Water-Energy-Food Nexus in Action: Global Review of Policy and Practice 1

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Water-Energy-Food Nexus in Action: Global Review of Policy and Practice[1]

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Abstract

Dominance of insular, supply-side, technocratic thinking has posed a major challenge to improving water governance in the face of mounting resource scarcity, accentuated by climate change. During the 1990's, global discourse moved from supply-driven sectoral thinking to more holistic approaches to water governance as part of larger socio-economic and environmental processes. Integrated Water Resources Management (IWRM) emphasized demand-side water management by using prices, participation, entitlements, laws and regulations as tools to strengthen water governance at hydrological instead of territorial units. More recently, there have been pleas for even more integrative approaches that incorporate powerful inter-linkages between land, water, energy, food, livelihoods, environment and other spheres-- each with its own, often insular, governance structure. The drift in global thinking is to meet growing human needs by innovating approaches that enhance resilience and sustainability of landscapes, the biosphere, and the Earth system as a whole. In this same vein, the Water-Energy-Food (WEF) nexus has advocated that society would be better off seeking a system-level optima rather than maximizing sectoral objectives. The 'nexus approach' has produced prolific analytical literature over the past decade but integrating it into policy and governance is faced with many challenges. This review paper explores these challenges by focusing on 'WEF nexus in action'. We compare the play of the nexus in several water-stressed geographies of the world including Iran, Saudi Arabia, Mexico, China, Bangladesh, Gujarat (India) with evidence drawn from other geographies such as Morocco, Punjab-Haryana and such other. We synthesize these case studies to interrogate the gap between the 'nexus ideal' and actual state of play in different geographies and tease out practical lessons for mainstreaming 'nexus thinking' in water policy and governance. The key conclusion is that national and sub-national policies are driven by specific context, contingencies and constituencies involved; and driving the outcomes towards the 'nexus ideal' of system optima depends on the nature of the state, investment in institution building and above all, ingenuity in policy design and implementation that overcomes popular resistance to change, and builds political capital for leaders who back such policy.

1. Global Challenge of Water Governance

Past fifty years have witnessed unprecedented concern about water scarcity globally. For centuries, when human settlements grew where water was plentiful and the rules of water sharing were relatively simple, water infrastructure and top-down supply-side solutions dominated water resources management. With burgeoning population, urbanization, changing life styles and agricultural intensification, however, large swathes of the world are facing absolute water scarcity. The challenge is expected to worsen under all climate change scenarios (Seckler et al. 1999; Hoff 2011). In 2015, the World Economic Forum (2015) highlighted water scarcity as the greatest risk facing the future of humanity. With limits rapidly

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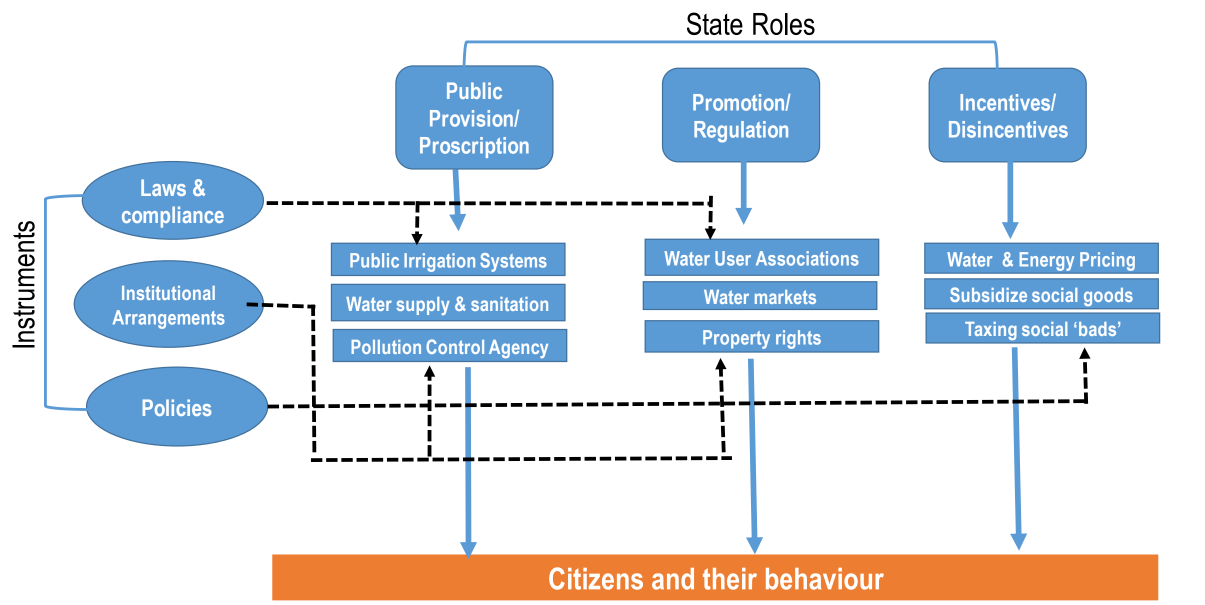
approaching of infrastructure investments to increase water availability, global discussion has increasingly veered towards options for managing demand. The key factor that impedes demand-side management is fragmented, insular and territorial nature of water institutions and governance that are oriented towards infrastructure solutions (Shah 2016; Agarwal et al. 2000).

Global view has thus shifted from sectoral supply-side water management to holistic governance of water economy as part of larger socio-ecological processes. The water governance discourse has put into bold relief the role water laws, policies and institutions can play in meeting the challenge of water scarcity. As SIWI has described, “Governing water includes formulation, establishment and implementation of water policies, legislation and institutions, and clarification of the roles and responsibilities of government, civil society and the private sector in relation to water resources and services.”[2] Water governance process creates a framework of rules, policies and protocols to oversee and guide water management, which includes, *inter alia,* planning and organizing the mobilization, conservation, allocation, distribution of water. In the business context, management guru Robert Tricker (2015) suggested that governance is about ‘doing the right thing” while management is about ‘doing it right’. The distinction fits equally well a society’s governance of its water economy.

Figure 1 attempts a schematic on the process of water governance in a society. In governing any sectoral economy, the state plays three roles: expanding the supply of social goods either by public provisioning (dams, canals, water supply and sanitation systems by government departments or municipal agencies) or promoting institutions (Water User Associations (WUAs or basin organisations) or incentivizing private agents to do so (subsidies on private irrigation or solar energy; fiscal support to water utilities). The state also limits ‘social bads’ by taxing them, by regulating the behavior of agents producing them (e.g., depleting or polluting aquifers) or by banning harmful activities all together (factories polluting rivers or aquifers). To play these roles, the state deploys three instruments: make and enforce laws, evolve or change institutional arrangements (roles of bureaucracy, markets, property rights, NGOs, WUAs, community organizations, businesses), and enunciating appropriate policies from time to time. The speed and scale on which governance interventions impact citizenry varies depending on how well instruments help role-play . The impact of a new law depends upon how vigorously it gets enforced. Promoting WUAs or basin organizations helps only if these get properly managed. Pollution gets regulated only if the regulator has the necessary capacity and will to regulate, ban or tax polluters. In some situations, policies produce quicker and stronger impact as they directly reshape incentives of citizens or intermediaries. All of the above constitutes water governance, and is distinct from the management of water resource, water infrastructure and water services. These entail planning, designing, managing dams, canals, watersheds and basins, water supply and sanitation systems and such like.

[2] https://www.siwi.org/priority-area/water-governance/

Figure 1 Unpacking Water Governance



During the 1990's, Integrated Water Resources Management (IWRM), emerged as the global mantra of water governance for 'doing the right thing' in meeting water scarcity. IWRM, whose roots go back to the experience of the US Tennessee Valley Authority (TVA) during the 1930's, emphasized demand-side management, stakeholder participation, sustainability and the need to integrate water resources management both within the water sector and as an inseparable part of a nation's social and economic development. Global Water Partnership (GWP) defined IWRM as: "a process which promotes coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

IWRM thinking introduced three key ideas in global water discussions:

- Limits to the carrying capacity of the earth and its natural resources like water;
- Criticality of demand side management of water, and
- Need for integrated management of water resources as part of broader socio-economic development processes of a society.

The global community adopted the IWRM philosophy with much enthusiasm. Global Water Partnership, an international NGO, adopted IWRM propagation in a mission mode. World Summit on Sustainable Development, Johannesburg, 2002 adopted the IWRM philosophy, and most recently, UN's Sustainable Development Goal (SDG) 6 recommitted its support for IWRM (UN nd). Countless workshops and conferences advocated IWRM as a nuanced response to water scarcity. In many developing countries, donors and multi-lateral financial institutions made IWRM a part of their water financing. There was no gainsaying the IWRM philosophy as enunciated by GWP and other influential global players. However, what got implemented on the ground in the name of IWRM was often a package of silver bullets which included, *inter alia*:

[a] adoption of a new water policy formulation that formally adopted IWRM and declared water as national property and an economic good;
[b] enactment of a new water law that provided a legal framework for IWRM implementation;
[c] formal acceptance of water as an 'economic good', enforcing 'user pays; polluter pays' principle, and mandating pricing of water and water services to ensure cost recovery and efficient resource allocation;

[d] replacing territorial water administration by catchment or basin level organizations for basin scale water-land management;
[e] registering water users/uses and issuing permits, preferably tradable, for water abstraction and use;
[f] promoting participatory, inclusive and gender-equitable water governance to make 'water everybody's business'.

Since the 1990's, IWRM emerged as the ruling paradigm for water sector reform in the developing world, promoted aggressively by bilateral donors and multi-lateral funding agency, commonly as part of financial assistance to developing economies. Early in the new Millennium, however, realization began to down that while the IWRM Package offers sound guidance for good water governance, it not itself a prescription for it. Researchers found that in developing countries, IWRM as a philosophy and process had proved problematic to migrate from theory to practice (Schulze 2007). Blanco (2008), an IWRM-observer in Columbia, lamented that IWRM meant 'paralysis-by-analysis'. Many began to wonder if IWRM is a relevant concept or just an irrelevant buzzword (van der Zaag 2005); and others asked why had IWRM advanced so slowly and typically only at the conceptual level (Najjar and Collier 2011). The United Nations Environment Programme (UNEP) thought that converting IWRM theory into practice remained 'unfinished business' (IWA/UNEP, 2002). In Asia, Cambodia, Thailand, Indonesia, Vietnam, Sri Lanka adopted IWRM policies and made laws under donor persuation; but their implementation remained a tepid (Samad 2005 for Sri Lanka; Mang 2009 for Cambodia; Yu 2014 for China; Molle and Hoanh 2011 for Vietnam). In Sri Lanka, under the influence of Asian Development Bank, the government announcement to price water for paddy irrigation invoked such strident popular backlash that the government quickly backed off (Samad 2005). In Sab-Saharan Africa, where IWRM was more vigorously imposed, scholars and observers reported widespread push-back from communities (Schulze 2007). IWRM was proffered as a theory of action, guiding how water governance in developing countries should be reformed; but facing persistent difficulties in operationalizing the package on the ground, the doctrine began losing sheen (Biswas 2008). Shah (2016; Muller 2010; Giordano and Shah 2014 and van Koppen and Schreiner 2014) argued that the IWRM project was about transforming highly informal water economies of poor societies into a highly formal one; but this is a long term process tied to overall economic transformation of a society and hard to telescope simply by implementing the IWRM 'package'.

Despite these frustrations in IWRM implementation, global discourse on water governance persisted in arguing the 'silo' approach of water management as archaic in contemporary world. The clamour for holistic management of land and water became stronger following the land-grab rush after the food crisis of 2008-9 (Unver and Mansur 2018: 120). While traditional water management pursued single-minded focus on efficiency or water productivity, newer concepts sought to situate water governance within a larger setting of ecosystem governance at multiple scales. Based on early lessons teased out from a pilot project in Kagera trans-boundary basin, FAO (2017) developed and advocated a landscape based agro-ecosystem approach as a variant of integrated land and water management.

If IWRM advocated demolishing administrative, territorial and functional silos within the water sector, newer frameworks advanced in the same genre carried integration much further. With growing concerns with climate change and Anthropocene, there has emerged a new clamour for 'a planetary food revolution' shifting the focus from 'productivity first to sustainability first' (Rockstrom et al 2017). While addressing water use in food production, Rockstrom et al (2017) accord primacy to "managing natural capital for long-term productivity and social–ecological resilience at field, watershed, and regional scales, in agricultural systems that operate within planetary boundaries to safeguard Earth system." (p:7). The key challenge, according to them, is of feeding the humanity within 'a safe operating space of a stable and resilient Earth system' which would mean striving to achieve: (1) net zero emissions of greenhouse gases, (2) very low or zero expansion of agriculture into remaining natural ecosystems, while restoring others providing vital ecosystem services, (3) zero loss of biodiversity, (4) drastic reduction in excessive use of N and P (recycling nutrient flows), and (5) major improvement in water productivity and safeguarding of environmental water flows (Rockstrom et al 2017).

2. Water-Energy-Food (WEF) Nexus: Towards A New Approach?

Operationalization of the IWRM 'philosophy' in to the IWRM 'package' suggesting a six-point blueprint for water governance seems to have been problematic (Giordano and Shah 2014). Although IWRM theory emphasized that water management should be integrated with larger processes of socio-economic development of societies, many players felt that the IWRM 'package' (though not the philosophy) is too water-centric an approach that failed to sufficiently engage decision makers across closely related spheres such as food, agriculture, energy, environment and climate change. The IWRM package overlooked the fact that unsustainable water use is often driven by policies pursued in energy or food-agriculture sectors and it does nothing to change that. A 2011 report by Hoff (2011) and the report of a 'nexus conference' by the World Economic Forum (2011) argued that Water-Energy-Food (WEF) Nexus offered a more integral approach to water policy making in the wider socio-economic perspective. " Many global challenges, though interconnected, have been addressed singly, at times reducing one problem while exacerbating others. Nexus approaches simultaneously examine interactions among multiple sectors" (Liu et al 2018)... and, further 'nexus approaches can uncover synergies and detect trade-offs among sectors" (Liu et al 2018). Hoff's much-cited report showed how a nexus approach can enhance our understanding of water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors." (Hoff 2011: p4). Nexus thinking aims to maximize system efficiency rather than sectoral efficiency. It addresses externalities across sectors. According to FAO, "The water–energy–food nexus is about understanding and managing often-competing interests while ensuring the integrity of ecosystems."[3] The nexus approach, for instance, contrasts high water productivity of intensive agriculture with its low energy productivity; energy intensity of desalination with water intensity of biofuels. It recognises that controlling soil degradation can save water or investing in groundwater recharge can save energy (Hoff 2011). FAO incorporated the WEF nexus as part of sustainable food and agriculture in its "larger mandate of eradicating hunger, reducing poverty and sustainably managing and using natural resources and ecosystems" (FAO 2014:9). It advocated integrated management of land, water and ecosystem in the quest for food security in terms of food availability, access, stability of supply and utilization. In operationalising this perspective of WEF nexus, FAO has focused on evidence, scenario development and response options (FAO 2014: 10). In the same vein, Flammini et al. (2014) evolved a protocol for participatory WEF nexus assessment to "inform nexus-related responses in terms of strategies, policy measures, planning and institutional set-up or interventions." The protocol aimed to help 'walk the nexus talk' through a step-wise process for nexus policy making, combining qualitative and quantitative approaches and linking interventions with the context.

