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Energy and Water Resources Scarcity: Critical Infrastructure for Growth and Economic Development in Arizona and Sonora***

ABSTRACT

Climate change, rapid urbanization, and the emerging carbon economy, among other factors, have elevated the energy-water nexus from an operational tool to a new joint-resource management and policy paradigm. Nowhere in North America, and in few regions globally, is this need greater than in the Southwest United States and Northwest Mexico. In the states of Arizona and Sonora, investment is inadequate to meet energy and water infrastructure needs. On par with critical infrastructure in economic development terms, agriculture is likewise energy-intensive and currently consumes the largest share of water resources in both states. The important gains

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to be made through coupled energy- and water-based conservation, including the potential of certain types of renewable energy development to reduce water requirements for electricity generation, raise questions over conventional plans to rapidly increase investments in infrastructure. The purpose of this paper is to assess the region's energy-water nexus through analysis of data on water supply, electrical power generation, and energy consumption. Four cases are examined to illustrate the coupled nature of policies for energy and water: (1) rapidly growing urban centers; (2) water consumed in power generation and the "virtual water" implications of regional interstate power trade; (3) the irrigation-electrical power nexus in agriculture; and (4) coastal desalination and proposed transboundary transfer schemes. The paper concludes that conventional water management for cities has a large and rising energy footprint. Conversely, power generation that is often considered "non-consumptive" in this arid region is a major consumer of water. Similarly, there is a major opportunity for energy and water conservation in groundwater irrigation. Finally, desalination may hold promise, particularly for coastal communities, but current costs and institutional barriers suggest that transboundary transfer of desalinated water for general purposes, including environmental conservation and agriculture, has low feasibility.

I. INTRODUCTION: THE ENERGY-WATER POLICY NEXUS

Energy and water are both essential for meeting a broad range of societal goals, including quality of life, economic opportunity, and resilient and sustainable ecosystems. Despite the increasing degree to which these two resources are interlinked, energy and water continue to be managed in mutual isolation and are subject to distinct policies in the United States[1] and globally.[2] To set the context for the article, this Part

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[1] *See generally* Peter H. Gleick, *Water and Energy*, 19 ANN. REV. ENERGY ENV'T 267, 299 (1994); Denise Lofman, Matt Petersen & Aimée Bower, *Water, Energy and Environment Nexus: The California Experience*, 18 INT'L J. WATER RES. DEV. 73 (2002); U.S. GOV'T ACCOUNTABILITY OFFICE, GAO–10–23, ENERGY-WATER NEXUS: IMPROVEMENT TO FEDERAL WATER USE DATA WOULD INCREASE UNDERSTANDING OF TRENDS IN POWER PLANT WATER USE (2009), *available at* http://www.gao.gov/new.items/d1023.pdf; Bevan Griffiths-Sattenspiel & Wendy Wilson, *The Carbon Footprint of Water*, RIVER NETWORK (2009), *available at* http://www.rivernetwork.org/sites/default/files/The%20Carbon%20Footprint%20of%20Water-River%20Network-2009.pdf.

[2] *See generally* Tushaar Shah, Christopher A. Scott, Jeremy Berkoff, Avinash Kishore & Abhishek Sharma, *The Energy-Irrigation Nexus in South Asia: Groundwater Conservation and Power Sector Viability*, *in* IRRIGATION WATER PRICING, THE GAP BETWEEN THEORY AND PRACTICE 208–32 (François Molle & Jeremy Berkoff eds., 2007) (discussing irrigation issues in South Asia); Christopher A. Scott, Tushaar Shah, Stephanie J. Buechler y Paula Silva Ochoa, *La fijación de precios y el suministro de energía para el manejo de la demanda de agua subterránea:*

aims, in broad terms, to identify key gaps between energy and water management and to explore points of policy synergy between these resources. In so doing, the principal objective is to establish the conceptual bases for assessment of critical infrastructure[3] in the context of energy and water scarcity. In Part V, this article examines four cases of coupled energy and water resources, based on primary and secondary data, and provides conclusions that should have relevance beyond the specific cases considered.

For a variety of reasons explored below, energy policy at all geographical scales is undergoing more rapid and creative reform and interpretation than is water policy. Because policies for water, particularly in their relation to energy, encounter a number of "predictable surprises," our analysis is informed by the recently published work of Max Bazerman.[4] He observes that wise energy policies, including efficiency improvements, are clouded by cognitive biases such as overly discounting the future, maintaining positive illusions leading to inaction, and erroneously assuming others will act.[5] At the same time, organizational barriers exist that complicate policy development and implementation, including poor institutional articulation to address emerging energy challenges.[6] Crucial for our interest in coupled energy and water policy analysis, Bazerman calls for cooperative regulatory reform.[7] Reform involves not simply devising creative solutions and their institutional and administrative implementation, but crucially, undoing obstructionist bureaucracies.[8]

Perhaps the most serious barrier, however, is presented by special interest groups, which often oppose reform by questioning the need for change and by clouding information to confuse public support for re-

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enseñanzas de la agricultura mexicana, *in* HACIA UNA GESTIÓN INTEGRAL DEL AGUA EN MÉXICO: RETOS Y ALTERNATIVAS 201–208 (R.C. Tortajada et al. eds., 2004) [hereinafter Scott et al.].

[3] *See* Richard L. Church, Maria P. Scaparra & Richard S. Middleton, *Identifying Critical Infrastructure: The Median and Covering Facility Interdiction Problems*, 94 ANNALS ASS'N AM. GEOGRAPHERS 491, 491 (2004) ("We define critical infrastructure as those elements of infrastructure that, if lost, could pose a significant threat to needed supplies . . . services . . . and communication or a significant loss service coverage or efficiency. These services and supplies are often termed as 'lifelines' . . . Those elements of infrastructure that are most important in a lifeline system are often called the 'vital' links.") [hereinafter Church et al.].

[4] *See generally* Max H. Bazerman, *U.S. Energy Policy: Overcoming Barriers to Action*, 51 ENV'T 22, 31(2009).

