasing from NPR67,000 per ha to NPR 130,000 per ha.

This leads to concern, whether proposed groundwater pumping at this level is sustainable or not in the Ara Canal Command and the Nepal Terai. Results from a groundwater modelling inform that the proposed levels of extraction in Nepal Terai is sustainable. Another groundwater modelling study for the ACWPIP is currently underway.

The mighty River Ganga and its tributaries, some of them traverse through the Ara Canal Command and the Nepal Terai, have an abundance of surface water during monsoon months. According to World Bank's "Ganges Strategic Basin Assessment", all active and potential small and large storages can store only little over 20% of the runoff of about 520 billion cubic meters (World Bank 2015). Due to the huge variability of the flow, the World Bank study recommended that underground storage is one of the best options available for taming the floods and increasing irrigation and livelihood benefits everywhere in the basin.

Okwany et al. (2015), studied historic groundwater fluctuations in ten districts in India, Nepal and Bangladesh. In most locations, pre-monsoon water tables were within 9m below the ground level (bgl). In a few localized areas pre-monsoon levels were 12 m bgl concentrated around urban centres with high population densities. In all cases post monsoon groundwater levels recovered to within 2 m bgl. The lack of voids within the aquifers is one of the reasons for high runoff volumes during monsoons. Enhanced groundwater pumping within both project areas will increase voids pre-monsoon, creating additional storage capacity for recharge, and reducing runoff volumes. Hence groundwater pumping in these project sites is expected to be sustainable while increasing food production and farm incomes.

In Maharashtra, the impact of secure energy and the potential to increase area cultivated through drip irrigation may impact negatively on groundwater resources. The fraction of groundwater development in the State of Maharashtra is 53% in 2011 (Suhag, 2016). Groundwater development is the ratio of the annual groundwater extraction to the net annual groundwater availability. Hence, at the state level, the risk of groundwater being overexploited due to secure energy supplies appears less. However, if the secure feeders are provided to any of the blocks which are identified as semi-critical, critical or overexploited, groundwater sustainability will be threatened. Hence, it may be prudent to limit the hours of secure electricity supply or rotate electricity supply in feeders in the blocks identified as semi-critical, critical or overexploited.

#### **4. ENERGY TO ACCESS WATER**

In the Eastern Gangetic Plains (EGP), which includes the Ara Canal Command area and the Nepal Terai, groundwater is shallow. Farmers depend on diesel pumps to abstract groundwater. On-call access to groundwater to all farmers is limited due to technical, social and economic constraints. Large areas of land remain fallow during the dry months.

Currently, farmers who do not own a tube well and a pump, buy water from their neighbours, often to save their crop from failure. The tube well owner provides the service when he does not require groundwater, and when the buyer has money to pay for the service. Furthermore, most of the farmers own small land holdings, often fragmented, and distant from the nearest available tube well owner. Kishore (2014) found there was one bore-well for every 2.5 hectares of cultivated area in Bihar, which

is inadequate to meet the irrigation demand, even if all existing tube well owners help their neighbours with groundwater irrigation.

Studies have shown that in this region, the average cropped area and irrigated area per household are higher for tube well owners as compared to water buyers. The relationship between ownership of tube-well and the size of land holding is positively related; that is, the larger the size of land holding the greater is the likelihood of owning a tube-well.

Overall, the constraints can be categorized into two: (1) financial attractiveness or feasibility to install and operate tube wells and (2) energy required to operate tube wells. Size and fragmentation of land holdings are central to both. Some farmers hold more than a hectare or two, but their holding is so fragmented, the farmers do not consider investing in a tube well to be financially viable. The average land holding in the ACWPIP command area is about 0.54 ha, but ownership is skewed. About 65.0% of land holdings are of marginal size (< 0.5 ha) and these occupy just 24.6% of the land. This implies that 35% of land holdings are greater than 0.5 ha. However, these land holdings are often fragmented. The BPPS proposed has the potential to deliver water on demand, without farmers investing in wells.

In addition to land tenure characteristics, access to a reliable supply of energy at affordable rates to pump groundwater economically is a challenge for millions of small and marginal farmers. Solar PV systems for groundwater irrigation is actively promoted in the EGP. It is assumed that if a capital subsidy is available, farmers who are now dependent on neighbours for irrigation water, could install solar PV systems to pump groundwater instead of purchasing water from neighbouring well owners.

However, there are also physical barriers to introducing PV-powered irrigation pumps in Eastern India, where the average size of land holdings is very small (Kumar et al., 2014). Although considerable subsidies are making solar irrigation financially attractive, the need to sacrifice land for the solar panels is a disincentive for the adaption of solar pumps. In states such as West Bengal, there is a shortage of barren and uncultivable land which could be used for solar arrays (Ramachandra et al., 2011). Therefore, from the technical point of view too, large-scale adoption of solar pumps appears to be limited in Eastern India (Kishore et al., 2014), which includes the Nepal Terai and the Ara Canal Command.