The WEF nexus approach was thus viewed as an improvement over IWRM. FAO (2014:6) argued that "by explicitly focusing on water, there is a risk of [IWRM] prioritising water-related development goals over others, thereby reinforcing traditional sectoral approaches. The Nexus approach considers different dimensions of water, energy and food equally and recognizes the interdependencies of different resource uses to develop sustainable agriculture."Cai et al (2018) argued that "The [WEF] nexus paradigm provides the water community specific channels to move forward in interdisciplinary research where integrated water resources management (IWRM) has

[3] http://www.fao.org/land-water/water/watergovernance/waterfoodenergynexus/en/

fallen short" and that "In contrast to IWRM… the [WEF] nexus approach has a clearer scope of integration since it explicitly sets the sectoral bounds (i.e., food, energy, and water resources) of integration, whereas IWRM attempts to integrate seemingly all resources and objectives related to water, which is often subject to institutional barriers." (p 259). "The nexus approach aims to identify trade offs and synergies of water, energy, and food systems, internalize social and environmental impacts, and guide development of cross-sectoral policies." (Albrecht et al 2018). "The nexus approach means that when governments and industries determine policies in one sector—whether it is energy, agriculture or water—they take into account the implications in other sectors. Similarly, policy and planning processes within each sector would account for different scales, from local to transnational" (Bird et al 2014).

According to many observers, a key advantage of the nexus approach is the primacy it accords to eco-system services and global warming. It also fits well with the idea of Green Economy which maximizes human wellbeing while minimizing environmental risks, ecological scarcities, carbon output and pollution (Hoff 2011; Allan and Matthews 2016). Nexus thinking is critical to understand the socio-ecological implications of the global annual fossil fuel subsidy at US $ 5.3 trillion/year (or US $ 10 million/minute) in terms of environmental impact and global warming (Allan and Matthews 2016 p82). Allan and Matthews (2016) have shown that food supply chains account for 92 percent of the world's water and 20 percent of the total energy; in contrast, non-food supply chains explain 80 percent of the world's energy and 8 percent of global water supply.

While the nexus approach has won wide support, it has faced criticisms, too. The approach has had a far stronger appeal among researchers than among practitioners and policy makers. Ever since the nexus approach came into prominence, it has generated a vast and growing corpus of research. Some have argued that there is nothing 'new or innovative' about the concept; it is neither necessary not useful, and that 'interactions involving water, energy, and food have been known and studied for many years by scientists and policy analysts' (Wichelns 2017:113). Others have questioned the scope of work the nexus has promoted. According to Albrecht (et al 2018), between 2011 and 2016, Scopus had recorded 221 published articles on WEF nexus and more book chapters and conference papers; since then more material is getting available in published and other forms. Much WEF research has had to do with models and methods to analyse cross-sectoral interactions and less to do with policy and practice. A systematic review of 245 WEF journal papers and book chapters on WEF nexus by Albrecht et.al (2018)'s concluded *inter alia* that: [a] less than a third used reproducible methods; [b] nexus methods often fail to capture interactions among water, energy and food; [c] it strongly favours quantitative approaches, and [d] deploys social science to a very limited extent, if at all. Common methods used in nexus research include engineering efficiency analysis, supply-chain analyses, and agronomic soil-plant-water relationships. These fail to fully capture the inter-sectoral interdependencies and interactions. Other works offer input-output based quantitative prognoses of cross-sectoral impacts of sectoral policies (Vats 2019). Most importantly, WEF research itself is often a victim of disciplinary silos; and only 1/5th combines quantitative with qualitative analysis. Albrecht et al (2018) conclude:"… while the WEF nexus offers a promising conceptual approach, the use of WEF nexus methods to systematically evaluate water, energy, and food interlinkages or support development of socially and politically-relevant resource policies has been limited." (Albrecht et al 2018:1).

While the vast corpus of new datasets and information generated by nexus approach are very useful for planning and policy making, their impact on policy is yet to be visible. Despite all its infirmities, IWRM was a policy paradigm with a clear, even if unfounded, pathway to guide water policy making and its implementation. Nexus approach, in contrast has largely remained confined to promoting 'nexus thinking' with ambivalent, even confusing, signals for practitioners and policy makers. As van Gevelt (2020:6) points out, "Although our technical understanding of water–energy–food (WEF) nexus dynamics continues to improve, this knowledge has not yet been translated into effective and implementable policy."

This is perhaps not surprising. The challenge of implementing the 'IWRM package' was just to break silos within water economies—irrigation, WASH, hydropower, groundwater, surface water, large versus small irrigation systems, territorial versus aquifer, watershed and river basin boundaries. The challenge of implementing 'nexus thinking' is breaking many more and bigger silos—water, fossil energy, renewables, food-agriculture, poverty and livelihoods, pollution, GHG emissions and the challenge of limiting our consumption of natural resources within the planetary boundaries. Moreover, while IWRM led to groundswell of field research on actual working of new policies and their impact, the 'nexus approach' has generated hardly any such research. Indeed, there has been surprisingly little effort to understand, analyse and synthesize myriad WEF distortions that pervade national water economies, why these persist and how to deal with them. In the remainder of this paper, we explore several country/region case studies, each outlining a WEF dilemma. Towards the end, we attempt a synthesis about drivers of the WEF approach in action.

WEF nexus plays out in various settings. Trade offs in scheduling dam releases for hydropower generation versus irrigation present one such. Water use for cooling in thermal plants is another. Water transpired by biofuel plantations and evaporated by concentrated solar energy generation is yet another. But our case studies focus on energy use in groundwater irrigation. Groundwater overexploitation for irrigation has emerged as the most significant marker of water scarcity and insecurity around the world; and energy pricing and supply policies get directly implicated in the unfolding of the groundwater crisis in many developing countries. The case studies reviewed here are fairly representative of global scenario since they relate to geographies that account for 3/4th of current estimated groundwater use in agriculture (Siebert et al. 2010; NGWA nd; Shah 2009a). The key questions we ask is: how and to what extent has nexus thinking informed water governance in each of these settings and, going forward, how can it be used to create nuance and balance in the play of water, energy and food policies at local, meso, national and regional scales.

In summarizing each country situation, we adapt the Drivers-Pressures-State-Impacts-Response (DPSIR) framework popular in exploring human impact on nature and environment (Spangenberg J. and O'Connor 2009). We begin by briefly outlining the 'nexus context' to highlight the consequences of 'silo' governance. We then summarise main drivers that explain how things have come to be what they are. We then discuss governance response and conclude each case study by teasing out highlights and lessons specific to the geography.

3. Groundwater and Food Self-sufficiency: WEF Nexus in Iran

Nexus Context

The Islamic Republic of Iran is described as a country heading towards 'water bankruptcy' (Collins 2017), with growing dependence of its food production on groundwater over-exploitation. Despite mounting investments in dams and canals, FAO estimates show the area equipped for surface water irrigation in Iran declined by 15 percent between 1993 and 2007, while the area irrigated with groundwater increased by 39 percent during the same period (Nabavi 2018). The number of tubewells increased from less than 50,000 during the 1970's to over 500,000 by 2006 and over a million by 2016. More recently, according to Nabavi (2018), Iran has over 800,000 illegal and prohibited wells accounting for a significant share of the 50 BCM of groundwater abstracted annually. Thanks to this groundwater boom, Iran's wheat output grew rapidly but its key farming areas are witnessing annual decline in groundwater levels of 1 meter on average (Collins 2017). Extensive soil salinization, water quality deterioration, dereliction of thousands of qanat irrigation systems and shrinking of canal commands are the direct socio-ecological outcomes of the boom in tubewell irrigation.

Drivers

Since the Islamic Revolution, the country has pursued national food self-sufficiency as a policy objective, whose importance is heightened, during recent years, by increasingly tough US economic sanctions. A triad of three policy instruments--purchases by government of wheat harvest at guaranteed price above global prices, heavy import duty on grains and subsidized energy supply for pumping groundwater—has been used to achieve national food self-sufficiency and has remained the overarching tenet of governance of irrigated agriculture. In 2016, for example, the government purchased 85 percent of the wheat produced (and mostly irrigated with groundwater) at a price of US $ 405-425/mt, way higher than prevailing global wheat price. In 2015, it imposed import duty on wheat at US $ 45-50/mt which made commercial imports unprofitable (Hogan 2015). Similarly, owners of irrigation tubewells, which are mostly unmetered, pay just 5 percent of the cost to serve electricity (Collins 2017:16). In recent years, there is a growing concern about extensive groundwater depletion, with increasingly strident measures to control overdraft.

Governance Response

Iran has a long history of water law, particularly laws made during the 1940's for the management of qanats (Nabavi 2018). But land reforms of the 1960's changed the *qanat* institutions in fundamental ways. Regulating groundwater draft has been a long standing concern; and a succession of laws including water nationalization was made but widespread groundwater depletion has imbued a new urgency to this concern. Under a series of water laws passed between 1966 and 1978, all water in Iran—surface and ground—became the property of the state. Under the notion of *dasht-e-momno* (prohibited plain), the Iranian Ministry of Energy was given powers to issue well permits, regulate water consumption pattern, acreage under irrigation, well depths, horse power of the pumps and their hours of operation. Recent amendments to the law also addressed the issue of countless unauthorised wells (Nabavi 2018); however, enforcing the new provisions has remained an anathema because of its provision that any action on well owners has to be approved by a court judge[4]. A new bill now provides groundwater managers more teeth in determining fines and penalties for groundwater over-exploitation. To take advantage of these new provisions, the Regional Water Utility of the province, a subsidiary of the Iranian Ministry of Energy, started a new project in 2009 to enforce the water law by deploying Intelligent Energy and Water Meters (IEWM) which measure energy consumption of the electric pump but then use a built-in algorithm to compute the volume of water withdrawn.[5] During 2009-10, 1250 such IEWM meters were installed in groundwater-stressed Esfarayen basin, a 4545 km^2 sub-basin of central Kavir (desert) basin located in Northern Khorasan province. In 2014, Iran's Supreme Council for Water directed by the president mandated installing 'smart metering' systems in all irrigation wells, equipping all drilling rigs with GPS, and recruiting hundreds of troops for patrolling and inspection of tubewells. These policing mechanisms form the main strategy of groundwater regulation (Nabavi 2018).

In Esfarayen, where groundwater levels had declined at 75 cm/year between 1992 and 2008, water quality deteriorated and poorer farmers were forced to quit farming and migrate to towns settling on urban peripheries, there was some evidence of improvement recorded by a 2011 assessment by

[4] Article33 of the Water Nationalization Act of September1968 that "… holders of groundwater use permits are required to install measuring equipment on their wells and, upon request of the Ministry of Water and Power, to submit reports on the amount of water used".

[5] Since it is not in direct contact with water, its performance is not affected by water quality. Moreover, several security features in its design make them relatively tamper-proof. The meter enables the farmer to monitor water use and avoid the penalty for exceeding his quota.

the Iranian Water Authority. Groundwater quota enforcement through regular monitoring of IEWM showed significant behavioural change. There was little tampering with the meters; and culprits were forced to pay for repairs/replacements. Meters were programmed to shut off pumping for three non-growing seasons. Self-monitoring as well as monitoring by the Water Authority encouraged farmers to increase water use efficiency which until now is woefully low at 33 to 37 percent (Jaffery and Bradley 2018). Annual overdraft is believed to have decreased from 30 MCM in 2008 to 10 MCM in 2011 (Vaseteh et al. nd). The annual decline of the water level in Esfarayen basin is claimed to have decreased from 75 cm in 2008 to 28 cm in 2011 and later to 6 cm in 2013 (ibid). The cropping pattern shifted from barley, wheat and watermelon to high-value crops such as pistachio, Persian walnuts, pomegranates, peaches, spinach and tulips. Spread of modern, water-saving irrigation methods began to increase.

Sustainability Prospects

While results of this intervention seem promising in Esfarayen, its impacts elsewhere and in future seem uncertain (Vaseteh et al. nd). The IEWM project made no effort to entail farmer participation; the project was implemented top down by a government agency. Groundwater quotas issued by the Ministry of Energy and enforced by the Iranian Agricultural Jihad Agency are in direct conflict with traditional historical water rights determined under *qanats* that farmers follow (Jafary and Bradley 2018). The project penalises wrong-doers but has no mechanism to reward water savers. A major risk is from the political system, since 'lack of political will prevails generally, and is linked to the extreme political costs of enforcing restrictions on groundwater resources... [Moreover,] punishing illegal water pumping, and closing or destroying wells, are not easy tasks for the state as they come with high political costs, and have no short-term benefit for politicians' (Nabavi 2018:716-717). Moreover, financial surcharges and penalties may lose some of their potency as farmers move to high value crops which deliver high water productivity, making water demand price-inelastic.

Collins (2017) also hints at the potential threat posed by increasing stridency of US embargo on Iran. Political leaders may not take kindly to large scale shifts away from wheat to high value crops 'because allowing extensive mining of groundwater in the near term is acceptable if it yields the impression of food security and greater national self-sufficiency, even though it leaves a much more serious set of problems for future generations of political leaders.' (p7) Such myopic outlook is evident in regularization of illegal tubewells. In early 2010's, a 'blanket issuance of permits for the illegally bored wells (upwards of 190,000, countrywide), decided by the majority vote in the House, is tantamount to rewarding the law-breakers' *(*Rahnemaei et al. 2013: 4)*.*

As Iranian currency suffered devaluation since 2018, government wheat purchase has become increasingly unattractive for growers. Early in 2020, the government announced a new wheat price lower than was widely expected[6]. Many farmers have been selling their wheat to livestock industry than to the government. This has brought to the fore an open conflict between the Ministry of Agriculture which considers grain self-sufficiency sacrosanct and the Ministries of Energy and Water which are under pressure to ease water stress. Moreover, reduction in wheat cultivation may not ease pressure on groundwater as the cropping pattern shifts from barley, wheat and watermelon to high-value crops such as pistachio. Spread of modern, water-saving irrigation methods began to increase; shift to micro-irrigation often encourages farmers to expand irrigated area with water saved.