[5] *Id.*

[6] *Id.*

[7] *Id.*

[8] *Id.*

form.[9] Bazerman puts forth five principles to overcome barriers to implementing wise energy policies: (1) educate the public on policies that make sound tradeoffs beyond just energy (for our analysis, this could include water and energy gains); (2) seek "near-pareto solutions" (plans in which winners do not cause losers, but in which some parties may simply maintain their current positions) that place societal benefits above those of special interest groups; (3) identify "no regrets" policies even in the face of uncertain climate impacts; (4) "nudge" the public and agencies in the direction of energy reform but without compromising personal liberties; and (5) allow for temporary delays if this would permit the implementation of successful policies.[10]

In reflecting on coupled energy-water policy, we add two more principles to this set: (6) harness specific growth patterns (low environmental-impact real estate, "green economy" jobs, particularly in renewable energy and water conservation retrofits, etc.) that have positive global outcomes; and (7) devise creative cross-subsidization mechanisms to leverage public and private initiative on the resource agency or provider side with individual behavior change on the consumer side of energy and water resources.

Water and energy are crucial factors of production in any functioning economy. Both must be developed, processed, transported, and distributed adequately and affordably to consumers. Additionally, the use, transformation, and release of their byproducts by consumers have important implications for environmental quality, locally and beyond their immediate point of use. The transmission of energy and water typically makes use of grid networks that are considered critical infrastructure.[11] And energy supply invariably involves the use of water, while water supply requires energy. This conceptualization of the energy-water nexus[12] views both resources as inextricably linked. As demonstrated in the cases below, such linkage offers opportunities for their

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[9] *Id.*

[10] Bazerman, *supra* note 4, at 29–31.

[11] Church et al., *supra* note 3.

[12] *See generally* Mike Hightower & Suzanne A. Pierce, *The Energy Challenge*, 452 NATURE 285 (2008); EPRI, WATER & SUSTAINABILITY (VOLUME 3): U.S. WATER CONSUMPTION FOR POWER PRODUCTION-THE NEXT HALF CENTURY (2002), *available at* http://mydocs.epri.com/docs/public/000000000001006786.pdf; EPRI, WATER & SUSTAINABILITY (VOLUME 4): U.S. ELECTRICITY CONSUMPTION FOR WATER SUPPLY & TREATMENT-THE NEXT HALF CENTURY (2002), *available at* http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/EPRI-Volume-4.pdf; CALIFORNIA ENERGY COMM'N, CALIFORNIA'S WATER-ENERGY RELATIONSHIP (2005), http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.pdf.

joint management in operational terms, i.e., water as a necessary input for energy supply and vice versa.

On the energy side of the nexus, the implications for water resources of increased electrical power generation to meet energy demands have been well-documented.[13] Accordingly, research and development are underway to reduce water diversion and consumption for power generation via reuse and recovery of cooling-tower water, use of effluent for cooling, improved air-cooling technologies, and faster development of renewable energy sources that do not require cooling water, such as wind power. However, because implementation necessarily lags research, aggregate water demand for power generation is expected to increase by 74 percent between 2005 and 2030 for the Rocky Mountain/Desert Southwest region.[14]

On the water side of the nexus, virtually all of the options for improving water services require more energy. For example, California uses a fifth of all its electricity for water service provision, and this share is expected to grow.[15] Nationwide, energy demand for water and wastewater treatment (already as much as 75 billion kWh/year in 2004, or about 3 percent of total load)[16] is projected to increase 20 percent over the next decade and a half.[17] Water utilities currently spend an average of 11 percent of their operating budgets on energy.[18] Some water utilities spend much higher percentages of their budgets on energy, particularly when long-distance conveyance or deep pumping are involved. Both of these conditions are found throughout the Southwest United States and Northwest Mexico. From the water and wastewater utility perspective, it may come as a "predictable surprise" that energy cost and variability in supply will profoundly influence the way utilities operate in the future.[19]

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[13] *See generally* Mike Hightower, *At the Crossroads: Energy Demands for Water Versus Water Availability*, 6 SOUTHWEST HYDROLOGY 24 (2007); DEP'T OF ENERGY, DIMINISHING WATER RESOURCES AND EXPANDING ENERGY DEMANDS: THE ENERGY WATER NEXUS IN THE UNITED STATES, Draft Report to Congress (Nov. 18, 2005).

[14] NAT'L ENERGY TECH. LAB., DEP'T OF ENERGY, ESTIMATING FRESHWATER NEEDS TO MEET FUTURE THERMOELECTRIC GENERATION REQUIREMENTS 3 (Aug. 2006, rev. Apr. 8, 2008), *available at* http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/2006%20REVISED%20May%208-2008%20Water%20Needs%20Analysis-Phase%20I.pdf.

[15] *See* CALIFORNIA ENERGY COMM'N, INTEGRATED ENERGY POLICY REPORT (2005), http://www.energy.ca.gov/2005publications/CEC-100-2005-007/CEC-100-2005-007-CMF.PDF.

[16] For more information, see http://www.nyserda.org.

[17] EPRI, *supra* note 12 (see both reports listed in that note).

[18] Larry Jentgen, Harold Kidder, Robert Hill & Steve Conrad, *Energy Management Strategies Use Short-Term Water Consumption Forecasting to Minimize Cost of Pumping Operations*, 99 J. AM. WATER WORKS ASS'N 86, 86 (2007) [hereinafter Jentgen et al.].

[19] *See generally* EDWARD G. MEANS III, LORENA OSPINA, NICOLE WEST & ROGER PATRICK, A STRATEGIC ASSESSMENT OF THE FUTURE OF WATER UTILITIES (2006); CALIFORNIA EN-

As valuable as the nexus approach is, it does not fully consider the embedded nature of energy and water policies or the potential outcomes of pursuing coupled resource-management frameworks. Institutional and administrative arrangements for both resources share several commonalities including mixed public and private ownership and management, agencies at multiple levels of government created and mandated with their regulation, and non-state actors that seek to influence policies and programs for the development, supply, use, and pollution abatement associated with both resources.