The ACWPIP and MIIP overcome energy constraints to access irrigation water. The ACWPIP commits Southern Bihar Power Development Corporation (SBPDC) to supply electricity to the pump houses. The ACWPIP will require 22 MW for 60,000 ha, with power supplied to about 410 pump houses (avg. 150 ha, 50kW per scheme). Dedicated 11 KVA lines, approximately 1000 km in length, will provide power (along distributaries) to pump houses. At each pump house, a 100KVA transformer will be installed to provide 415 V power. Besides, the ACWPIP proposes a total of 30 ha of solar arrays be placed over irrigation canals. Electricity produced will be fed to the SBPDC grid.

In the MIIP, energy production from the 30 MW Solar Power Panels is estimated to be 42540 MW-h annually. This energy will be available through the NEA grid for tube-well irrigation improving supplies of the NEA grid. Hence, access to year-round water for irrigation through ACWPIP and MIIP due to secure energy supplies would significantly promote the productivity of agriculture, improving incomes and food security.

In Maharashtra, feeder separation will assure electricity to farmers for restricted hours every day. It will restrict the supply of electricity to agriculture to several hours through the introduction of HVDS, and efficient pumps. Farmers will be provided with a certain number of hours every year based on assumptions of pump efficiency, voltage,

irrigation practices. As HVDS is adopted, it will be reviewed and rationalized. A possible revision considered is tiered pricing for electricity, by which farmers may be provided free or subsidized electricity up to a threshold level and then charged more if they exceed the threshold, possibly due to water-intensive cropping patterns.

## 5. COMPETITION FOR WATER BETWEEN FOOD AND ENERGY IN ACWPIP

There are two dams, Rihand and Bansagar, upstream in the Sone River catchment which stores monsoon water for release during the year. Rihand and Bansagar Dams are 180 km and 325 km upstream of the Indrapuri Barrage, respectively, which diverts water to the Ara Canal Command. A Joint Operations Committee (JOC) meets annually after the monsoon and recommends water releases based on water availability and demand for water for hydropower and irrigation.

In most years, the actual release has followed JOC's recommendations on an annual basis which were based on water availability than the demand for irrigation or hydropower. On average (Figure 4), JOC's recommendations are closer to the demand for hydropower, than demand for irrigation, but the actual release did not meet the demand of either sector, especially during dry years, due to lack of storage in the dams. Hence, a case of competition for water between hydropower and irrigation cannot be supported.

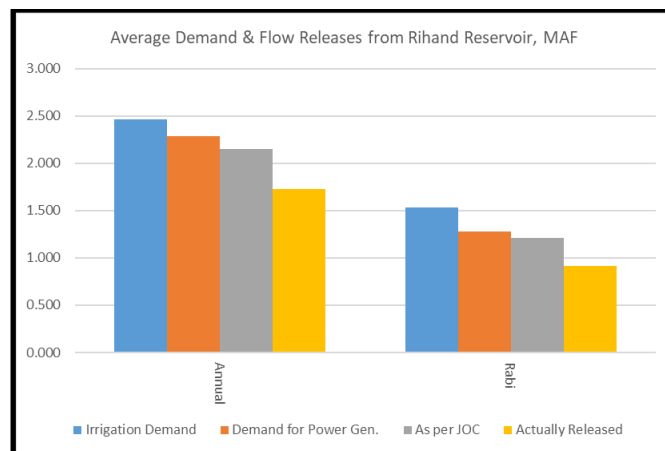


Figure 4: Demand and Release of Water from Rihand Dam for Hydropower Generation and Irrigation in Million Acre-feet (MAF)

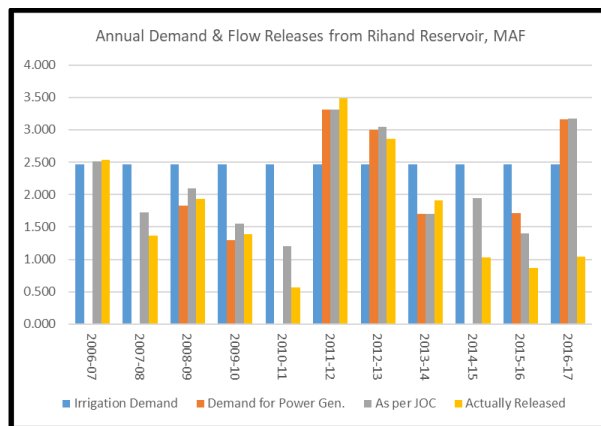


Figure 5: Annual variation in Demand and Release of Water from Rihand Dam for Hydropower Generation and Irrigation in Million Acre-feet (MAF)

Figure 5 shows a comparison of demand for irrigation, hydropower, JOC decision and actual release from Rihand Dam between 2006 and 2017. It is noted that the irrigation demand reported had been constant through these years, reflecting the area to be irrigated and an assumed unchanged cropping and climate pattern. On the other hand, reported demands for hydropower varied annually. Demand was low in dry years (2008-2010) and high during wet years (2011-2012) and (2016-2017). We may surmise that the releases may have little effect on on-farm water availability due to the distances between the dams and the irrigation commands, groundwater for irrigation and the state of irrigation canals.