Governance Lessons

[6] https://www.presstv.com/Detail/2019/09/30/607546/Iran-what-farming-buying-prices-government

1. Every new technology—such as deep tubewells, in this case-- gives birth to new institutional arrangements which tend to crowd out pre-existing technologies and institutions. Carefully designed interventions to integrate the new and the old can improve water governance. In Iran's case, newly implemented water quotas would have received greater acceptance from farmers had they built upon customary water rights around *qanats*.
2. Reviving qanats and improving canal irrigation can ease pressure on groundwater resources; however, Iran's water professionals and leaders think of them as relics of the past with no role in the future of the country.
3. The Iranian Agriculture Jihad Agency, working for national food self-sufficiency works at cross purposes with water and energy ministries. Creating coherence among the objectives these pursue is critical for improved water governance.
4. The political regime will remain under pressure to renege on food self-sufficiency as long as it operates under the 'embargo mindset'. A global pact to eschew food as a weapon of diplomacy can help ushering holistic governance of water and ecosystems.
5. Finally, elected political leaders will block or frustrate policy measures that adversely impact farmer interests due to "extreme political costs of enforcing restrictions on groundwater resources which force farmers to live within hydrological limits." (Nabavi 2018: 715)
6. Water saving impacts of new technologies and economic policies are uncertain as farmers respond to protect their incomes in ways that many not necessarily reduce water use.

4. Saudi Arabia: Food Security or Sustainable Water Governance?

Nexus Context

Like Iran, Saudi Arabia too has valued food self-sufficiency, given its rapid population growth (3.5%/year) and excessive oil dependence of its economy. The global oil crisis of the 1970's heightened these concerns. Lack of renewable water, however, was always a major deterrent to such ambition in the desert kingdom. Given that rainfall is scant and surface water non-existent, Saudi agriculture depended almost entirely on traditional groundwater irrigation mostly from non-renewable aquifers formed, according to researchers, 600 million years ago (Altukhais and Saad, 2002: p.3). For want of money and machines, however, the country's aquifers remained largely undisturbed until the early 1980s when new vistas opened for irrigated agriculture. The oil boom of the 1970's made Saudi Arabia prosperous; and new surveys in the early 1980s estimated the country had some 500 BCM of (mostly unrenewable) groundwater reserves, considerably more than was previously estimated. Together, these unleashed an ambitious program to make the desert bloom. A related objective was to settle transhumant poor *Beduin* communities in productive agriculture. Between 1980 and 2000, Saudi Arabia pursued an aggressive strategy of expanding irrigated food production with the help of liberal government subsidies to groundwater irrigation in general and to growing wheat and barley in particular (Elhadj 2004). For a brief while, this made Saudi Arabia one of the world's leading wheat exporters; but its implications for water security were so severe that after 2000, its rulers were obliged to abandon this path.

Drivers

Saudi Arabia used the same triad of incentive policies as Iran did. Between 1984 and 2000, the Saudi Government purchased wheat from farmers at over US$500 per mt, which was way higher than international wheat price, implying a subsidy of US $ 15 billion for the 16 year period. Subsidies were also offered on purchase of expensive irrigation machinery and energy used to operate it. In sum, during 1984-2000, Saudi government and the private sector invested US$17.9 billion to double the irrigated area from 609,000 hectares in 1980 to 1.12 million hectares in 2000, at a capital cost of

US$35,029 per hectare. Deep tubewell numbers increased from 26,000 to 86,000. Water extraction from “partially renewable” sources climbed from 3.2 Billion Cubic Meters (BCM) in 1980 to 14.3 BCM in 1993. During the 1980-1999 period, groundwater extracted was estimated to be 300 BCM, at a per hectare water use of over 14,000 m^3/year, 2/3d of which was only partially renewable. While rainwater after evaporation for the Kingdom is less than 2 BCM per annum, annual groundwater extractions had increased from 4.3 BCM in 1980 to 6.6 BCM in 1996 (Elhadj 2004). Not surprisingly, an agricultural boom followed, and Saudi Arabia surprised the world by emerging its sixth-largest exporter of wheat (Plumer 2015).

The strategy was unviable in ecological as well as economic terms. Elhadj (2004) estimated that between 1984 and 2000, Saudi agriculture invested US$83.6 billion in government and private money (not including various subsidies) to locally produce foodstuffs that could have been imported for less than US$40 billion. It made even worse environmental sense. In four years between 1997 and 2001, Saudi agriculture exported 12.4 BCM of virtual water in the form of cereals, meat, fruit and vegetables; this was nearly 6 times the country’s domestic water use of 2.1 BCM/year, 3/4th of which can potentially be reused after treatment. Some experts believe 4/5th of Saudi Arabia’s fossil water deposits got used up to support the 20 year agricultural boom. By the close of the millennium, most Saudi aquifers were in a precarious state of depletion, and the country had to invest in 31 massive plants to desalinate sea water to meet half of its domestic water demand[7]. In the Al Hassa Oasis in eastern parts, since time immemorial, 35 artesian springs had supplied domestic as well as agricultural needs under traditional irrigation. Come deep tubewell irrigation during the late 1970’s and by the mid-1980’s, all the natural springs had dried up and tubewell water levels fell to 40-60 m at a rate of 4 m/year (FAO 2009). Some commercial farms witnessed groundwater levels fall by more than 200m. Saline intrusion became endemic and serious in coastal aquifers; and water quality declined in large swathes. In Al Hassa itsef, irrigated area declined from 16000 ha to 8000 ha due to salinization (FAO 2009).

Governance Response

By 2000, Saudi policy makers recognised the prohibitive cost of food independence and virtual water exports. In 2004, a new Ministry of Water and Electricity was mandated to manage water resources and desalination plants. In 2005, General Administration for Agriculture and Irrigation was created to manage irrigation projects. A comprehensive set of rules and regulations was created. “But despite the existence of regulations and decrees to control excessive groundwater use, the government has had limited success” (FAO 2009). From 2015, the government began reducing wheat purchases by 12.5 percent/year and decided to import all wheat from 2016 onwards (Collins 2017). However, like in Iran, Saudi government is finding it hard to put genie of groundwater overdraft back in to the bottle. Even after reducing subsidies drastically, decline in irrigation water use has been far less than proportional to the drop in cereal production or irrigated area. Between 1994 and 1999, irrigated area declined by 23 percent, but water abstraction for irrigation fell by only 9 percent (Elhadj 2004). Initially, government disincentivized wheat irrigation and promoted fruit crops. But this only deferred the problem, since as these trees mature, they will be groundwater-guzzlers (FAO 2009). Moreover, when wheat area was whittled down, farmers made a large-scale switch to alfalfa for livestock farming which uses 5-6 times more water per hectare compared to wheat. So the government relaxed wheat restrictions to curtail alfalfa cultivation. Thanks to a virtual ban on wheat cultivation, by 2018 the wheat area was already down to 10000 ha or less from a peak of 1.1 m ha in 1993 (Elhadj 2004). In 2019, the wheat area was allowed to increase to about 90,000 ha to help small and medium farmers who have been forced to reduce their alfalfa irrigation by over 40 percent to reduce groundwater depletion (Reidy 2019).

[7] https://www.theguardian.com/cities/2019/aug/06/oil-built-saudi-arabia-will-a-lack-of-water-destroy-it

Sustainability Prospects:

What drove the Saudi government to persist with costly food self-sufficiency while risking the country's water security for all time to come? Some observers see no logical basis for the urge for food independence as a national policy objective (Elhadj 2004). However, geopolitics often limits the degrees of freedom policy makers believe they have. Food trade has been used in global diplomacy; and given Saudi Arabia's role in global oil trade, it is perhaps legitimate for its rulers to seek food independence. Indeed, following the 1973 oil boycott and quadrupling of oil prices, US media was rife with reports about threats to withhold food supplies to oil producers as leverage against oil embargo. A second justification for irrigation expansion is helping poor *Beduin* farmers to settle down and improve their lot through irrigation development. In 1968 the Regulation for Fallow Land Distribution was promulgated to settle the *Bedouins*. By 1999, over 600,000 ha were distributed to over 93000 Beduins. However, the bulk of the irrigated agriculture has little *Beduin* footprint. Compared to Iran where 18 percent of the population depends on farming livelihoods in 2013, the ratio in Saudi Arabia is just around 8 percent (Collins 2017). In retrospect, there might arguably have been more benign ways to support this group than by endangering future water security for the entire country. Moreover, there is little evidence that *Beduin* farmers gained from the irrigation boom. In actuality, according to FAO (2009), it has mostly helped large farming companies holding from a few hundred hectares up to several thousand hectares, mostly located in areas with good quality groundwater aquifers. These owned 2/3rd of the newly irrigated areas, with Beduin beneficiaries of 1968 act owning only the remaining 1/3rd.

Governance Lessons

1. Water governance operates through laws, policies and institutions. However, legal and institutional reforms often get compromised or even annulled by policies driven by political stakeholders whose thinking and action are influenced by their particular context, extant contingencies facing them and constituencies exercising pressure on them;
2. Once a farming society is used to groundwater use in agriculture, is hard to wean it away through techno-economic means;
3. Elite interests in farming tend to be more resourceful and versatile than the poor in manipulating institutional rules and norms to capture the resource; these also put toughest resistance to governance improvements.
4. Abjuring the goal of food self-sufficiency has not fully stopped groundwater overdraft in Saudi Arabia

5. Groundwater Governance in Mexico: Governments Propose, Farmers Dispose

Nexus Context:

Agriculture is the largest user of groundwater in Mexico – 18.91 km^3/year of a total of 31.2 km^3/year and is the driver of persistent groundwater depletion. By 2000, 100 of the 653 aquifers assessed were declared overexploited in the country. Things are worse in some states. For example, all the aquifers in the Guanajuato are overexploited with annual abstraction some 40 percent greater than annual recharge, leading to sustained annual falls in groundwater levels of 1.22–3.30 m. Well depths of 200–400 m are now common, while depths up to 500–1,000 m are reported. Irrigation pump sizes range from 75 to 300 HP. Annual land subsidence of 2–3 cm is reported in Bahio as a result (Scott 2011).

Drivers:

Rapid expansion since the 1960s of poultry, beef, and fresh and processed fruit and vegetable production for exports has led to rapid expansion in groundwater irrigation in states like Guanajuato, often with heavily subsidised groundwater pumping for the poor *ejidatarios,* former tenant who were given small plots of land as part of land reforms. Around 2000, the electricity tariff covered just one-third of the cost, implying an annual subsidy of US$592 million on farm power supply at a rate of around US $ 1600/ha. A major subsidy programme to fund land-levelling, sprinkler and drip irrigation systems, and fertigation improved the field efficiency of water use, but did nothing to reduce the pressure on aquifers, because farmers used the water 'saved' to expand the irrigated area.

Governance Response:

Mexico has among the longest histories of groundwater demand-side management through laws and regulations, promotion of water-saving technologies, specification of marketable water quotas (concessions) aquifer level user organizations, and energy pricing (Hoogesteager and Wester 2017). In 1948 Mexico introduced a law to restrict groundwater overdraft and the number of wells in prohibited areas, called *vedas*, in which drilling permits were required. This law was further strengthened in 1972. But its enforcement remained lax and patchy (Scott 2013; Shah 2003). Moreover, illegal well owners were repeatedly reprieved by regular amnesties decreed by the Mexican president. Between 1948 and 1962, for instance, ten *veda* decrees were issued in Guanajuato and in 1983, the entire state was put under a strict *veda*. Yet, the number of wells in Gunajuato increased from 2,000 in 1960 to 19,600 by 2000. There was an on-going battle between the need to regulate groundwater depletion and the politicians' need to attract the farming vote. As a result, *veda* decrees were announced at the same time as subsidies and credit for drilling, equipment, and electricity for new tubewells. In 1992, the new Law of the Nation's Waters mandated a National Water Registry of newly created private property rights in water. Under this, a user could not impound or divert more than 1,080 m^3 of water annually, except by obtaining a 'concession' from the *Comisión Nacional del Agua* (CNA – the federal water agency). All existing and new tubewells were to be registered and assigned a quantitative water right in the form of a concession much like in Iran. In theory, this was to give teeth to the *veda*, but in reality illegal tubewells proliferated.

Against this backdrop, Mexico turned to community-based self-governance through the formation of technical water councils of groundwater abstractors (COTAS), Vincente Fox supported as the vehicle to create a 'new water culture' during his stint as governor of Guanahuato and later as president of Mexico . COTAS were to be participatory institutions that would form and enforce agreements to reduce groundwater abstraction. During the early 2000s, COTAS grew in number and membership, trained several thousand aquifer users, created a tubewell database, identified irregular wells, and became a useful service window to access government assistance, especially groundwater concession titles and 'technification' subsidies for adoption of water-saving technologies. However, the COTAS role in reducing groundwater overdraft was very limited, if at all. They were embroiled in political infighting between states and the federal government. Their representative structure was uneven; large abstractors, like municipalities and large companies, preferred to deal directly with the CNA and bypass COTAS. Since agriculture, which accounted for 80 percent of groundwater use in states like Guanahuato, was not adequately represented, the COTAS had little hope of reducing abstractions. They had no authority or resources and no 'buy-in' from all aquifer users, especially irrigators. The only support came from state funding, which meant that years after their formation, they failed to emerge into genuine, autonomous, user organisations and were overly influenced by the government water agencies.

Sustainability Prospects:

Energy pricing did what COTAS could not. A substantial rise in farm electricity tariff during the early 1990's reduced tubewell energy consumption substantially from 72 GWh in 1989 to 57 GWh in 1992 (Hoogesteger and Wester 2017), suggesting the power of WEF nexus as a tool for holistic groundwater demand management. However, presumably to minimise further pain to farmers, the Congress blocked all subsequent proposals to raise energy prices for farmers. It was only in 2002, under the new Rural Energy Law, when the National Electricity Commission began insisting on valid concessions before granting new electricity connections for wells, that the increase in the number of illegal wells declined. Not having concessions now meant forgoing electricity subsidy, 2/3rd of the rate levied on farmers without concessions. Existing tubewell owners were eligible for subsidised electricity (about 65 percent of the commercial rate) only if they obtained a concession. This pressured existing tubewell owners to secure concessions and made it very difficult, if not impossible, to drill new tubewells in areas covered by the ban. But given the impracticality of monitoring actual groundwater abstractions by farmers, using 'concessions' to restrict pumping was difficult to implement. However, groundwater volumes were now translated into electricity-equivalents and electricity used above the 'concession equivalent' was charged at commercial rates. This created a powerful incentive to reduce excess pumping beyond concessional volumes.