Despite these similarities, significant differences exist between energy and water resources, particularly for policymaking. For decades now, energy has been viewed globally as a strategic resource, with clear definition in national security terms. The energy crises of the 1970s were prompted by inadequate development and restricted supplies of petroleum. These, in turn, created shortage conditions and associated economic impacts. By contrast, water has narrowly been considered a local management challenge, despite calls from the research community for greater attention to the regional, transboundary, and global significance of water governance.[20] The growing importance of water resources in strategic terms is changing, principally because the security establishment recognizes that climate change, drought, and variable supplies can threaten national interests.[21] Our emphasis for the present analysis lies in the implications of scarcity—natural or induced—which has raised the profile of energy and water as resources that require investment in critical infrastructure, coordinated management, and collaborative policy.[22]

In the United States and globally, energy demand and water scarcity are often viewed independently, each as a question of resource development and service provision to consumers. As evidence of

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ERGY COMM'N, WATER-ENERGY RELATIONSHIP; IN SUPPORT OF THE 2005 INTEGRATED ENERGY POLICY REPORT (2005), http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011.PDF; Robert C. Wilkinson, Gary Wolff, William Kost & Rachael Shwom, An Analysis of the Energy Intensity of Water in California: Providing a Basis for Quantification of Energy Savings from Water System Improvements, Address Before the American Council for an Energy Efficient Economy Summer Study on Energy Efficiency in Buildings (2006).

[20] *See generally* Robert G. Varady, Katherine Meehan, John Rodda, Matthew Iles-Shih & Emily McGovern, *Strengthening Global Water Initiatives to Sustain World Water Governance*, 50 ENV'T 18 (2008).

[21] We believe that the specter of armed conflict over water resources, even in a transboundary context, is overstated.

[22] For analysis of examples of collaborative natural resource policy processes, see David J. Sousa & Christopher McGrory Klyza, *New Directions in Environmental Policy Making: An Emerging Collaborative Regime or Reinventing Interest Group Liberalism?*, 47 NAT. RESOURCES J. 377 (2007).

Bazerman's "cognitive bias," planners are only beginning to seriously consider the energy requirements for water development.[23] Development of new water supplies generally requires more energy than existing supplies because new supplies require more treatment and conveyance than those already tapped. The new sources—including interbasin transfers, groundwater pumping in areas previously served by surface water supplies, desalination, aquifer storage and recovery, and municipal wastewater reuse—are driving up the total energy required to meet urban water demand resulting from growth and climate change.

Bringing new power plants online will also require creative water management, given the increasing competition for water supplies and the additional water needed for required air pollution control, such as the control of sulfur dioxide. As water and energy are intricately linked, managing each resource separately is shortsighted and inefficient. Treating them together, on the other hand, will broaden the identification of emerging sustainability challenges and lead the way for the increasingly difficult challenges that decision-makers face; many of whom entertain "positive illusions" about the ease of future policy choices.[24]

Given these observations on the multiple challenges (not least, cost) of securing additional supplies of energy and water, it is crucial to note that significant potential exists to manage for efficiency and conservation of water and energy simultaneously. Water conservation has low-cost, socially acceptable benefits to both water and energy supplies, and when conservation benefits are evaluated collectively, cost-effectiveness improves dramatically. The potential for energy savings through efficiency is extremely high.[25] At the national level in the United States, the financial savings of efficiency measures in the residential, commercial, and industrial sectors would more than double the upfront investment costs, although these would need to increase from present levels by a factor of four or five. Sustained investment in efficiency over a decade would potentially reduce non-transportation energy consumption in

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[23] *See* Bazerman, *supra* note 4.

[24] Federal legislation has been proposed to link energy and water. Energy and Water Research Integration Act, H.R. 3598, 111th Cong. (2009), Energy and Water Integration Act, S. 531, 111th Cong. (as referred to S. Comm. on Energy and Nat. Resources, Dec. 2, 2009). Differences between H.R. 3598 and S. 531 center on mandated responsibilities of the Secretary of Energy and the Secretary of the Interior, although the primary intent of both is to assess and reduce the impacts of energy development on freshwater resources.

[25] *See* Martin J. Pasqualetti, 98 ANNALS ASS'N AM. GEOGRAPHERS 504 (2008) (reviewing ENERGY AND AMERICAN SOCIETY: THIRTEEN MYTHS (Benjamin K. Sovacool & Marilyn A. Brown eds., 2007)).

2020 by 26 percent while cutting greenhouse gas (GHG) emissions by over 1.1 gigatons annually.[26]

While increasing energy efficiency saves water, increasing energy demand uses water. Indeed, water services (infrastructure and operations) could play an important role in realizing energy savings, because water-supply systems can combine low costs per energy-unit saved, and there exists relevant experience among water utilities on how to save energy through water conservation:

> Community infrastructure could provide 290 trillion end-use BTUs or NPV-positive potential in 2020; unlocking this potential would require upfront investment of $4 billion and provide present-value savings of $45 billion. The potential resides in several sub-categories: street/other lighting (43 percent), water services (12 percent), telecom network (25 percent), and other electricity consumption (20 percent). End-uses and facilities managed by local governments account for 200 trillion end-use BTUs of the potential, while end-uses and facilities managed by private-sector entities make up 90 trillion end-use BTUs of the potential.[27]

End-use energy savings in commercial "community infrastructure" (including water and wastewater treatment and distribution) exhibit among the lowest costs per unit saved. On the other hand, savings in residential and commercial water heaters tend to have significantly higher costs per unit saved.

Beyond financial costs, legal and institutional impediments exist to realizing savings. Principal among these are the need for collaboration and trust among multiple parties in order to realize savings as well as reductions in the significant risks associated with capturing savings. The opportunities for joint energy-water policy and management provided by the end-use efficiency gains referred to here are clear examples of our contention that conservation retrofits have multiple positive outcomes. Trust among parties can be strengthened by leveraging public and private initiatives on the part of utilities (to offset the increased costs of

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[26] *See* HANNAH CHOI GRANADE, JON CREYTS, ANTON DERKACH, PHILIP FARESE, SCOTT NYQUIST & KEN OSTROWSKI, MCKINSEY & COMPANY, UNLOCKING ENERGY EFFICIENCY IN THE U.S. ECONOMY 8 (July 2009), http://www.mckinsey.com/clientservice/electricpower naturalgas/downloads/us_energy_efficiency_full_report.pdf. Efficiency improvement potential by industry is lower in percentage terms than for commercial and residential use. Industry represents both the largest primary and end-use consumer of energy and the lowest number of users, entailing that commercial and residential efficiency improvement would need to reach large numbers of smaller users.

