

Water–Energy–Food Nexus in Distant Past

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The concept of water–energy–food (WEF) nexus is gaining favor as a means to highlight the functions of the three individual nexus elements as interrelated components of a single complex system. In practice, the nexus approach projects forward from the present, seeking to maximize future WEF synergies and avoid undesirable tradeoffs. This article seeks to gain insights into how the ancients dealt with WEF relationships, whether currently relevant principles were practiced millennia ago, and how past WEF dynamics compare to today.

Keywords: water–energy–food ; WEF nexus ; Dujiangyan ; qanats ; irrigation ; China ; Persia ; water governance

1. Introduction

Our understanding of the interactions between water, energy, and food (WEF) has deepened in recent years, as the world struggles with climate change and begins to seriously confront planetary limits ^{[1][2][3][4]}. First formalized a decade ago ^{[5][6]}, the concept of WEF nexus coalesces thinking about these relationships into a conceptual framework that assigns priority to the coupling of the three components. Focus on interrelationships de-emphasizes fragmented treatment of the three individual components and underscores their functional roles in the underlying system ^{[5][6][7]}. In practice, the nexus approach seeks to maximize the advantages of WEF synergies while avoiding the disadvantages of WEF tradeoffs ^{[8][9][10]}. This requires a shift from viewing water, energy, and food as competitors for land and other resources, as well as renewed attention to the potential for mutual benefits. Technology and governance become crucial tools for achieving these goals ^{[11][12][13]}.

The concept of WEF nexus has triggered a lively and ongoing debate in scientific and policy circles ^{[14][15][16][17][18]}. Although the basic concept is evolving and certainly not the only framework for assessing WEF relationships ^{[19][20]}, the nexus approach has the advantage of balancing treatment of the three components. It also challenges scientists to emerge from their water, energy, or food silos and pay attention to the interfaces between the three ^{[5][12][21][22][23]}. Policymakers, in turn, are pressed to optimize broad mutual benefits rather than generate narrow, often short-term advantages for one single component. There is a vast and growing literature on these complicated dynamics, which tend to view water and food from the perspective of access, affordability, and security ^{[11][13][24]}. The energy component, on the other hand, has become increasingly dominated by controversies over damming the world's major rivers for hydropower ^{[25][26][27][28]}. Land use change, the consequences of climate change, rapid urbanization, increasing global interconnections, technical advances and innovation, and science-based decision making have all emerged as important cross-cutting issues for the WEF nexus ^{[24][29]}.

WEF thinking had begun to coalesce several decades before formalization of the nexus concept ^{[5][15][30]} and was de facto imposed by the former Soviet Union on its Central Asian republics ^{[31][32]}. Most consideration of the nexus nevertheless projects forward from the current situation and recent past as the baseline ^[33], ignoring WEF practices from the more distant past. The nexus was nevertheless as relevant during earlier times as it is now, and indeed, missteps could prove deadly in a world that lacked the cushion provided by modern communications, transportation, and other technological advances. This review focuses on the distant past and has three specific objectives. The first is to find evidence that early humans adopted what today would be termed WEF nexus approaches to secure water, energy, and food. The second is to understand the relationships that were created among the three WEF components, especially synergies and how they were achieved. The third is to compare and contrast early approaches to WEF nexus challenges with contemporary approaches to similar challenges.

2. Early WEF Nexus Perspective

When contemplating their options for complex engineering of the landscape, the ancients would have envisioned certain constraints. The lack of benefits until all work was completed mandated long-term perspective and commitment, unambiguous identification of intended beneficiaries, and tacit acknowledgement of the limits of local expertise and

resources. The need to avoid conflicts among future beneficiaries would have loomed large, and thus all conceivable means to forge cooperation—social, cultural, governmental, and religious—must also have been contemplated in advance.