This powerful effect was, however, greatly diluted in 2004 when the government offered additional 20 percent subsidy, on top of pre-existing subsidy- on night power consumption for groundwater pumping. This encouraged a switch to night-time pumping and significantly increased groundwater withdrawals. Moreover, since 2000, farmers had organised into in to a politically powerful interest group-- *Comité Pro-Mejoramiento del Agro Nacional Guanajuatense* (CPANG)-- to resist any further increase in electricity prices. CPANG members began refusing to pay their bills (Hoogesteger and Wester 2017). The federal government kept issuing waivers for repayment of unpaid past dues by defaulting farmers, and in 2009, wrote off US $ 200 million as drought relief. This made energy pricing impotant as water demand management tool (Hoogesteger and Wester 2017: section 3.2.2). On paper, between 2009 and 2013, agricultural groundwater concession volumes in Mexico decreased by 1.96 BCM/year, but in reality, groundwater abstraction as well as unauthorized tubewell connections kept soaring. In 2009, estimated groundwater pumping across the country was 1.36 times greater than concession volumes (Hoogesteger and Wester 2017).

The federal government, through CNA, also tried to create a market in groundwater rights by buying up concession titles from willing sellers. However, this only added to the problem. Many farmers with dry wells sold their titles and used the money to deepen their wells and many others sold part of their concession, but kept pumping as before. Urban developers bought farmers' concessions and drilled in the same aquifer; but farmers continued to pump their wells, too. Without real-time monitoring of groundwater withdrawals by title-holders, the market in titles has only served to increase the groundwater overdraft.

According to Scott (2011) the long-term outlook points to continued depletion. The solutions to Mexico's WEF nexus, in his view, lie in "increasing agricultural power tariffs, eliminating reduced night time tariffs, enforcing legislation linking groundwater extraction to power use, and limiting new power connections for groundwater wells." The moot question is: does any of these pass the political economy test.

Governance Lessons

1. Mexico experimented with some very innovative institutional interventions for sustainable groundwater governance such as COTAS and marketable water rights, but to little avail.

Government can make all the laws and rules it wants; impact is limited by quality of enforcement.

2. The moment a policy begins to hurt farmers, elected politicians—including the president-- act to nullify it.
3. It is hard to create aquifer user organizations that work against the direct interests of aquifer users.
4. Energy pricing and supply could have been a powerful water demand management tool; but political stakeholders blunted it as it began to bite. Similarly, it was energy policy that gave teeth to water concessions as also a means to monitor draft against concessions. But subsidy on nightly power supply again nullified this.
5. Poor enforcement, myopia of political stakeholders, lure of export markets, and resistance by the farming elite interests work against return to sustainable irrigation.

6. China: Regime of Direct Groundwater Governance

Context:
North China plains have emerged as one of the world's largest hotspots of groundwater overexploitation (Wang etal 2019).The region has 30 percent of China's water but produces 2/3rd of China's food requirements (ibid). During the past 50 years, the region' has come to depend heavily on groundwater for irrigation.

Drivers:

However, subsidies on energy or equipment have played a far smaller role in China's groundwater boom compared to other countries covered by this review. Rather, high water productivity, easy availability of affordable irrigation equipment, poor upkeep of canal infrastructure and heavy population pressure on farm land were the key drivers of rapid expansion in groundwater irrigation (Shah 2009a). A far more important driver was privatization of tubewell irrigation under the Household Responsibility System. According to Wang et al (2005), "privatisation of tubewells has affected cropping patterns..[as] farmers move into more water-sensitive and high-value crops."

Governance Response:
Thanks to its unique political context, China has contained cross-sectoral WEF externalities better than many other countries. China bought into the 'IWRM package' like no other country had; it never succumbed to high energy subsidies to irrigation; if anything, many Chinese provinces charged farmers higher electricity tariffs compared to other consumer segments (Shah et al. 2004a). Elsewhere, falling water levels and soring energy costs of pumping would reduce water demand. But, thanks to high farm productivity, Chinese farmers have continued depleting aquifers in northern plains (Wang et al 2019). China has also been vigorous and innovative in ensuring full collection of irrigation and energy fees (Shah et al 2004a). To curb electricity thefts by farmers, China incentivised the village electrician to maximise tariff collection with the backing of the village party leaders in ways that neither Mexico nor Iran nor any other country managed to do (Shah et al 2004b). It implemented a similar arrangement in collecting irrigation fees as well (Shah et al 2004b). Similarly, China introduced early on smart cards to ensure that energy use in irrigation was fully accounted and paid for (Wang et al 2017). While these neutralised WEF interaction from turning into a perverse nexus it became in Mexico, Iran, Saudi Arabia and India, yet China continued to face growing pressures on its groundwater resources (Wang et al 2019). Faced with growing water scarcity and pollution, evident in declining water levels and deteriorating quality, China has now moved to rein in agricultural groundwater demand using a three-pronged strategy: direct regulation, participatory water management through water user associations and outcome-linked-direct-funding to local water bureaus (Lao, Zhu ad Yu 2017; Leshan et al 2017).

Direct Regulation: The quantitative water permits—like Mexico's concessions-- introduced by the 2002 Water Law were expected to catalyze trade in water rights. But the permits remained ineffective and trade in water rights negligible. Since 2016, there are more vigorous attempts to pilot the permits as well as a new water pricing system. However, despite a vast water bureaucracy down to the county level, transaction costs of enforcing water permits and collecting consumption-linked water price has remained a challenge in China.

Participatory Water Management: Inspired by a World Bank project to promote Water User Associations during the 1990s, China mainstreamed WUAs as the chief vehicle for water demand management. By 2014, some 834,000 registered WUAs covered around 30 percent of China's irrigated areas. While these helped somewhat in increasing water use efficiency and reducing conflicts, WUAs in China remain under the shadow of the Village Committees, the lowest rung of the communist party organization.

Outcome-linked-funding of innovative projects: A striking governance innovation is Central Government making direct grants to local governments—cutting out provincial and prefecture levels—based on design of innovative water saving projects/interventions fitting the objectives and guidelines provided by Beijing. Strapped for funds since the abolition of agricultural tax in 2006, local governments compete aggressively for such discretionary fiscal transfers from the central government. Despite limitations, including overregulation by Central Government and regressive bias, this policy has 'showcased' some high-tech approaches to agricultural water demand management (Lao, Zao and Yu 2017; Leshan et al 2017).

One such 'showcase' project is in water-short Shiyang basin (Gansu) whose limited runoff comes from its low precipitation and snowmelt from Qilian mountain range. Rapid increase in surface water diversions upstream to meet growing demand reduced water inflow in to the downstream Minquin oasis by 80 percent between 1950 and 2003. Minquin county farmers responded by launching a tubewell digging spree causing secular decline in groundwater levels generating myriad socio-ecological impacts. In 2006, the central government approved a Comprehensive Water Management Plan (CWMP) proposed by Shiyang River Basin Management Bureau (SRBMB) to:[a] reduce water consumption in the basin from 2.88 BCM in 2003 to 1.97 BCM by 2020; [b] increase surface water flow to Minquin oasis from 97 MCM to 290 MCM;[c] reduce Minquin county's groundwater abstraction from 514 MCM in 2003 to 86 MCM and reduce the entire basin's annual groundwater use from 747 MCM to 417 MCM over this period.

This experiment became a showcase because SRBMB achieved all these objectives in 2014, way before the target date of 2020. An official evaluation showed that agricultural water-use efficiency increased from 0.53 to 0.58; water used for irrigation reduced from 1.71 billion m^3 to 1.39 billion m^3, and water use per acre of irrigated land reduced from 626.72 m^3 to 430.25 m^3. Water productivity jumped from 1.93 Yuan/m^3 in 2009 to 9.33 Yuan/m^3 in 2015 (Leshan et al 2017).

On the downside, coercive enforcement accelerated exodus from farming, with mounting ranks of 'ecological refugees' who had begun leaving their farms for towns and cities to escape the groundwater crisis. Thanks to the government policy of 'close the wells, abandon the land', the farming area dropped by 40 percent from the 2007 levels as farmers moved on to non-farming livelihoods. The farmers in Minquin surveyed by a researcher had lost an average of 0.231 ha/household of farm land (Aarnoudse et al, 2012; He and Perret 20120). Between 2007 and 2014, 60 percent of the working age farmers left for off-farm livelihoods; and those who stayed derived 43 percent of their income from off-farm sources, up from 26 percent in 2007.

Direct regulation, top-down, played a large role. 3318 tubewells were closed; and abstraction was severely curtailed on others. Irrigated area was reduced by 663000 mu. Growing of water-loving onion, corn and wheat was forbidden. A typical household water permit allowed 2.5 mu of irrigation at a rate of 415 m^2/mu. Those with more land could get limited additional water but only for greenhouses and at a steep price. Smart cards with readers installed on each tubewell were used to monitor abstraction against quota on real time basis in County Water Bureau. Canal water price was increased 2.5 times in 7 years and vigorously collected. Groundwater price was collected in two parts—Yuan 2/mu and Yuan 0.174/m^3 of water drawn. Green houses and drip-irrigated farms enjoyed 20 and 50 percent discount respectively. For others, a 'water price ladder' was enforced (Shah 2017, Aarnoudse et al 2012, He and Perret 2012): water use above the permitted quota entailed steep penalty over base price: 50 percent up to an excess of up to 30 percent over the sanctioned quota, 200 percent for 30-50 percent excess use and 300 percent for an excess of over 50 percent over permitted quota. Attractive subsidies were given for greenhouses, grape wines and fruit trees. However, the hope that the 'water permit regime' would catalyze broad and deep water markets was belied.

Central government's support of 5 billion Yuan to CWMP was another major reason for success in Minquin county. It financed concrete lining of canals, piped water distribution, subsidies to drip irrigation and greenhouses, promotion of medicinal crops, fruit trees, cotton and sunflower. Besides CWMP, funds from Sino-Israel Financial Cooperation were used to demonstrate and install Israeli high-tech automated irrigation systems. The long term sustainability of these automated systems, their wider diffusion among small farmers are important issues as are the eco-system impacts of reconstructing concrete-lined canals.

In 2014, 874 WUAs deployed 2517 water managers and 'served' 308,000 households operating 2.37 million mu of irrigated farmland in Shiyang bsin. These played a central role not so much as farmer organizations but as implementers of government policies and programs. Their key role was to collect irrigation fees, buy water in bulk and allocate it among members. Director, assisted by a Deputy Director, of the WUA board, mostly Village Committee members, were paid a fixed salary of 3000-4000 Yuan and a profit share of 12000-16000 Yuan depending on fees collected, irrigated area and their performance. The Director received 70 percent of this, in addition to his other salaries, and happily operated as water-manager-in-chief for the village. He took care of the water infrastructure, was the point person for all water complaints. WUA Director ensured that water fee collection increased from 60 percent earlier to 90 percent, water conflicts fell from 10 per village to zero, and water management in general improved—although there was nothing participatory about the way WUAs functioned. In sum, much of the groundwater governance was done by the water user committee and the local government, while farmers paid the bills and accepted the outcomes (Shah 2017: 34).

Shiyang basin's CWMP is regarded globally as an exemplar of successful direct water demand management. But it has had social costs, which were borne by farmers. It reduced greatly the basin's role as a key grain producing region. Moreover, the program was implemented top-down, with little say for farmers in decision making, with help from WUA directors who were rewarded for performance in enforcing permits and collecting water price. He and Perret (2012, p. 11) concluded: "This case is a successful model, but not all …regions …can copy these experiences. Government dominated …in the administration domain, but also in market and civil society domains. Government helped to establish the market mechanism through pricing… and helped to establish the self-governance …at village level." (cited in Shah 2017: 35). Leave alone replicating this model elsewhere in the emerging economies, its out-scaling within China itself may prove problematic if it threatens large decrease in grain production and national food sufficiency (Leshan et al 2017).

Governance Lessons

1. China successfully showcased effective approaches to controlling and reversing groundwater overdraft. However, how far will these be scaled out within China or replicated elsewhere is an open question.
2. Strong enforcement capacity down to the county and village levels made all the difference. With backstopping from the communist party cadres, SRMB intervened deeply in all three water governance roles: provisioning and proscription, promotion and regulation, incentives and disincentives.
3. The social costs of curtailing groundwater use are high; but the top level political decision makers have favoured sustainability over social equity.
4. Even with strong party and village organization, institutional interventions—such as WUAs and markets in water permit—have not worked as well as was expected.
5. Chinese political system does not commonly retract from a policy otherwise considered necessary simply because farmers oppose it. Such retraction has been rampant in Iran, Mexico, India and elsewhere.
6. China's unique political system has shaped its water governance; both Iran and Saudi Arabia have authoritarian regimes; but none has a strong party and state machinery down to the village level that can use state power to force behaviour change to achieve the goals of the top leadership.
7. Politico-administrative context and ecological contingencies generated pressures for holistic management of water and ecosystems; affected constituencies were left to adapt.

7.Barind Model, Bangladesh: Centrally Managed Distributed Irrigation Service

Nexus Context:

The context of Bangladesh's Barind project is different from other geographies covered by this review. Agricultural stagnation and dependence on rice imports were among the key challenges that confronted Bangladesh on Independence in 1971 (Boyce 1989; Palmer-Jones 1999). Belated adoption of shallow tubewell irrigation during the 1980's, which made possible a bumber crop of irrigated pre-summer (*boro)* rice, addressed both these challenges. Thanks to budgetary constraints, Bangladesh steadfastly steered clear of energy subsidies for groundwater irrigation, despite the debilitating poverty of its millions of small farmers. High energy costs have deprived Bangladesh's agrarian poor from benefitting fully from its abundant water resources (Shah 2007). How to make irrigation access pro-poor without introducing energy subsidies has been a challenge. The Barind model in drought-prone (but rainy) north-western Bangladesh offers an interesting large scale intervention of holistic, participatory tubewell irrigation development with many lessons for creating a pro-poor WEF synergy.

Drivers:

The Barind tract, in the catchment of Ganga (Padma), includes Rajshahi, Dinajpur, Rangpur and Bogra districts of Bangladesh besides Maldah district of West Bengal in India. This large tract with hard red soil has heavy monsoonal rainfall of 1600 mm (although low relative to 2550 mm for Bangladesh as a whole). Yet for the want of winter and summer irrigation, its 1.44 million ha of farming areas remained largely unproductive depending only on a rainfed monsoon crop. After monsoon, the landscape would turn extremely dry with mud cracks sometimes 15 meters deep. Scattered private tubewell owners made hay by trading irrigation for summer paddy for 1/4th or more of the value of irrigated output. During the 1970s and earlier, Barind lagged behind the rest of what became Bangladesh in agricultural growth and rural development.

Governance Response:

In 1985, the Bangladesh government established Barind Multipurpose Development Authority (BMDA) as a para-statal and charged it with the implementation of Barind Integrated Area Development Project (BIADP). The project included a diverse array of interventions such as road development, agricultural extension, electrification, drinking water and even pond construction. However, the project's experimentation with government-managed participatory tubewell irrigation has been by far the most innovative, distinctive and impactful.