[27] *Id.* at 71.

developing new water and energy supplies as the response to resource scarcity) with individual behavior change on the consumer side of energy and water resource use (appeal to a growing customer conservation ethic, and reduced costs over the long term). Actions on "both sides of the meter" (the utility or provider delivery-point for energy and water to the end consumer) cross-subsidize broader resource and financial savings. However, special interests that profit from growth and the associated development and construction of new infrastructure question the savings potential of conservation and demand management. In this view, the conservation potential we addressed above is overridden by resource scarcity, which can only be addressed through development of new supplies.

Energy and water requirements may be managed through innovative short-term demand forecasting,[28] an example of the energy-water operations nexus. Technology innovation is also promising; for example, through improvements in membrane technology, the energy requirements for desalination fell drastically from the 1980s through about 1995, after which point seawater reverse osmosis stagnated at approximately 2,000–4,000 kWh/acre-foot.[29] Alternatively, as Pacific Institute data indicate, the energy required to treat and distribute reclaimed water is an order of magnitude lower than for seawater desalination,[30] suggesting that this is an overlooked water source with significant conservation potential.

It is beyond the scope of the present analysis to characterize the full range of potential opportunities that renewable energy sources offer to offset the combined scarcity of water and energy. As a result, we limit the discussion here to renewables in the U.S.-Mexico border region, in which Arizona and Sonora are located. These focal states are characterized in Part II; however, the role of renewables in mitigating the impacts of energy and water development is central to our present discussion.

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[28] Jentgen et al., *supra* note 18, at 87.

[29] *See generally* U.S. BUREAU OF RECLAMATION & SANDIA NAT'L LABS., DESALINATION AND WATER PURIFICATION TECHNOLOGY ROADMAP (2003), *available at* http://www.usbr.gov/pmts/water/media/pdfs/report095.pdf; Chris Rayburn, Rich Kottenstette & Mike Hightower, Advanced Water Treatment Impacts on Energy-Water Linkages (The Water Utility Perspective), Address before the First Western Forum on Energy & Water Sustainability (Mar. 23, 2007), *available at* http://www2.bren.ucsb.edu/~keller/energy-water/5-3%20Christopher%20Rayburn.pdf; Srinivas Veerapaneni, Bruce Long, Scott Freeman & Rick Bond, *Reducing Energy Consumption for Seawater Desalination*, 99 J. AM. WATER WORKS ASS'N 95 (2007).

[30] Heather Cooley, Pacific Institute, Energy Implications of Alternative Water Futures, Address at the First Western Forum on Energy & Water Sustainability (Mar. 23, 2007), *available at* http://www2.bren.ucsb.edu/~keller/energy-water/5-2%20Heather%20Cooley.pdf.

The technologies of interest include: (1) wind, (2) geothermal, and (3) solar. Regarding the first, few outstanding wind energy locations exist in Baja California. However, there are few suitable wind energy locations in the state of Sonora. A similar story can be told for Arizona. Although a few areas of mid-range wind potential are available along the Mogollon Rim, on Gray Mountain, and near Kingman, no locations match the wind-power classes already developed in California.

The second renewable energy source commonly discussed in the border region is geothermal. As a country, Mexico has over 300 identified geothermal sites, including one of the largest geothermal installations in the world, at Cerro Prieto, 20 miles south of Mexicali. In Arizona, most available geothermal energy is lower grade and only suitable for direct-use applications. In some limited areas, geothermal energy is already used for agriculture, fish-raising, and space heating.

The third important renewable energy source in the border region is solar. Arizona has the greatest solar energy potential in the United States.[31] Across the border, in the northwest region of Mexico, Sonora is similarly well-endowed with solar energy potential.[32] The border region represents an especially iconic opportunity for developing this resource. Such development, of course, will have to consider the availability of the electricity to meet demand. With peak demand occurring in the evening, integration of alternative energies into the existing energy infrastructure must address this issue.

Changing the views of decision-makers and the public about including renewable energy sources as part of the U.S.-Mexico border region's critical infrastructure will require continued effort and improved institutional articulation, e.g., joint energy- and water-planning initiatives and, in the transboundary context, enhanced cross-border cooperation. The policy implications of the energy-water nexus, as outlined in this part, present a primary "near-pareto" opportunity to address resource scarcity in a manner that has beneficial societal outcomes while not infringing on personal liberties such as might result from drastic water restrictions or prohibitively expensive power prices. This all means that local employment and commercial opportunities, enhanced regional cooperation, and reduction in global GHG emissions are possible, and indeed desirable, without curtailing economic development.

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[31] *See* Front Page Public Relations, *Arizona: A Golden Business Opportunity for Solar Power*, http://www.frontpagepr.com/arizona_solar_business_opportunity.asp (last visited Mar. 4, 2011).

[32] *See* Oso Oseguera, *Sunny Mexico: An Energy Opportunity*, GREENTECH MEDIA, July 7, 2010, http://www.greentechmedia.com/articles/read/sunny-mexico-an-energy-opportunity.

II. GROWING DEMAND FOR ENERGY AND WATER IN THE SOUTHWEST UNITED STATES AND NORTHWEST MEXICO

The energy-water nexus, in both operational and policy terms, is acutely articulated under conditions of resource scarcity. We explore and present results from several cases of energy-water coupling in the Southwest United States and Northwest Mexico. The states of Arizona and Sonora share an arid climate with drought and flood extremes that contribute to a context of water scarcity.[33] The landscape, environment, habitat, and wildlife are common on both sides of the border.[34] Similarly, both states have common traditional economic mainstays of mining, farming, and ranching. Nevertheless, the border marks significant differences in culture and language, economic conditions, political and legal systems, roles and powers of government, indigenous societies, the relative vigor of civil society, and educational and research establishments.