## 5. COLLABORATION BETWEEN SECTORS

In the ACWPIP, for the 60,000 ha of BPPS, the Bihar Water Resources Department (BWRD) has consulted the SBPDC and have received assurances that uninterrupted electricity of 22 MW will be available for the BPPS. BWRD and SBPDC have opted for dedicated feeders, planned to provide 11 kilovolt-ampere (KVA) along each tributary from the BPPS will benefit. BWRD also confirmed the requirement for a grid-tied solar plant as a part of ACWPIP to offset all or part of electricity subsidies to the BPPS. It is proposed that the solar panels will be placed on top of the irrigation canals to alleviate pressure on valuable land. It is noted that in 2018 agricultural power tariff was subsidized at 87%; for each kilowatt-hour, farmers paid ₹0.75 instead of ₹5.75 charged to urban consumers. SBPDC believes that the Ara canal pressure pipe system would also benefit from the subsidized agriculture power tariff. Such high subsidy, if maintained, is unsustainable. The construction of a solar plant could partially mitigate this risk.

## 6. DISCUSSION

In Bihar, demand for water will not increase, but the demand for electricity will increase due to the BPPS. The project will improve the extent of conjunctive use of water for irrigation without increasing the demand for water. Agricultural productivity is also expected to increase. The project includes a solar energy component in anticipation to reduce reliance on power from the SBPDC. The motivating factor for this component is the reduction of financial subsidies to purchase power from the SBPDC. It is noted that, the BWRD, not the SBPDC, canvasses for solar energy to reduce energy subsidies in future. In Nepal, the project is supported by the National Energy Authority, which also supports the installation of solar panels, in anticipation of reduced subsidies for electricity. It is noted that a single Ministry is responsible for Water and Electricity in Nepal.

The Maharashtra project acknowledges that agriculture is a significant client of improved energy supplies through its feeder separation program and targets energy efficiency through a reduction in conveyance losses and thefts. It is concerned that reliable supplies of electricity do not endanger sustainable use of groundwater and therefore planning to revise electricity subsidies and tariffs regularly.

In Bihar and the Terai, due to the abundance of groundwater, and the potential for recharge during monsoon, groundwater use can be sustained. It is unclear if that will be the case in Maharashtra.

There is no evidence to show that the three projects were conceptualised in consultation with other sister Ministries. Despite the lack of consultation among the three sectoral agencies when project concepts were formulated, there appears enough consultation among them during project planning. The Executing Agencies for ACWIP is the Ministry responsible for water; the Ministry responsible for MIIP is responsible for Electricity and Water, and the Executing Agency responsible for the Maharashtra

Project belongs to the Ministry of Energy. During project planning and the feasibility analysis, agencies from all three Ministries are regularly consulted. They tend to subscribe to the National Agenda on maximising production, increasing farmers' incomes and environmental sustainability. They also try and protect the interests of their agencies. The above does not necessarily result in the optimal use of the resources to maximise social, environmental and outcome for the resources consumed.

## 7. CONCLUSIONS

The projects considered show that despite the lack of consultations among Ministries responsible for water, energy and food when the respective project concepts were developed, there's adequate cooperation among them during project planning and feasibility analysis. All agencies are guided by a high-level agenda, that aims at providing adequate and reliable supplies of the concerned resource equitably to improve socio-economic and environmental outcomes. They are also protective of their respective mandates. Opportunistically, the agencies show interest in the resource managed by a sister agency, in the National interest.

The analysis of WEF Nexus at Bihar and Nepal sites does not indicate any trade-offs among each other. Introduction of solar energy, a renewable source, the abundance of runoff water during monsoon in Bihar and Nepal tend to mitigate trade-offs if any. It is unclear if there could be a negative impact on groundwater resources due to HVDS in Maharashtra. Strategic investments in these projects seem to overcome socio-economic constraints such as land holdings and personal finances to make efficient use of water and energy.

Developing policy instruments using WEF Nexus to improve resource use efficiency simultaneously has been the goal of many planners. It is constrained by data, information and knowledge gaps in the understanding of the WEF Nexus. Furthermore, political and administrative responsibilities among Ministries are not necessarily conducive either. The proponents of the WEF Nexus need to understand this reality. The options are (1) for them to work with a higher-level agency, such as the Finance or Planning Ministries, or (2) to embed the WEF analysis within the Executing Agency responsible for the project formulation and implementation.

## 8. ACKNOWLEDGEMENT

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