By the mid-1980's, India, Pakistan and Bangladesh had all tried managing public tubewell irrigation through government corporations or parastatals managing public tubewells. But these programs failed everywhere thanks to bureaucratic lethargy, inefficiency, lack of service orientation and poor operation and management (O&M). The Barind project has proved an exception as an irrigation parastatal because it evolved a different participatory management model with following features:

<u>Demand-led Intervention</u>*:* Government tubewells are generally made on sites favourable for groundwater supply. BMDA instead followed the demand. Farmers desiring a tubewell must come together with a minimum command of 30 acres, form into a WUA, pay a token membership fee, and apply for a tubewell where upon BMDA staff undertake a survey, examine resource availability and proceed to install a tubewell of 0.5-2 cusec capacity depending upon groundwater conditions; the WUAs are responsible for its smooth functioning, for water distribution, operation and maintenance (O &M) and safe custody of the equipment;

<u>Full cost recovery and pre-paid metering</u>*:* Farmers have to use pre-paid smart-cards (or coupons) on Chinese-made meters (or in earlier years, pre-paid coupons) to buy the exact amount of irrigation required; the price covers the full cost of energy, O&M and establishment costs (but not capital costs which are covered by government); but is still 40-60 percent lower than the high monopoly price private tubewell owners charge;

<u>Incentivized operators</u>*:* one among the group members, increasingly a woman, is appointed tubewell operator and gets paid a 10 percent commission on irrigation sales. Mobile Vendor Units (MVUs) recharging smart card and selling coupons, also operated largely by women, too get 2.5 percent commission on sales. Evaluations suggest that the system is regularly monitored and vigorously managed. The BMDA officials daily collect used coupons and monitor meters to record pump usage and tally it with electricity meter reading.

<u>Technical Backstopping:</u> BMDA aims at full utilisation of irrigation assets; its bevy of technicians available on call fix maintenance and repair issues expeditiously to maximise uptime of tubewells;

<u>Technical Innovation:</u> To capture groundwater from Barind's peculiar geology, BMDA technicians experimented with and developed an 'inverted tubewell' to extract water from a water-bearing formation between 90 and 130 ft between two impermeable layers;

<u>Efficient service:</u> To minimise water losses in conveyance, BMDA has invested in replacing open channel distribution by buried pipe networks that effectively reduce irrigation cost to farmers;

moreover, all BMDA tubewells also created overhead storage tanks on tubewells to ensure domestic water security for households;

Sustainable Resource Management: Rapid expansion, especially in *boro* irrigation due to BMDA tubewells has created pockets of groundwater depletion in the hard Barind areas. BMDA began to address these concerns in right earnest. New tubewell construction has been stopped in such areas. Instead, BMDA has begun new irrigation by rehabilitating old canals; it began investing in afforestation, rainwater harvesting, re-excavating derelict ponds and old canals. It also launched extensive campaigns to wean farmers away from water guzzling *boro* rice to other water-saving crops (like wheat, maize, pulses, oilseeds, cotton and spices apart from converting paddy fields into fruit gardens like mango and guava that are proved to be highly remunerative). BMDA also aggressively promoted Alternate Wetting and Drying (AWD) method in place of flood irrigation of rice; it trained farmers to use a simple device—a 25 cm PVC pipe or bamboo with perforated side—to gauge soil moisture level and choose the right time of irrigation. Banerjee (2016) in his field visits met farmers who had reduced *boro* rice irrigation frequency from thrice a month to twice a month.

Groundwater Governance Regime: Bangladesh had issued a Groundwater Management Ordinance way back in 1985 to regulate runaway groundwater abstraction; but this remained on paper. Local politicians ensured that 1987 rules for minimum distance between tubewells were annulled in 1992. As BMDA became a dominant player in Barind's groundwater economy, it issued its own irrigation policy and rules in 2008 which prohibited private tubewells in the command of BMDA tubewells, thus enhancing its power to enforce sustainability and O& M norms on its members. Since 2016, when depletion issues came to the fore, BMDA completely stopped new tubewells and refocussed its strategy on surface water development, conjunctive use and aquifer recharge. BMDA also successfully controlled proliferation of private tubewells because of its better service, lower price and ability in winning farmers' trust.

Frugal Organization and Tight Management: In 2016-17, BMDA's 200 strong technical and managerial staff managed irrigation of 1/3rd of Barind's cultivated land, undertook rehabilitation of ponds, canals and check dams, trained farmers, afforested wastelands, constructed roads and did several other things. The staff cost was 18-20 percent of gross revenue during 2013-16; and the tubewells generated annual surplus of around 15-17 percent of gross revenue. This is commendable when compared to canal irrigation systems and public tubewell corporations throughout South Asia which recover just 8-20 percent of the O&M costs from Irrigation Service Fees.

Impact:
The Barind project has been prodigious in output, outcomes and impact. BMDA's 15813 deep tubewells served irrigation to 496,200 hectares in 2015-16 (Banerjee 2016) in a largely rainfed landscape where scattered private shallow tubewell owners ruled irrigation as water lords. The irrigation cost the farmer pays of Rs.1000-1200 taka (US $ 90—108.8/irrigation/hectare) to BMDA is a lot cheaper than Taka 2500-3000/bigha (or US $ 225-270/hectare[8]) that farmers pay to private shallow tubewell owners (Banerjee 2016). In 2015-16, BMDA served nearly a million farmers. BMDA share in the area irrigated was 2/3rd and in farmers served with irrigation 56 percent (see table 1). Its affordable irrigation rice alone benefited its members to the tune of (estimated) tk 100 million/year; the actual benefit is larger since most members would have had no irrigation source since BMDA tubewells are concentrated in hard Barind pockets where BMDA's inverted tubewells are far more successful than normal tubewells. BMDA thus became dominant enough to assume a credible role in groundwater governance.

[8] US $ = 82.64 Bangladesh Taka in 2017; I hectare = 7.5 Bangladesh bigha

Table 1 Operating Results of BMDA, BADC and Private Tubewells in Barind region 2015-16[9]

	Total electric DTWs	Total area served (electric & diesel) (ha)	Average area served/TW) (ha)	Farmers served	Farmers served/tw
BADC	2943	82117	27.9	293986	100
BMDA	15319	492208	32.1	952504	62
Private	5678	191749	33.8	458156	81
Total	23940	766074	32	1704646	71

Among all the country case studies reviewed in this paper, Bangladesh's Barind project is by far the best example of proactive and holistic governance of the WEF nexus in a democratic political set up. For its sterling success, the Barind project has remained under-assessed and unappreciated. Kang (2013) a close observer has marvelled about 'Barind's Three Crop Revolution' (Kang 2013), and Zaman (2013) called prepaid metering system as 'A Revolutionary Change' (Zaman 2013). Tubewell irrigation increased Barind's cropping intensity from 117% to 200% while Bangladesh's national average was 174.64% (Jahan et al 2010). In 2014-15, Rajshahi and Rangpur divisions that encompass Barind reported higher yield/hectare of paddy in aus, aman and boro seasons compared to Bangladesh as a whole.[10] The institutional arrangement is incentive compatible and creates supplementary jobs. The BMDA dealers supplement their income through commission on coupon sales and recharge of cards. Farmers, many of whom are women, double up as tubewell operators and earn supplementary income by being 10 percent commission.

Why has BMDA succeeded all these 35 years in creating a brand new groundwater irrigation economy and in managing it sustainably remains an enigma. It is puzzling that, unlike in Iran, Saudi Arabia, India and Mexico, politicians in Bangladesh have actually helped BMDA to pursue the path it has chosen leading to the triad of goals of productivity, equity and sustainability. BMDA board is chaired by a farmer politician and according to Banerjee (2016) who interviewed him, he wanted BMDA to pursue even more vigorously the mandate of holistic, sustainable pro-poor governance of groundwater irrigation.

Governance Lessons:

1. BMDA harmonized context, contingencies and constituencies to create an innovative water governance regime. The Barind model is replicable in landscapes at early stages of groundwater development.
2. The secret is BMDA's organizational success as a centralized provider of decentralised irrigation service. Many groundwater parastatals in India and Pakistan were created to do precisely this but went defunt because of bureaucratic lethargy, inefficiency, poor service and inability to compete with private irrigation service providers.
3. The Barind project has achieved pretty much what the Shiyang River Basin Authority did in terms of demand management, but without the social costs imposed by the latter.

[9] Source: Minor Irrigation Survey 2015-16, Ministry of Agriculture, Government of Bangladesh
[10] Yearbook of Agricultural Statistics, 27th series, Bangladesh Bureau of Statistics, 2016, www.bbs.gov.bd

4. Barind project is the only case where the political class helped and nurtured the development of a holistic water governance regime.
5. The Barind project proved that centralised provision of decentralised irrigation service can achieve social ownership and control over water in ways that laws nationalising water could not achieve in countries like Iran and Mexico.

8.Gujarat's *Jyotigram Scheme*: Indirect Route to Holistic Water Governance

Context and Drivers

We use Gujarat as a case study representing the groundwater governance challenge in some 1.8- 1.9 million km^2 semi-arid landscape of north-western, western and peninsular India. Over the past 50 years, South Asia—especially, all states in semi-arid western India, Balochistan and Khaibar Pakhtunwa in Pakistan-- has been the grand theatre where a perverse nexus played out between energy subsidies and groundwater depletion. Begun as a benign policy to expand irrigation by exploiting aquifer storage, which then appeared to be inexhaustible resource, in time created a vast invidious political economy with economy-wide ripple effects. In terms of people, land and water volumes affected, the play of the nexus in South Asia has impacts orders of magnitude larger than Iran, Saudi Arabia, Barind and Mexico combined. We summarize seven of the key impacts of perverse WEF nexus in the region.

1.<u>Food Production and Agrarian Livelihoods</u>*:* Electricity subsidies encouraged private investment in tubewell irrigation on a massive scale, accelerated groundwater irrigation, stimulated high tubewell density (tubewellls/1000 ha), ensured high operating factor of average tubewell and, in general, boosted food and livelihoods security at household and national level. Electricity subsides are responsible for larger area brought under reliable irrigation than all government investments in canal irrigation have managed to do since the time of East India Company (Shah 2009a). Indian data shows that: [a] districts with high groundwater irrigation have higher than average value of crop and dairy output per hectare of net sown area; [b] some of the most productive agricultural districts also have intensive groundwater irrigation; [c] intensification of dairying and livestock production is strongly associated with intensive groundwater use. Groundwater offered better drought resilience and made famines history in South Asia. By enhancing food and livelihood security to the poor, it prevented social unrest, helped farmers to intensify and diversify land use and increased the 'carrying capacity' of the agricultural economy (Shah 2009a).

2.<u>Water Markets</u>*:* Low-cost energy supply in water abundant areas created highly competitive, informal pro-poor water markets as in central Gujarat (Shah 1993) and with electric tubewells in West Bengal (Mukherji 2007). Millions of marginal farmers and tenants in South Asia depend heavily on purchasing irrigation service from tubewell owners. Where tubewell owners depend on expensive diesel to pump groundwater, as in eastern India, Nepal terai and Bangladesh, high diesel price creates monopoly water markets with buyers paying 25-30 percent of output as water price (Shah 2009a; Kishore et al 2015). Tubewell owners here often force marginal farmers and tenants into disadvantageous tenancy contracts as recorded by Shah and Chowdhury (2017) in West Bengal. Many have argued that electricity subsidies benefitted only the better off tubewell owners (Howes and Murgai 2003; Shah et al 2020). However, marginal and tenant farmers would have been far worse off in the water markets but for subsidized flat tariffs (Shah and Chowdhury 2017).

3. Inefficient use of energy and water: Since groundwater is not priced in South Asia, energy prices convey to the farmer scarcity value of both energy as well as water. In Indian Punjab and other states where energy is supplied free or at heavily subsidized cost, farmers use energy and groundwater as if they had no economic cost (Modi 2010). In contrast, in much of the Ganga basin, which is flush with groundwater, high diesel prices force small farmers to use less irrigation than is beneficial in private and social terms.

4. Electricity industry: In many Indian states, electricity used in groundwater irrigation is 25-30 percent of total consumption in the economy (Shah 2009a,b; IDFC 2012; Monari 2002). Here, power subsidies cause financial drain and imperils investment in energy development (IDFC 2012). Subsidised supply to farmers also encourages rampant theft by non-farm users who otherwise are subject to higher tariff rates (Shah and Verma 2008). It also imposes a tax on honest commercial and industrial users who pay unduly high power tariff to cross-subsidize irrigation (Monari 2002; World Bank 2001). Maharashtra state of India, for example, charges industry US c 7.15/kWh to cross-subsidize free power to farmers. The high tariff is a significant competitive disadvantage while attracting investment in industries.

5. Groundwater Depletion and CO2 emission: In the absence of farm power subsidies, 'sustained groundwater over-draft tends to be self-terminating' (Vaux 2011) as rising cost of groundwater irrigation forces farmers to switch to rainfed farming. With free electricity supply, farmers do not worry about groundwater depletion and engage in competitive deepening of borewells to chase falling groundwater levels, in the process jacking up the subsidy bill further. Since they can keep doing this by replacing small pumps by bigger ones, they show little enthusiasm for groundwater recharge to arrest resource depletion—except in hardrock aquifers where groundwater runs out before free energy does. Power subsidies also created asymmetries between cropping patterns and water resource endowments. Water-short Punjab began growing water-guzzling rice in vast areas just as drought-prone western Maharashtra emerged as a sugarcane hub of India. Finally, intensive use of thermal electricity and diesel in pumping has increased the carbon footprint of groundwater irrigation to 5-6% of the total for India; and deep tubewells have a lion's share in this (Shah 2009b; Nelson et al 2009).

6. Public and Community Irrigation Systems: Farm power subsidies are an important reason for stagnation in canal as well as tank irrigation systems in many parts of South Asia (Shah 2009a) just as they have marginalised *qanats* in Iran. As WEMs enjoying free or subsidized electricity proliferate in command areas of public and community irrigation systems, farmers stop demanding quality irrigation service from canal or tank managers which over time tend to decline and decay. Deteriorated canals become inefficient recharge canals while irrigation occurs through tubewells as evident in Indian Punjab and Haryana. These were largely canal irrigated until the 1960's but are predominantly tubewell irrigated today.