Linked by trade, social and cultural bonds, and crucially by scarce water and energy resources, the states of Arizona and Sonora face increasingly variable precipitation, high temperatures, and rapid population growth.[35] These trends portend rampant increases in demand for energy and water. Of special relevance for comparative water and energy research, Mexico's petroleum-dependent economy and hydrocarbon-based power-generation mix are different from the United States' diversified portfolio of coal-, hydro-, nuclear-, and nonconventional power-generation mix. Similarly, wide gaps exist in infrastructure for water resources management. While the U.S. side has greater adaptive capacity, its mitigation options may be more difficult to achieve than in more-centralized Mexico. Both sides share a fundamental vulnerability

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[33] *See generally* Margaret Wilder, Christopher A. Scott, Nicolás Pineda Pablos, Robert G. Varady, Gregg M. Garfin & Jamie McEvoy, *Adapting Across Boundaries: Climate Change, Social Learning, and Resilience in the U.S.-Mexico Border Region*, 100 ANNALS ASS'N AM. GEOGRAPHERS 917 (2010); Gregg Garfin, Michael A. Crimmins & Katharine L. Jacobs, *Drought, Climate Variability, and Implications*, *in* ARIZONA WATER POLICY, MANAGEMENT INNOVATIONS IN AN URBANIZING, ARID REGION 61 (Bonnie G. Colby & Katharine L. Jacobs eds., 2007); Barbara J. Morehouse, Rebecca H. Carter & Terry W. Sprouse, *The Implications of Sustained Drought for Transboundary Water Management in Nogales, Arizona, and Nogales, Sonora*, 40 NAT. RESOURCES. J. 783 (2000).

[34] *See* CONSERVATION OF SHARED ENVIRONMENTS: LEARNING FROM THE UNITED STATES AND MEXICO (Laura López-Hoffman et al. eds., 2009).

[35] *See* R.G. Varady & B.J. Morehouse, *Cuanto Cuesta? Development and Water in Ambos Nogales and the Upper San Pedro Basin*, *in* THE SOCIAL COSTS OF INDUSTRIAL GROWTH IN NORTHERN MEXICO (Kathryn Kopinak ed., 2005).

in their energy-intensive water delivery systems. And environmental stresses continue to exacerbate both adaptation and mitigation.[36]

Neither state expects to be able to afford to invest in the full range of water and energy infrastructure needed to service growing demand. In both states, these needs include power generation based on conventional and renewable energy sources, expanded distribution systems, water transfer projects that cross river-basin divides, and water augmentation including energy-intensive desalination.

Despite the economic downturn that began in 2008, growth in Arizona is expected to add over four-million new residents in the coming quarter-century.[37] Over this period, the state's infrastructure needs have been estimated to cost half a trillion dollars for the following sectors: transportation ($253–$311 billion), telecommunications ($1–$23 billion), water and wastewater ($109 billion, with two-thirds allocated for water and a third for wastewater), and energy ($74–$86.5 billion).[38] These estimates for water infrastructure could be compared with the $4 billion cost of the Central Arizona Project (CAP) and $277 billion nationally assessed by the Environmental Protection Agency for public water-system infrastructure needs over 20 years. Projections of future water demand are based on reported current consumption levels in gallons per capita per day, i.e., not accounting for conservation trends resulting either from voluntary action, price elasticity of demand, or potential mandates.[39] The study concludes that new growth will pay for itself, although it proposes

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[36] *See generally* Andrea J. Ray, Gregg M. Garfin, Luis Brito-Castillo, Miguel Cortez-Vazquez, Henry F. Diaz, Jaime Garatuza-Payán, David Gochis, René Lobato-Sánchez, Robert Varady & Chris Watts, *Monsoon Region Climate Applications, Integrating Climate Science with Regional Planning and Policy*, 88 BULL. AM. METEOROLOGICAL SOC'Y 933, *available at* http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-88-6-933 (downloadable pdf at website).

[37] Growth and increasing energy demand are rampant across the Southwest United States where per capita power demand is increasing more rapidly than population. Gary Pitzer, *The Water-Energy Nexus in the Colorado River Basin*, COLORADO RIVER PROJECT, WATER EDUCATION FOUNDATION, RIVER REPORT 7 (Summer 2009), *available at* http://www.watereducation.org/userfiles/RiverReport_Summer09_WEB.pdf (reporting that in the states of Arizona, Colorado, Nevada, and New Mexico, population grew by 71 percent from 1980 to 2005, while power demand increased by 130 percent over the same period.).

[38] ARIZ. ST. UNIV., INFRASTRUCTURE NEEDS AND FUNDING ALTERNATIVES FOR ARIZONA: 2008–2032 (May 2008), *available at* http://www.arizonaic.org/index.php?option=com_content&view=article&id=36:-link-to-infrastructure-report-full&catid=3:aic-news&Itemid=9 (downloadable pdf at website) [hereinafter INFRASTRUCTURE NEEDS]; *Arizona's Infrastructure Needs to Cost a Half-Trillion Dollars over Next 25 Years*, BUSINESS WIRE (May 22, 2008, 4:30 PM), http://www.bqaz.gov/PDF/052208BusinessWire.pdf.

[39] ARIZ. DEP'T OF WATER RES., 8 ACTIVE MANAGEMENT AREAS WATER ATLAS (2010), *available at* http://www.azwater.gov/azdwr/StatewidePlanning/WaterAtlas/ActiveManagementAreas/default.htm (downloadable pdf at website).

a mechanism of usage fees to finance capital projects complemented by issuing bonds, both of which pass at least part of the burden of growth to current residents.[40] This would be especially welcome in Sonora, where growth, particularly in the capital of Hermosillo and border cities like Nogales and Agua Prieta, is characterized by aging infrastructure that is largely inadequate to meet current, much less future, demands for energy[41] and water.[42]

Several institutions exist through which to pursue binational governance of water and energy, including institutions intended to bolster relations, e.g., the Arizona-Mexico Commission, the International Boundary and Water Commission, or the Border Energy Forum. These institutional links must be strengthened. It is essential to have access to appropriate government agencies as well as easy access to research sites, information, and informants. On the other hand, challenges remain to be addressed, including the poor match between research priorities and decision-making, difficulty in overcoming bureaucratic inertia, barriers to sharing resources and credit, and in relation to border security, poor binational relations, suspicion of motives, and the challenges of forging close-working relations with agencies.

In this context, power generation will increasingly compete with municipal water supply for the water currently used in agriculture. In Arizona, this process is mediated by existing water rights, market transactions, water supply regulations, and other legal and administrative institutions. In Sonora, as throughout all of Mexico, water allocation for power generation, urban growth, and agricultural demand is administered by federal authority that is increasingly contested by state and local institutions.