2.1. WEF Nexus Characteristics of Qanats and the Dujiangyan Irrigation Scheme

Qanats are the products of decisions taken with the full knowledge of the risks involved, and indeed, many attempts ended in failure. The possibility of WEF nexus could never be assured until water consistently emerged from the tunnel's outlet—often after decades of investment in excavation. Policies codifying access rights, maintenance responsibilities, and boundaries to prevent encroachment and other conflicts were key

to qanat sustainability, but inefficiencies and tradeoffs are nevertheless apparent. Animal herding and harvest of firewood removed groundcover, allowing shifting sands to obstruct nearby qanat shafts [68]. Significant quantities of water were lost due to seepage and evaporation from qanat streams, and flows were wasted during seasons when food was not being produced. These losses could nevertheless be partially mitigated by constructing reservoirs, lining channels with impervious clay, and even timing releases of water into longer canals at night, when evaporation was minimal.

There was also no advance guarantee for the success of the uncertain irrigation venture at Dujiangyan, which required intricate water-energy balance among the elements of the headwater infrastructure. This could only have been perfected by repeated trial and error adjustments as floodwaters rushed past over a period of years. The history of failure of a contemporaneous irrigation project on the Wei River, in what is now Shaanxi Province, serves as a stark reminder of the difficulty in preventing buildup of silt and salinity. The challenges on the Wei River, which have never been completely overcome, were avoided by well-designed engineering on the Minjiang River, finely tuned maintenance of the headworks, and the linpan settlement pattern, which fostered sustainable irrigation practices and ensured upkeep the vast irrigation area below the headworks. Waste was also minimized, because excess water flowing through the irrigated fields was eventually returned to its source in the Minjiang River.

The WEF nexus relationships of qanats and the Dujiangyan irrigation scheme have remained remarkably stable and resilient as political structures changed over the centuries and under all but the most extreme environmental and social disruptions. Such sustainability was due in large part to the constraints imposed by limited availability of water and energy, resources that with few exceptions, could not be stored in quantity for later use. Moreover, humans could not transport water and energy over significant distances. Water from wells could be used domestically and for drinking, and trees, shrubs, and crop residues could be harvested for heat and cooking, but these sources could hardly be used to grow food. Available sources of water and energy were for the most part appropriated for food production in real time, a practice that permitted exploitation but not overexploitation.

Effective principles of governance to ensure smooth operation of the physical WEF components also fostered stability and resilience. These principles arose in tandem with the technology and proved to be flexible and customizable. Qanats and their associated principles of governance radiated from the Iranian plateau and may also have arisen independently at sites as far east as the Turpan basin of what is now Xinjiang, China. Early qanat distribution included the Levant, North Africa, Central Asia, and areas now in Pakistan, Afghanistan, and Oman. Effective governing practices similarly characterized the Chengdu plain as the headwater infrastructure was updated and the irrigation area enlarged and reconfigured over time.

3. Conclusion

The three components of WEF nexus have now been largely released from the stringent spatiotemporal constraints of the distant past, but new constraints have appeared. Energy has been converted into an expensive global commodity, and its flows can be readily separated from those of water. Energy now allows irrigation water to be stored and transferred from basin to basin, often across significant distances and against the force of gravity. Energy availability has also become a key factor in agricultural mechanization, but WEF tradeoffs are becoming apparent. Hydroelectric dams disrupt seasonal water cycles that are important for food production, and their associated reservoirs often flood fertile farmland. Inter-basin transfer of water creates winners and losers, and the drive for renewable energy and lowered levels of atmospheric carbon creates food crop versus energy crop tradeoffs. Release from the spatiotemporal constraints of long ago has nevertheless increased WEF resilience, generated buffering capacity against natural disasters and other threats, and uncovered comparative advantages that can be exploited locally. These benefits are unquestionable, but they have also heightened awareness about overexploitation of resources and unintended consequences.

Paying careful attention to WEF interrelationships in advance rather than after decisions have been made, assigning as much authority as possible to those impacted by decisions, and taking advantage of local knowledge and knowhow are as relevant today as they were millennia ago. Strategies to in effect revisit these principles have been recently proposed and implemented in a few cases. Although there can be no return to the circumstances of the distant past, when scale and complexity were much simpler than today, the principles of ancient WEF nexus governance nevertheless deserve another look.

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