7. Political Gridlock: By far the most pernicious fall out is the emergence of a political gridlock which makes subsidy reduction or rationalization politically extremely costly in states like Indian Punjab where massive private tubewell investment was stimulated by energy subsidies in the past. West Bengal as well as Bangladesh which began tubewell electrification later than states in western India could not only meter tubewells but charge farmers commercial tariff (Shah et al 2008) when tubewell owners were too few to organise political action. Elsewhere, this was not so. Years ago, when subsidies were first started, the prognosis of its future positive and negative impacts was hazy. By the time, the perverse impacts became visible, it became politically costly to change the policy. Millions of farmers, having made massive private tubewell investments based on past promises of energy subsidy, congealed into a political interest group that compelled political decision makers to continue with the subsidy, as happened in Mexico and Iran. Arguably, elected political leaders under

parliamentary democracy submit to farmer pressure more easily than leaders in China do. Since 1990, at least two chief ministers of Indian states (Chandrababu Naidu in Andhra Pradesh, Digvijay Singh and Madhya Pradesh) suffered electoral reverses because they publicly resolved to meter tubewells. In Pakistan, the only attempt to meter tubewells was made by the Pakistan army under General Musharraf (Shah et al 2004c; Shah 2009a); the attempt fizzled out as soon as Musharraf was ousted. Global nexus debates sometimes imply that policy makers are oblivious to pernicious cross-sectoral impacts of nexus policies. The truth is they are stuck in a political gridlock not of their own making and would heartily try solutions as long as they do not demand their political hara-kiri. One such was tried during early 2000's in India's western state of Gujarat. If Barind project in Bangladesh and Shiyang Basin Authority's work in China are examples of direct instruments of groundwater governance, the Gujarat experiment is a case of indirect instrument of holistic groundwater governance. By definition, an indirect instrument which skirts difficult direct decisions—such as metering tubewells, charging commercial energy price, banning new tubewells—is easier to implement but is likely to produce similar outcome, albeit on a smaller scale. Because it does not launch a frontal attack on the problem, it is sometimes referred to as second-best. In executing such a strategy, Gujarat totally bypassed water administration, and acted in the energy sector to produce sweeping changes in the water sector.

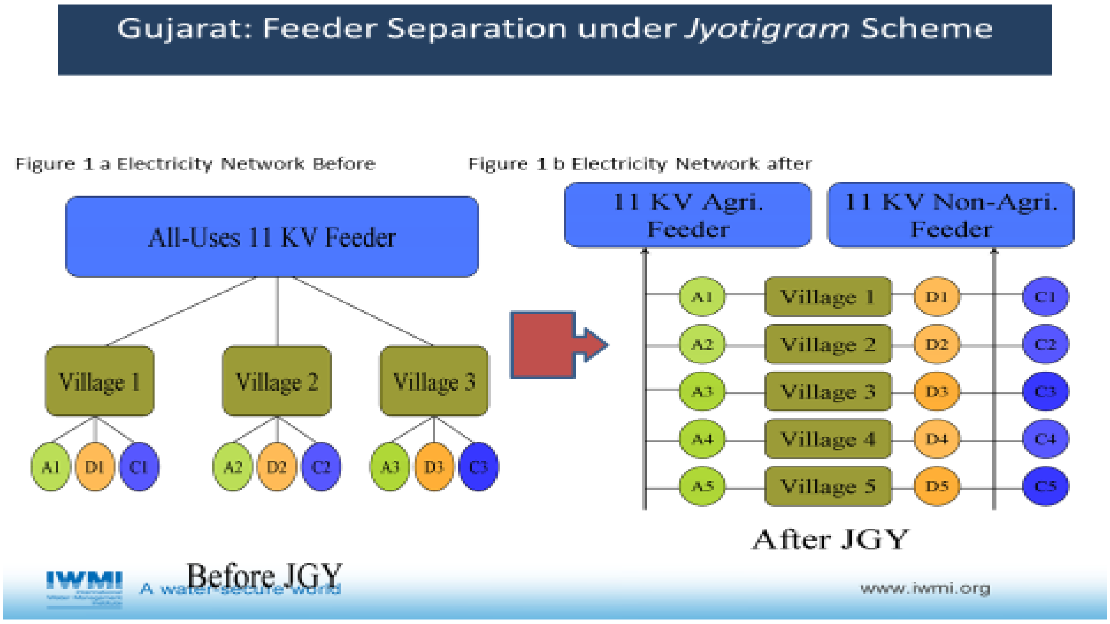
Governance Response:

In 2001, as the new chief minister of western India's semi-arid state of Gujarat, Narendra Modi tried, with some success, a nexus solution without doing political hara-kiri. He had inherited a state with a nearly bankrupt government electricity monopoly, an electricity distribution network in advanced state of disrepair and a groundwater-irrigated agricultural economy facing persistent decline in groundwater levels in vast areas. His instinctive move was to meter tubewells and charge farmers tariff linked to energy consumption. However, he was surprised by the scale and stridency of opposition from farmer lobbies who not only rejected metering but demanded better quality of power supply.

Around 2000, a group of researchers had argued that metering tubewells and charging commercial tariff to farmers would impose high political costs and that a second best, but acceptable, option might be 'intelligent rationing' of quality farm power supply. Their argument was in four parts: [a] prevailing system of providing 16-18 hours daily of poor quality rural power supply at subsidized rate was wasteful and reduced the wellbeing of farmers as well as non-farm rural electricity consumers; [b] farmers' demand for electricity is derived demand for irrigation water; and as long as farmers get sufficient electricity on 40-45 days of peak irrigation demand, they would be willing to accept reduced hours of supply during the remainder of the year; [c] improving the quality of power supply by improving voltage, minimizing interruptions and proper maintenance of distribution network would increase farmer acceptance of rationed supply; [d] rationing of farm power supply would reduce aggregate subsidy burden and cap groundwater withdrawals without hurting farmer welfare (Shah et al 2001; Shah 2009).

Modi fought 2002 election of Gujarat assembly on the promise of round-the-clock uninterrupted electricity supply to villages, something that no Indian state had achieved. But doing this without controlling tubewell pumping would be disastrous for elecricity utilities as well as groundwater aquifers. The only viable way was to ration energy supply to tubewells. In 2003, he launched *Jyotigram* (Lighted Village), a campaign to physically separate agricultural electricity feeders from non-farm rural feeders by rewiring of rural power grid in 1000 days. His leadership skills got proved when Gujarat completed this between 2003 and 2006 at a modest cost of US $ 250 million. The campaign affected over 9000 rural electricity substations, 18000 villages, 40 million people, 3.5-4 million hectare of irrigation. This done, the government announced 8 hours/day supply to tubewells on a weekly roster. Every village gets its 8 hours during the day in one week and during the night in the following week. There was then, for the first time ever, round-the-clock three-phase power supply to all non-farm users—homes, schools, shops, cottage industry, institutions. During that period, the electricity utility was reorganised and modernized; power generation capacity was ramped up; and power distribution network thoroughly overhauled.

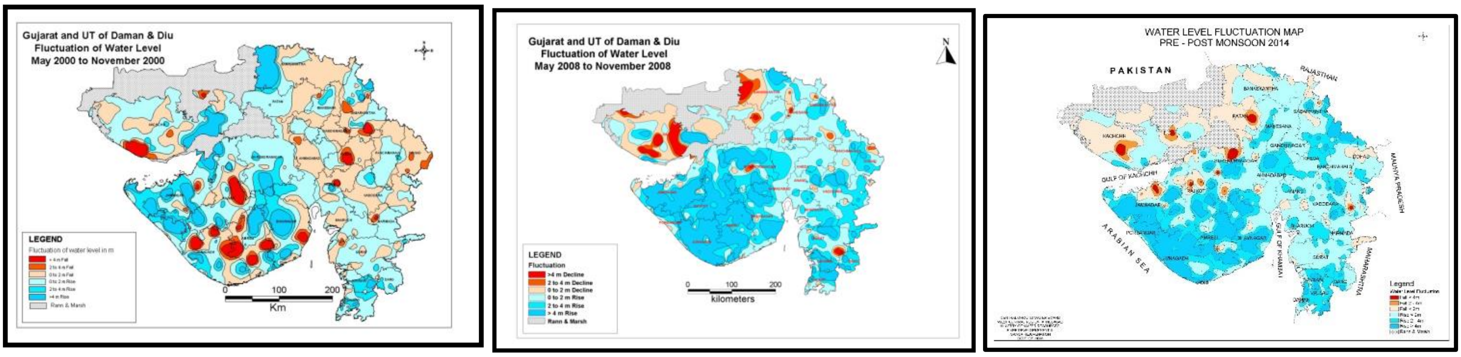
Figure 2



Impact:
Evaluations and studies after 2006 showed *Jyotigram* to be a resounding success on many counts. Gujarat became the first Indian state with round-the-clock supply of reliable and uninterrupted power supply leading to massive improvement in quality of life as well as rural economic activity. Farmers grudged reduced hours and nightly power supply half the weeks, but surveys showed they were happy with improved voltage, timeliness, minimal interruptions and, in general, better quality (Shah and Verma 2007). Farmers in groundwater-stressed northern districts accepted rationed power supply as a hidden blessing; but for power rationing, they knew all along that they faced totally depleted aquifers in a few years. All new tubewell connections issued after 2006 were compulsorily metered (thought with a subsidized tariff); and old flat tariff connections were subjected to 120 percent hike in flat tariff/HP. The finances of the power utility turned around; in 1999-2000, it had made losses of US $ 550 million; in 2006, it turned in a small profit. Since then, Gujarat's 4 power distribution companies are among the few in India that make profits year after year. Between 2001 and 2006, aggregate electricity consumption in tubewell irrigation fell by 37 percent from 15.7 billion kWh to 9.9 billion kWh. Yet, instead of stuttering, Gujarat agriculture experienced a boom. During early 2000's, when agricultural GDP of India was growing at 2.9%/year, Gujarat's farm GDP grew at 10%/year. *Jyotigram* won Modi 2007 state election as well. But *Jyotigram's* eco-system impacts were heightened by a complimentary strategy that Modi had inherited but scaled out manifold.

Over half of Gujarat is underlain by hard-rock aquifers with limited storativity. Since the late 1980's, at the behest of Gurus with mass following, religious organizations, NGOs and philanthropies, hard-rock areas of Gujarat witnessed a mass-based water conservation and groundwater recharge movement (Shah 2000; Shah 2009). In 2007, the government of Keshubhai Patel began lending financial support to this community-based movement. When he came to power, Modi hugely expanded and streamlined government support to the groundwater recharge movement. By 2008, 113,738 check dams, 55,917 *bori bandhs*[11], and 240,199 farm ponds were constructed by communities, in addition to 62,532 large and small check dams constructed by government machinery (Shah et al. 2020) —all in a campaign mode. Had Gujarat inherited Iran's *qanats,* there is little doubt Modi would have launched a massive campaign to restore them in support of the burgeoning tubewell irrigation economy. Studies have shown that hundreds of thousands of such decentralised structures—check dams, percolation ponds, recharge wells, etc—increased groundwater availability during dry seasons and made Gujarat agriculture more drought-resilient. The demand-side intervention of *Jyotigram* and supply-side intervention through recharge movement made Gujarat the only state of India where groundwater situation has steadily improved in the new millennium. Figure 3 shows three maps developed by India's Central Groundwater Board. They show that the areas where groundwater levels were falling *during monsoon* (red pockets) declined from 2000 to 2008 and further in 2014.

Figure 3 Progressive Improvement in Groundwater regime in Gujarat: 2000-2014



What happened in the aftermath of *Jyotigram'*s success indicates trade-offs political leaders face all the time between people and eco-systems. One downside of *Jyotigram* was that it hardened village level water markets (Shah and Verma 2008; Shah and Chowdhury 2017). Studies showed that power rationing reduced tubewell water availability and raised its price for resource poor marginal and tenant farmers dependent on purchasing irrigation service (Shah and Verma 2008; Shah et al 2008). Modi government took this feedback seriously; to help the poor, it launched a special scheme to issue new electricity connections for small pumps for schedule case (SC) and schedule tribe (ST) farmers, some of the poorest in Gujarat peasantry. His successor went further. In December 2019, Gujarat's current chief minister, issued a full page newspaper advertisement announcing the pro-poor initiatives of his government: one of the long litany of achievements was the issue of 463,000 new tubewell connections issued in just past 4 years (taking Gujarat's total electric tubewells to 1.6 million) (Sunday Express, December 29, 2019). Over time, this reduced the effectiveness of energy rationing to limit groundwater draft and brought to the fore new tensions between the goals of saving water, reducing losses of electricity utilities, containing carbon footprint and providing succour to the poor.

Governance Lessons:

1. Gujarat achieved ecosystem impacts similar to Barind project in Bangladesh and Shiyang basin in China—but on a much larger scale-- by devising a regime of indirect instruments which worked around popular opposition to government interventions
2. Gujarat's strategy of intelligent power rationing and decentralized groundwater recharge reinforced each other to magnify ecosystem benefits.

[11] Low cost check dams made with sacks full of sand.

3. Modi accumulated political capital by successfully projecting these as some of his government's key achievements. During the first 15 years of the new millennium, Gujarat's agricultural economy grew at astoundingly high CAGR of 9 percent/year implying that improving groundwater sustainability had not imposed any cost in term of livelihoods as Shiyang basin's strategy has imposed.
4. In terms of scale—area, number of tubewells, farmers affected, and volumes of groundwater—Gujarat's groundwater governance reform produced by far the largest impact amongst all geographies covered in our review.
5. Feeder separation was replicated in Punjab, Haryana, Madhya Pradesh and other states, but as a 'technical fix' without complementary water interventions and, as a result, produced limited impacts. This highlighted the criticality of holistic interventions.

9.Gujarat's Program to Use Solar Pumps for Groundwater Governance

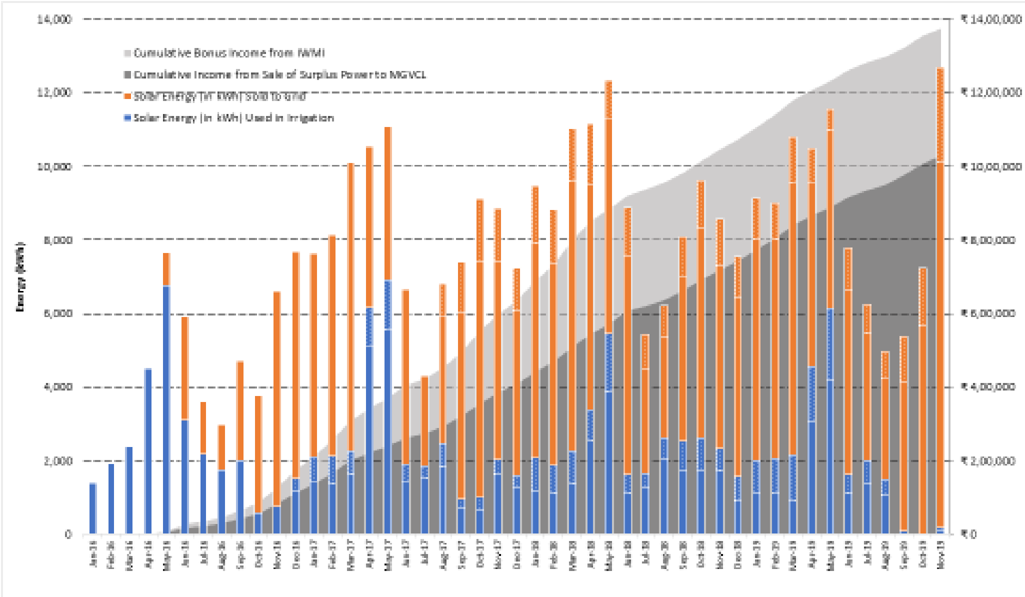
Context:
Near doubling of tubewell connections—issued to the poorest among Gujarat's peasantry since 2008—made irrigation access equitable but increased pressure on groundwater as well as finances of the electricity companies. Having succeeded with *Jyotigram*, these began looking for politically acceptable ways of reducing present and future farm power subsidy burden. One opportunity they spotted was in the arrival of solar irrigation pumps (SIPs). Every grid-connected tubewells solarized meant a reduction in annual power subsidy burden of the order of US $ 750-1000 for a long time to come. In groundwater-stressed western states of India, electricity utilities began aggressively promoting SIPs to reduce their subsidy burden on grid power supply to tubewells. Capital cost subsidies ranging from 60-95 percent got offered on SIPs to applicants long waiting for a grid power connection (Shah et al 2018). The apprehension was SIP's implications for groundwater depletion. Once installed, SIP's offer reliable daytime power free given India's high solar insolation for over 320 days/year. In many states, high diesel cost and poor quality, nightly power supply are irksome to farmers but the only check on unbridled groundwater pumping. By offering reliable daytime free power, SIPs may arguably exacerbate the pressure on groundwater resources (Kishore et al 2014; Gupta 2017; FAO[12]). Gujarat was particularly worried. Issue of numerous new tubewell connections had eroded the 'rationing' role of *Jyotigram.* Daytime power supply offered by SIPs increase annual hours of usable power supply compared to grid connections which deliver difficult-to-use night power supply half of the year.