III. CLIMATE CHANGE AND GROWTH CONTEXT FOR CRITICAL INFRASTRUCTURE

The impacts of climate variability and climate change are becoming more widely accepted as important contributors to the energy-water nexus. Electric power providers already comply with, or will face, multiple and complex regulations relating to GHG emission reductions, carbon sequestration, and state—and possibly federal—requirements for

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[40] INFRASTRUCTURE NEEDS, *supra* note 38, at xix.

[41] Christopher A. Scott, Robert G. Varady, Anne Browning-Aiken & Terry W. Sprouse, *Linking Water and Energy Along the Arizona/Sonora Border*, 6 SW. HYDROLOGY 26, 26 (2007).

[42] *See generally* Nicolás Pineda Pablos, *Construcciones y Demoliciones: Participación social y deliberación pública en los proyectos del acueducto de El Novillo y de la planta desaladora de Hermosillo, 1994–2001*, 19 REGIÓN Y SOCIEDAD 89 (2007).

increased use of renewable energy sources, as outlined below. There is increasing public attention to the issue of climate change, but so far there is an absence of clear national, state, or local policy to reduce GHG emissions. Over the longer term, however, the economic, environmental, and social costs associated with various technology options for meeting growing electricity demand without increasing GHG emissions remain unclear and are hotly contested. For example, while nuclear power is often cited as being a carbon-free solution to growing demand, it is faced with major safety and regulatory challenges, in addition to being among the most water-intensive generation options (largely due to cooling requirements). In the Arizona-Sonora region, with its serious water constraints and vulnerability to extreme drought under many climate models,[43] the climate change issue has gathered strong momentum. In a region of chronic multiyear drought, the importance of addressing the societal and environmental impacts of climate is essential to effective use of scarce water and energy resources.[44]

Climate change mitigation efforts for the Southwest focus on carbon cap and trade or carbon tax mechanisms, which are expected to be implemented regionally or nationally. Integrated "regional" and transboundary initiatives currently focus on the western United States and Canada, although Mexico has been a vocal proponent of climate mitigation with efforts underway to prepare state-level climate action plans (*Planes Estatales de Acción Climática*).[45] The Western Climate Initiative (Initiative) includes the states of New Mexico, Arizona, California, Utah, Oregon, Washington, and Montana, together with British Columbia, Manitoba, Ontario, and Quebec in Canada.[46] In per capita emissions levels, Arizona currently occupies the median position among the seven participating U.S. states. The Initiative includes a greenhouse gas cap-and-trade system that is projected to start in 2012, with the goal of reducing emissions in 2020 by 15 percent below 2005 levels. The American Clean Energy and Security Act[47] (the Act) proposes to create clean energy jobs, achieve energy independence, reduce global warming pollu-

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[43] *See generally Inconvenient Hydrology?*, 6 SW. HYDROLOGY 1 (2007) (containing numerous articles describing how the Southwest is particularly vulnerable to extreme drought, no matter which climate change scenario is used).

[44] *See generally* GUIDO FRANCO ET AL., CALIFORNIA ENERGY COMM'N, CLIMATE CHANGE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PLAN: CONSULTANT REPORT (Apr. 2003), http://www.energy.ca.gov/reports/2003-04-16_500-03-025FS.PDF.

[45] British Embassy Mexico City, *Desarrollo de Planes Estatales de Acción Climática*, http://ukinmexico.fco.gov.uk/es/working-with-mexico/programas-estrategicos/sucess-stories/action-plans (last visited Jan. 4, 2010).

[46] See http://www.westernclimateinitiative.org for more information.

[47] American Clean Energy and Security Act, H.R. 2454, 111th Cong. (2009).

tion, and transition to a clean energy economy. It is uncertain whether the Act would exert more stringent caps. According to various econometric and demographic models based on assumptions of different equilibrium carbon prices and the share of proceeds captured and reinvested in Arizona, the Act would have the greatest effect on energy-intensive industries. The Act would also have expansive economic impacts and cause decreased rates of population growth.[48] This analysis pays inadequate attention to the economic transformations that are expected in the renewable energy industry and to the economically quantifiable longer-term environmental benefits resulting from carbon emissions mitigation.

Cap-and-trade policies strive to attain both the goals of sustainability (by defining and establishing limits on the use of resources and/or pollution assimilative capacity) and efficiency (by exercising the exchange of allotments of the "commodities" capped).[49] For strategic resources like energy and water, the processes of capping and trading have significant political ramifications. Scientists, administrators, and politicians involved in establishing carbon limits for energy generation and use (e.g., footprints) as well as creating portfolio standards for renewable energy resources (such as solar and wind) are subject to political considerations influenced by ideology and competing interests. Similarly, trading essentially commodifies resources and ecological processes, leaving redistributive efficiency to the market.

Even where this exchange is regulated between willing sellers and buyers, concentration and monopolistic trading may result. Heinmiller has observed that market exchange of private property in cap-and-trade systems is eminently political.[50] Significant state intervention is required in the creation and maintenance of tradable property rights. Multiple, competing interests vie for influence in establishing caps (witness the Copenhagen 2009 climate negotiations). And, as we attempt to demonstrate in this article, the infrastructure required to facilitate energy and water (re-)distribution is subject to interest group politics.

Concerns over climate change and the need for GHG mitigation are being reflected in legislation and regulations that give energy policy a distinct dynamism compared to water policy, which remains entrenched in the "next bucket" augmentation mindset. Energy regulatory

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[48] *See* ARIZ. ST. UNIV., AN ASSESSMENT OF THE ECONOMIC IMPACTS ON THE STATE OF ARIZONA OF THE IMPOSITION OF A GHG EMISSION ALLOWANCE TRADING PROGRAM, i, iii, 16 (July 2009), http://www.arizonaic.org/images/stories/pdf/rpt_economicimpactofcarboncontrolsinarizona.pdf.

[49] *See generally* B. Timothy Heinmiller, *The Politics of "Cap and Trade" Policies*, 47 NAT. RESOURCES J. 445, 447–48 (2007).