In 2015, a group of researchers in Gujarat piloted a village scale model to explore if farmers can be persuaded to 'grow' solar energy as a cash crop (Shah et al 2017a; Shah et al 2019). They began with the proposition that small farmers' demand for water is a derived demand for food, income and livelihoods. Solar energy generation requires land; and farmers own half of India's land. If they could use their land to grow solar power to irrigate their land as well as earn income by selling their surplus solar energy at a remunerative price, it can arguably incentivize water and energy conservation. In a pilot experiment in Dhundi, a small village in Gujarat, 11 farmers were provided SIPs to replace their diesel pumps at a capital cost of US $ 147,000 (INR 92,00000). They were formed into a micro-grid managed by Dhundi Solar Pump Irrigators' Cooperative, the world's first such cooperative (Shah et al 2017b). The state electricity utility connected the cooperative to the 11 kv line, formally accepted it as an Independent Power Producer (IPP), and signed with it a 25 year power purchase contract at INR 4.63/kWh (US$ 0.066/kWh) on pooled energy evacuation by the cooperative members metered at a single point. The only condition was that the cooperative members formally surrender their right to grid power connections for 25 years. Figure 4 presents the monthly results of Dhundi cooperative for 45 months during which its members sold over 2,50,000

[12] http://www.fao.org/land-water/water/watergovernance/waterfoodenergynexus/en/

kWh of solar electricity and earned Rs 1.6 million as net income. Dhundi farmers used just about 35 percent of solar energy production for irrigation. Were they not paid for selling the energy, they would have surely used some or all of their solar energy production for irrigating more of their own fields and selling water to neighbours.

Figure 4 Dhundi SPICE: Operating Results Jan 2016 to Nov 2019



By 2016, Dhundi cooperative had become a national media hit, with hundreds of farmers, electricity utility officials, politicians and bureaucrats flocking there to see how marginal farmers made money by ‘growing’ and selling solar energy. A dozen stories about the ‘Dhundi model’ in national and state television news channels put its potential in bold relief. Electricity officials saw in it potential to reduce subsidy burden, achieve energy audit as well as curtail massive line losses in providing farmers grid power from generating stations hundreds of miles away. Environmentalists raved about clean and green irrigation with reduced carbon-footprint. Development professionals found here a way to put cash in the hands of the poor not as a give away but for valuable energy the economy needs. Farmers were happy because they got uninterrupted daytime power for irrigation, additional income for selling electricity and could raise high value shade-loving crops underneath the panels. All these years, farmers offered stiff resistance to metering tubewells; now they embraced meters since they got paid based on metered evacuation of solar energy to the grid. Above all, political leaders saw in Dhundi model an opportunity to create a new, benign WEF nexus while also reaping political dividends.

Governance Response:
For the Energy Minister of Gujarat, who spent half a day interrogating members of Dhundi cooperative in late 2017, promoting solar power as a remunerative crop (SPARC), was an even better idea than *Jyotigram* for all concerned: electricity companies, farmers, groundwater as well as climate change, but above all for his politics. In 2018, Gujarat government launched SKY (*Surya Shakti Kisan Yojana),* a large pilot scheme to replicate the Dhundi model on 12400 tubewells on 136

agricultural feeders in 33 districts at a total outlay of INR 7.8 billion.[13] The basic Dhundi features that farmers generate their own power *in situ* and they get 25 year surplus power purchase guarantee at a remunerative price were the core of SKY. Other features changed somewhat. Instead of village level micro-grid, SKY took a multi-village agricultural feeder as the unit of solarisation and mandated feeder-level management committees elected by SKY farmers. The financial model was different too. Farmers contribute 5 percent of the capital cost upfront. The balance is covered by 30 percent central government subsidy and 65 percent loan taken by the state government on behalf of the farmers. The solar energy purchase price—the so called Feed-in Tariff (FiT)—offered too is higher than in Dhundi at INR 7/kWh. However, farmers get Rs 3.50/kWh in cash while the government retains Rs 3.50/kWh towards loan servicing. At least 70 percent of tubewell owners must join to enroll the feeder for SKY. The SKY feeder is to be kept live for 12 hours during the day (instead of 8 hours during day and night in alternative weeks that Gujarat farmers get). Each SKY tubewell is net-metered. A farmer can use a mobile app to monitor his daily power generation, consumption and evacuation.

The SKY scheme is just a few months into implementation and not quite ready even for a preliminary assessment. However, electricity utilities can already see the benefits in terms of reduced line losses and subsidy saving[14]. Farmers are happy too with day time uninterrupted power for longer hours. The litmus test, however, is energy use in pumping groundwater. The expectation is that solar farmers on SKY feeders will reduce pumping significantly to enhance their income from energy sales compared to grid-farmers on SKY feeders. Data on 59 completed SKY feeders between May 2019 and October 2019 show little difference: 2190 SKY farmers used average of 246 kWh/HP for irrigation while 908 grid farmers on SKY feeders used 235 kWh/HP. With time and more rounds of payments for energy sales, there will be clear evidence to show whether or not SKY produces behavioural change among farmers. Because it has no losers, SKY is likely to get scaled out even faster than feeder-separation under *Jyotigram;* and to the extent perverse incentives through power subsidies have fueled groundwater overdraft in India, SKY can reverse this trend by providing small farmers strong incentive to conserve water and energy.

Impacts

SKY competes with another model of solar irrigation being implemented in Maharashtra. This model invites private investors to build tail end solar power plants (1-2 MWs in size) on government land to energise an entire separated agricultural feeder. The Utility offers investors Feed-in Tariff (FiT) on total generation, while farmers get free daytime solar power. Surplus power would flow back into the grid; and the deficit would be provided by the grid. This model, preferred by Utilities, will arguably offer them cost-savings, upscaling potential and mobilize private capital in solarization. Its drawback is that farmers have no skin in the game; it provides no incentive for energy and water conservation to farmers who continue to get free daytime power for irrigation.

[13] https://www.thehindubusinessline.com/news/national/gujarat-launches-sky-scheme-for-farmers-to-generate-solar-power/article24242176.ece

[14] On 59 SKY feeders in operation between May and October of 2019, estimated subsidy saving per HP of solar tubewells were Rs 851, Rs 1061, Rs 620 and Rs 1468 for Paschim, Madhya, Uttar and Dakshin Gujarat companies respectively (assuming cost to serve grid power at Rs 5/kWh) ; in contrast, on grid connected tubewells on those feeders, they incurred subsidy of Rs 881, Rs 1551, Rs 1330 and Rs 1228 per HP respectively (taking subsidy on cost to serve grid power as Rs 4/kWh).

Even before the impacts of these and other SIP promotion models become clear, however, Government of India has announced PM-KUSUM[15] scheme, a national program for agricultural solarisation with three components[16] with a proposed outlay of US $ 6 billion:

Component A: 10,000 MW of Decentralized Ground Mounted Grid Connected Renewable Power Plants of individual plant size up to 2 MW (after Maharashtra model).
Component B: Installation of 1.75 million standalone Solar Powered Agriculture Pumps of individual pump capacity up to 7.5 HP (for water-abundant-energy-starved districts).
Component C: Solarisation of 1 million grid-connected Solar Agriculture Pumps of individual pump capacity up to 7.5 HP (after SKY model).

Government of India's latest budget announced on February 2020 increased the target under component B to 2 million and under component C to 1.5 million SIPs.

SKY and KUSUM (Component C) are bold schemes to crack India's pernicious WEF nexus that has left behind bankrupted electricity utilities, depleted aquifers, a high carbon irrigation economy and unsustainable agriculture. The reason these have got policy traction are many; but the key is they have opened the 'political gridlock'. There are prohibitive political costs to measure and charge grid power supplied to farmers; in contrast, there are huge political dividends to be reaped from measuring and paying for solar energy farmers grow on their fields and sell to the grid.

Governance Lessons

1. Gujarat's search in SIP's for innovative indirect governance instruments for cracking perversities in WEF s nexus suggests a learning process that began with *Jyotigram.*
2. By definition, nexus refers to a class of multi-sectoral anomalies that can be resolved only together and at once. Maharashtra model of tail-end solar plants to solarize farm feeders is *not* a nexus solution. It assumes that energy solution must be implemented separately; and water sector anomalies that result should be later resolved through an independent water solution. This has been tried before and has never worked. SKY is a classic nexus solution.
3. Whether SKY will produce expected behavioural change will critically depend upon the design, especially of economic incentives and disincentives built into it.
4. Indirect nexus levers are benign in political costs; but designed right, they can deliver political dividends which tempt leaders to put their weight behind them.

8. Synthesis and Conclusions

The Nexus Ideal

Water governance is about the process of state intervening in the water economy via three roles, viz, public provision/proscription, promotion/regulation and incentives/disincentives. The state plays out these roles through making and enforcing new laws, changing institutional arrangements and making policies. IWRM and its sequel nexus approach outline the normative framework in which the state can govern the water economy to produce society-wide optimal rather than sectoral maxima. The nexus approach enjoins us to pay attention to interactions between water, energy and food security for "increasing efficiency, reducing trade-offs, building synergies and improving governance

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[15] Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (Prime Minister's Farmer Energy Security and Development Initiative)
[16] https://www.thehindubusinessline.com/economy/agri-business/norms-for-pm-kusum-scheme/article28657944.ece

across sectors" (Hoff 2011: p4). The nexus ideal is a water governance regime that achieves a balance between food security, water productivity, energy efficiency, resource sustainability, eco-system health and society's well-being.

In this review paper, we explored seven examples of groundwater governance regimes that strayed from this ideal and, for a period of time, undertook single minded pursuit of the sectoral objective of expanding irrigation and food production. However, in the process, they all digressed from the holistic 'nexus optima' and have struggled to inch towards the 'nexus ideal' with varying degree of success. Table 1 summarizes the the hydro-geological setting, the hierarchy of national policy priorities that drove irrigation-driven groundwater over-development and its direct and indirect socio-ecological impacts spanning some 100 million hectares of groundwater-stressed landscape in selected geographies. There is growing recognition of present and future environmental risks of this scenario and new groundwater governance measures have been instituted to restore the balance. The measures and their impacts are summarized in table 2.

Table 2

Drivers and Impacts of Rapid Expansion of Tubewell Irrigation on groundwater socio-ecology

#	Geography	Hydro-geology	Driver of groundwater boom	Hierarchy of policy priorities	Environmental impacts	Size of the drgraded landscape	Fate of pre-existing irrigation regimes
1	Iran: 1960-2020	Semi-arid, alluvial	95% subsidy on energy and tubewells; guaranteed grain purchaset at lucrative price	Food self-sufficiency; grow irrigation under *jihad* agriculture	Secular groundwater depletion; water quality deterioration; secondary salinization	15 million Ha	30000 qanats in dereliction
2	Saudi Arabia: 1982-2000	Arid alluvial	95% subsidy on energy and tubewells; guaranteed grain purchaset at lucrative price	National food self-sufficiency; resettle Beduin small farmers	Secular depletion of fossil groundwater; quality deterioration; secondary salinity	1.8 million ha	Numerous oases and wadis desciccated
3	Mexico: 1950-2020	Semi-arid, alluvial & carst	Subsidy on energy; high subsidy on night power supply	Support high value export agriculture; support ejidatarios	abstractions exceeded long term recharge in most aquifers; extensive land subsidence	12-15 million ha	Decline of Chinampa system of irrigation developed by Aztecs
4	North China plains: 1960-2014	Semi-arid, alluvial	Population pressure on farmland; moderate equipment subsidy	Food production and livelihoods of small family farmers	Extreme groundwater depletion; drying uo of surface flows; quality deterioration; low flows in Yellow river and tributaries	22-25 million ha	Ground water replaced surface water increasingly diverted for industrial use
5	Barind, Bangladesh 1985-2020	Humid, hardrock	Slow and unequitable groundwater development	Equitable irrigation access; integrated area development	Agrarian poverty; Patchy irrigation availability despite high rainfall; no summer paddy crop;	2.5-3 million ha	Old canals and ponds fell in disuse
6	Western India 1960-2006	Semi-arid, alluvial-hardrock	Energy subsidy; moderate equipment subsidy;	Improve farmer livelihoods; accelerate agricultural growth	Secular groundwater ddepletion over large swathes; increased fluoride and salinity in groundwater; drying of surface streams and rivers	45-55 million ha	0.5 million irrigation tanks derelict; irrigation canals turned percolation canals

Table 3 Towards the 'nexus ideal': Groundwater governance strategies and their impacts