[50] *Id.*

initiatives increasingly affect power utilities. These include measures such as California's that set specific goals and timetables for GHG emission reductions, and other state laws—renewable portfolio standards—that mandate electricity suppliers to generate or purchase a percentage of their power from renewable sources. Examples of such measures relevant for the Southwest include Arizona's Renewable Energy Standards,[51] and the 2004 resolution of the Western Governors' Association on clean and diversified energy.[52]

IV. WATER FOR ELECTRICAL POWER GENERATION

A central concern of this special symposium issue of the *Natural Resources Journal* is water for new energy development in the Southwest United States.[53] Accordingly, we address several generic water-for-power-generation issues pertinent to the Arizona-Sonora region. Currently, Arizona's generation mix is coal (36 percent), natural gas (34 percent), nuclear (24 percent), and renewables including hydroelectric (6 percent). Regulation of the electrical power industry's water use is based on a mix of federal and state law.

Prevailing water law in Arizona accords prior appropriation water rights to surface water and to groundwater within Active Management Areas (AMA), which were established by the 1980 Groundwater Management Act.[54] Within an AMA, water rights are fully allocated or over-allocated, implying that existing rights would have to be bought. Groundwater outside an AMA is subject to reasonable use but must be permitted. In addition to acquiring water permits through the Arizona Department of Water Resources, operators of power plants generating 100 MW or more must obtain a certificate from the Arizona Corporation Commission, which regulates siting with regard to water availability as well as power plant feasibility in environmental and economic terms.

Compliance with environmental standards, including those regarding discharge to receiving water bodies, is reviewed by the Arizona Department of Environmental Quality in accordance with the National Pollutant Discharge Elimination System program under the Clean Water Act. In Arizona, where numerous thermoelectric power plants rely on

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[51] *E.g.*, ARIZ. ADMIN. CODE §§ R14-2-1801–1816 (2007).

[52] *See* WESTERN GOVERNORS' ASS'N, CLEAN ENERGY, A STRONG ECONOMY AND A HEALTHY ENVIRONMENT 1–20 (2007), http://www.westgov.org/wga/publicat/CDEACReport07.pdf.

[53] "The Water-Energy Conundrum: Water Constraints on New Energy Development in the Southwest" Symposium was held at the University of New Mexico, Albuquerque, N.M., on February 12, 2010.

[54] ARIZ. REV. STAT. § 45-411.

groundwater, the state generally requires operators of plants that exceed 25 MW to cycle the cooling water at least 15 times to reduce freshwater pumping. In Sonora, power is generated by the Comisión Federal de Electricidad (Federal Electricity Commission, or CFE) using water that is concessioned for this purpose by the Comisión Nacional del Agua (National Water Commission, or CONAGUA), as we discuss below. For example, water to meet power generation requirements, from groundwater, urban effluent, or surface water, is tightly regulated.[55]

As demand for electricity in the region increases, so too will the volume of water needed to cool power plants. There are at least six options to meet this water need. First, it could come from transferring water from domestic uses, a source that is likely to itself be under stress. Second, it could be met by increased use of air-cooling technologies, an expensive tactic that would increase the cost of the power plants and lower their overall efficiency. Third, it could come from water diverted from agricultural use, a logical, if politically unpopular, approach in the short term. Fourth, it could be met by encouraging the construction and operation of new power plants in places with greater natural water availability, an option that presupposes the siting and installation of many new transmission lines, always contentious. Fifth, it could result from favoring the most efficient sources of conventional electrical energy; that is, those that use the least amount of water per kilowatt-hour generated, such as combined-cycle gas plants. And sixth, it could come from a substantial turn to renewable energy such as wind and solar cells, neither of which require water in the generating phase. Choosing among these options starts with understanding the operational aspects of the energy-water nexus.

Conceptually, the energy-water nexus is relatively simple because thermodynamic principles provide a general sense of the required water. We know, for example, that cooling-water requirements are inversely proportional to power-plant efficiency. That is, the higher the efficiency, the lower the cooling-water volumes required, and this is revealed in many published sources providing generalized values by technology. Nuclear power, being the lowest in efficiency, has the highest water de-

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[55] The National Water Commission's Public Register of Water Rights lists 64 percent of Sonora's water rights as being concessioned to the Federal Electricity Commission. With the exception of power plants utilizing groundwater in Alamos and Hermosillo, the entire volume of power-plant water is from surface water sources. A combined-cycle gas plant outside Hermosillo utilizes a portion of that city's effluent. *See* Mexico National Water Commission, Statistics, http://www.conagua.gob.mx/CONAGUA07/Noticias/son.pdf (last visited Nov. 10, 2010).

mands, while combined-cycle natural gas power plants are at the other end of the conventional energy spectrum.[56]

Such relative values are valid everywhere, although the specific volumes vary in response to the fuel mix and climatic conditions. The diverse generation portfolio in Arizona's Sonoran Desert region provides a useful opportunity to compare the water needs of different fuels (see Table 1, below). This portfolio includes uranium, hydropower, coal, natural gas (including combined-cycle), biomass, and solar (both photovoltaic and thermal). The state's natural gas and nuclear units are concentrated in Maricopa County. Most coal-fired power plants used by Arizona are on the periphery of the state, including several in neighboring states. Arizona also receives electricity from geothermal operations in California and wind turbines in New Mexico[57] (see Figure 1, below). Electricity in the state of Sonora comes mostly from power plants supplied with natural gas from the United States, although electricity is generated at several of southern Sonora's dams.

To prepare Table 1, we identified the water requirements for electricity used in Arizona. Such use is carefully monitored and the data systematically collected by each utility. We received the data from the three major companies—Arizona Public Service (APS), Salt River Project (SRP), and Tucson Electric Power (TEP)—and then verified their consistency by comparing them to power plants where the individual utility companies shared ownership, such as the Palo Verde Nuclear Generating Station. Last, we compared this data with data available from the U.S. Energy Information Administration (EIA).[58]

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[56] *See* J.A. VEIL, ARGONNE NAT'L LAB., USE OF RECLAIMED WATER FOR POWER PLANT COOLING 1, 2 (Aug. 2007), http://www.evs.anl.gov/pub/doc/ANL-EVS-R07-3_reclaimedwater.pdf [hereinafter VEIL].

[57] The first wind farm in Arizona, northwest of Show Low, is soon to be commissioned. Ryan Randazzo, *Harvesting Arizona Wind*, ARIZ. REPUBLIC (May 12, 2009), http://www.azcentral.com/arizonarepublic/news/articles/2009/05/12/20090512biz-windfarm0512.html (last visited Oct. 20, 2010).