#	Geography	Key Reforms initiated in Groundwater Governance since 1990	Eco-system Impact	Social Impact
1	Iran: 1960-2020	[1] Water abstraction quota's issued to each tubewell owner; [2] smart meters begun to get installed on tubewells to monitor water abstraction against quota; [3] penalty tariff collected for exceeding quotas; [4] campaign against illegal rigs and tubewells with special police; [5] subsidy for drip and sprinkler irrigation; [6] wheat purchase prices reduced	+	Resistance among farmers; new quota rules at variance with qanat allocation rules; enforcement capacity poor; qanats left in disuse and public irrigation performance poor
2	Saudi Arabia: 1982-2000	[1] government wheat purchase phased out and imports began to meet national requirement; [2] irrigation subsidies phased out; [3] new laws and decrees passed but enforcement poor; [3] massive investments in desalination	++	Wheat irrigation declined ; but groundwater abstraction fell less than proportionately; enforcement poor. Poor beduins left out, while farming companies gained.
3	Mexico: 1950-2020	[1] Aquifer Committees (COTAS) organised; [2] groundwater concessions issued; [3] markets in concessions catalysed; [4] ban on new tubewells announced; [5] electricity subsidies only on authorised tubewells. Overall, groundwater governance remained half-hearted and enforcement weak.	+	COTAs failed produce behaviour change; repeated presidential amnesty on ban on illegal wells made laws toothless; subsidy on night power supply deepened perverse behaviour. Ejidatario's left worse off.
4	Shiyang basin, China: 1960-2014	[1] 3300 tubewells closed; [2] irrigation reduced by over 6,50,000 ha; [3] household level water permits strictly enforced using smart meters; [4] progressive penalty for exceeding quota and bonus for using less than quota; [5] 874 WUAs helped village level enforcement; [6] aggressive promotion ofmicro-irrigation and high value crops	+++++	Shiyang Bureau achieved reduction in groundwater draft; but agrarian livelihoods were hit hard; many farmers quit farming; many others found off-farm livelihoods. May prove unreplicable elsewhere
5	Barind, Bangladesh 1985-2020	[1] Resource governance started with development and access; [b] demand-driven groundwater development; [c] tubewells constructed and managed centrally; [d]full-cost pricing and recovery; [e] groundwater monitoring; [f] demand and supply side interventions in stressed areas; [g] affofrestation, water conservation and recharge, conjunctive management of surface and groundwater	+++++	Barind model was closest to the 'nexus ideal'; it provided equitable irrigation, protected aquifers, invested in eco-system services and proved financially viable. Model for regions in early stages of irrigation development. More, BMDA's success may be hard to replicate.
6	Gujarat, *Jyotigram 2003-6*	[1] Community driven groundwater recharge movement helped improve groundwater capture and storage during 1990-2015; [2] agricultural feeders separated from rural feeders; [3] farmer provide 8 hours of high quality power ration during day and night in alternate weeks; [4] New scheme (SKY) replaces grid connected tubewells by solar pumps with 25 year guarantee for purchase of solar power at a remunerative price	++++	Improved groundwater regime, accelerated agricultural growth, improved livelihoods. Dissatisfaction with reduced power ration was overcome by improved power quality. Non-farm rural electricity consumers happy with improved quality of life. New solar program with power buy-back guarantee met with farmer enthusiasm.

The results have been variable. In Iran, Saudi Arabia and Mexico, reforms have produced only modest sustainability outcomes. In Shiyang basin (China), Barind project (Bangladesh) and Gujarat (Western India), there are indications that governance reforms are in the right direction of delivering holistic nexus outcomes. Strong enforcement capacity, bolstered by communist party hierarchy going down to the village level, was the hallmark of the Shiyang basin success. Barind Multi-purpose Development Authority (BMDA) promoted as a Special Purpose Vehicle (SPV) focused on integrated governance of water and land from the start of irrigation development was the key feature of the Barind success. In Gujarat, governance reforms had to contend with a long history of farmer-stakes in perpetuating energy subsidies, something BMDA was untrammeled by. Policy makers had to find indirect modes of intervening that would be easy to implement without adverse political consequences. As it turned out, the reform implemented by Gujarat helped the state move towards the 'nexus ideal'. The strategy is now replicated in several states of India, albeit with variable outcomes.

*Context, Contingencies and Constituencies:*To bridge the chasm between 'nexus thinking' and conventional groundwater governance, we need to pay attention to forces that shape the latter. Our review suggests three clusters of factors in each geography: context, contingencies and constituencies. Social, political and economic context of a country/province are key determinants of governance choices. India prioritizes farming livelihoods because 60 percent of its population depends on farming compared to Saudi Arabia (8 percent) or Iran (18 percent). Similarly, water policy interventions during a period get shaped by contingencies facing governments during that period. Iran and Saudi Arabia would be less hard-pressed to chase food self-sufficiency in a different global order in which it were confident about importing food at will. Finally, governance affects different constituencies differently. In Mexico as well as Iran, political leaders repeatedly announced amnesty to illegal wells because their owners constituted a powerful constituency. These showed that the constituency need not be numerically large to exert significant political influence. Even where beneficiaries of a policy are a tiny section of population, they can still form into powerful political interest group, as in Saudi Arabia and Mexico. Indeed, the elite are more inventive and energetic in capturing subsidies meant for the poor. Beduins in Saudi Arabia and ejidatarios in Mexico, in whose name subsidy policies were originally formulated, were edged out by elite groups which captured and monopolised benefits of state policies and exerted relentless pressure for their continuation. Understanding context, contingencies and constituencies facing national/provincial authority is critical to wean its water governance away from 'silo' thinking and moving it towards to a 'holistic' worldview.

Hierarchy of Priorities: Equally, nexus advocacy needs to recognize different hierarchies of over-arching national priorities within which water governance choices are made. These change over time. In Iran during recent years, in Saudi Arabia during the 1980's and India during the 1960's, national food self-sufficiency had paramountcy over other important objectives. Saudi Arabia has now consciously chosen to import food, and is now saving its water. But Iran continues to guard food security.[17] India has widespread hunger despite embarrassing food surplus; therefore, protecting farm incomes and livelihoods is higher priority than other national objectives as revealed by its water governance choices. Shiyang Basin Authority's success in reducing groundwater overdraft is impressive; but China may hesitate in scaling it out nationally if doing so threatens the country's grain production.

Institutional Capacity: Focussing on building deep and broad-based institutional capacities—of rule enforcement, of community and civil society organizations, citizen-centric bureaucracy, customer-oriented service providers—may be the most powerful way forward to actualise the nexus ideal in emerging economies. Even if political leadership somehow mustered courage to neutralise perverse WEF nexus outcomes, as it did in Saudi Arabia, Iran and India, success may take time due to limited institutional capacity to make and enforce rules and farmers' tendency to game them. In Mexico, all attempts of the government to rein in tubewell irrigation—bans on new tubewells, issue of concessions, using electricity consumption to enforce concessions and so on—failed to check continued groundwater depletion by unauthorised wells. Monitoring and enforcement capacity needed is determined more by number of groundwater users than volume of groundwater extracted. Mexico has trouble monitoring and managing its 100,000 tubewell owners; for India, monitoring groundwater draft by its 22 million tiny scattered tubewell owners would be a nightmare. Little surprise that numerous laws and decrees by national and provincial governments in India have merely remained on paper. It is also notable that in implementing an indirect governance intervention, Gujarat totally bypassed its water bureaucracy dominated by engineers with skills only to build infrastructure; it implemented the entire reform through electricity companies and community organizations.

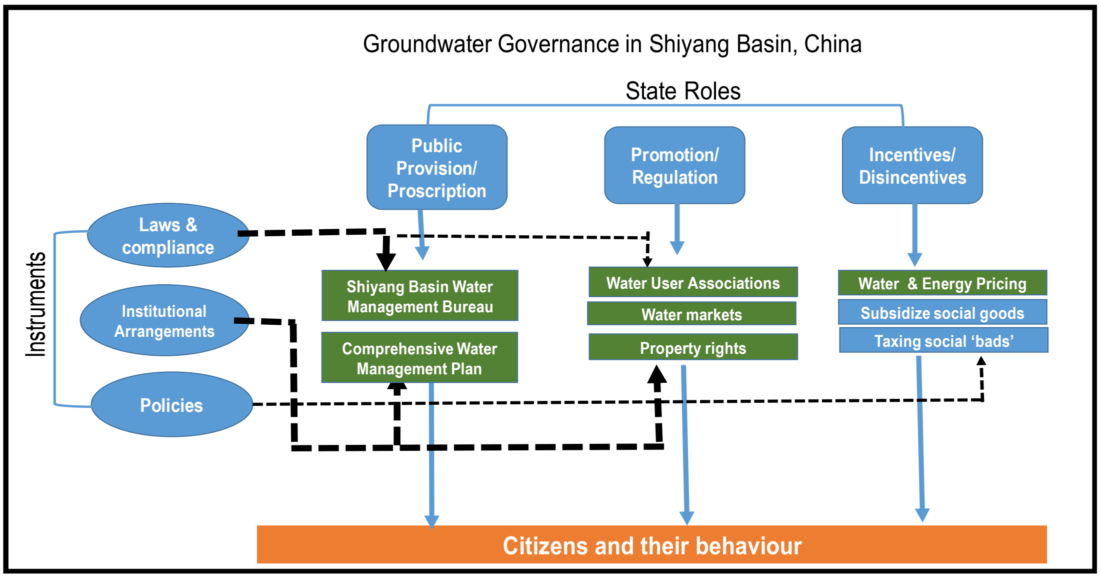
Inter-agency strategic coherence: A key aspect of capacity building is creating strategic coherence amongst different agencies dealing with water, energy, food, agriculture, environment. In countries like Iran, Mexico and India, these openly pursue contradictory objectives and work at cross purposes. Agriculture agencies aggressively pursue expansion in groundwater irrigation; water agencies concern themselves with dams and canals while energy agencies strive to mitigate subsidy burden. It seldom happens that these come together to surrender their worm's eyeview to take a bird's eye view of water, energy and food as components of a larger eco-system. Such integral view is generally offered only by top political or administrative leadership. In Shiyang basin, the directives for creating a groundwater-saving agricultural economy came from Beijing, just as in Saudi Arabia, the decision to phase out wheat export came from the top political leadership. But in Iran, even

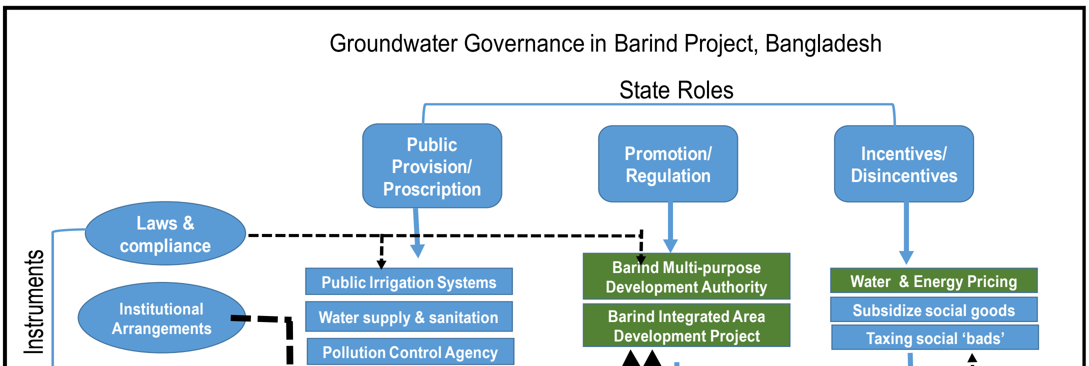
[17] https://www.world-grain.com/articles/12752-focus-on-iran

today Iranian Jihad Agriculture Agency pursues expansion in wheat irrigation by tubewells while Iranian Ministry of Energy has begun to control energy and groundwater use in irrigation.

Symptomatic versus Holistic Interventions: Experience with groundwater governance has shown that interventions may change the symptoms but leave the problem unresolved. This is because intervention design ignores Jevon's paradox and often assumes that farmers will not push back to protect their incomes. Saudi Arabia stopped purchase of wheat at lucrative prices which first began its groundwater boom. With government purchases stopped, wheat production came down drastically, but water withdrawals did not, as farmers took to alfalfa cultivation which uses 4 times more groundwater than wheat. Metering tubewells and penalising excess water use in Iran produced similar impact; farmers reduced wheat but began growing water-loving fruit trees which will guzzle more water when they grow. Every innovative solution invariably contains seeds of future trouble if it addresses only the symptoms and not the problem. Punjab and Haryana states of north-western India have experienced secular decline in groundwater levels thanks to vast areas of rice and wheat irrigation sustained by energy subsidies and attractive support price for state purchase of grains. During the early 2000's, scientists found that a large part of groundwater use in paddy irrigation was accounted for by farmers using tubewells for watering nurseries in very hot temperatures of May, weeks before the monsoon rains. The government made and enforced a law banning rice transplantation before June 10th. Eventually, government and scientists rejoiced in findings showing reduction in groundwater withdrawals as a result of the policy. However, the joy proved short-lived. Delayed planting of rice led to its delayed harvesting and left little time for farmers to prepare land for sowing the winter wheat crop. To empty their fields quickly, farmers began to set fire to rice fields to get rid of paddy stubble; and meteorological and climatic conditions of cold winter prevented quick dispersal of smoke these fires produced. This created a massive winter air pollution problem that seriously worsened air quality in Delhi and the entire Indo-Gangetic plain (Vasdev 2019). Now the issue is whether north India is better off depleting groundwater or dirtying its air.

Figure 5 Alternate Pathways to Holistic Water Governance





Alternative Governance Pathways: Barind project in Bangladesh, Shiyang basin in China and Gujarat in western India are three locales where we find notable movement in the direction of the ‘nexus ideal’. However, the governance route each has followed is different, as shown in figure 5. China created Shiyang Basin Water Management Bureau (SBWMB) as a special purpose vehicle (SPV) as a parastatal. Likewise, Bangladesh too created BMDA as a parastatal SPV. These led and executed a turn around in the groundwater situation. In Gujarat, the water administration was bypassed and regional energy companies were chosen to rewire the rural grid and began managing rationed farm power supply while CBO’s were directly funded to undertake a decentralized groundwater recharge movement. Contingency theory of management fits water governance as well: there is no best way to execute governance reform. Instead, the optimal course of action is **contingent** (dependent) upon the internal and external situation facing decision makers in a given setting.

We conclude this review by citing from the final remarks made by John Briscoe while receiving World Water Prize:

> “Every water solution is a local solution. Moreover, every solution is provisional and contains the seed of a future problem; it works for a time and there is a constant challenge and response cycle. The spiral-like reflexive relationship between water and economic growth [implies that] improved water management promotes growth, and economic growth creates opportunities for new kinds of water management interventions which are hard to implement when income levels are low…In poor countries,[we must] give primacy to creating appropriate water infrastructure and building capacity for its sustainable management as the first step to improving management of the water economy… [While] transparency, equity, good governance, and participation have high *intrinsic* value, they have doubtful *instrumental* value, in the sense that these are neither necessary nor sufficient for improving the working of a water economy or for removing poverty.”

Briscoe advocated a ‘pragmatic but principles approach’ to water governance. Pragmatic and principled—rather than formulaic—were the groundwater governance approaches that helped

Shiyang, Barind and Gujarat to move toward the ‘nexus ideal’. Had he been alive, he would have argued for nexus approach as conceptual backdrop against which national and local authorities might design pragmatic and principled water governance consistent with their respective contexts, contingencies and constituencies.

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