[58] The verified data were first published in a short article for the Arizona Water Institute. *See* MARTIN J. PASQUALETTI & SCOTT KELLEY, THE WATER COSTS OF ELECTRICITY IN ARIZONA 6 (2008), *available at* http://azwaterinstitute.org/media/Cost%20of%20water%20and%20energy%20in%20az (downloadable pdf at site) [hereinafter PASQUALETTI & KELLEY]. The source of the comparative government data was Form EIA-860 "Annual Electric Generator Report," *available at* http://www.eia.doe.gov/cneaf/electricity/page/eia860.html; and EIA Forms 906, 920, and 923, all of which fall under the title "Combined (Utility, Non-Utility, and Combined Heat & Power Plant) Database," available at http://ftp.eia.gov/cneaf/electricity/page/eia906_920.html.

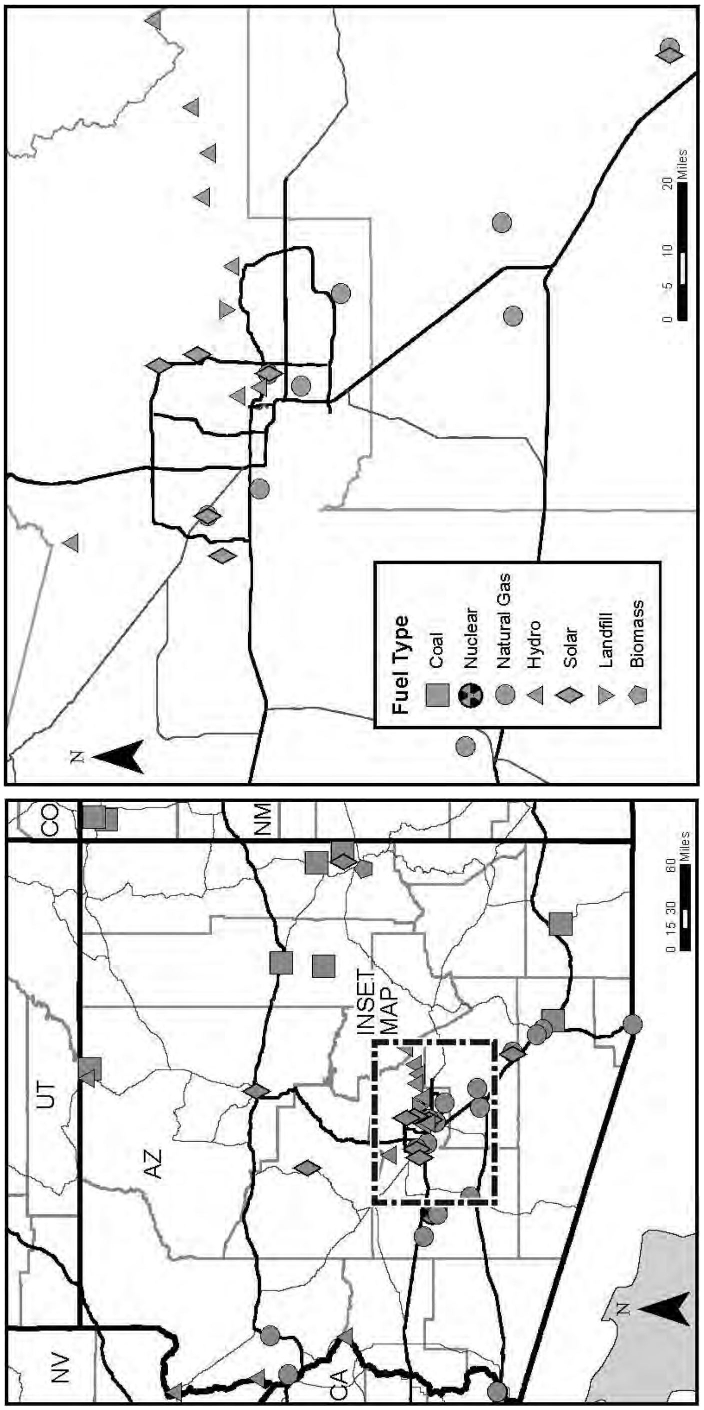


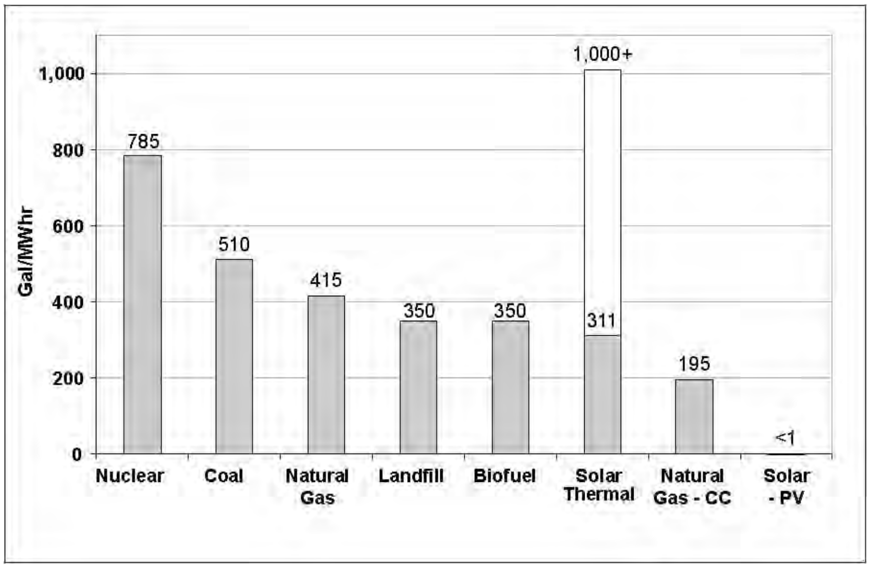
FIGURE 1. Arizona power plants with primary fuel type.

Table 1. Arizona electricity sources (MWh, 2002–2006 annual average).

	In-State Generation	Imported Generation	Exported Generation	Net In-State Use
Coal	38,526,671	13,706,962	9,308,761	42,924,872
Natural Gas	30,135,321	636,079	468,670	30,302,730
Nuclear	27,492,437		14,680,961	12,811,476
Biomass	12,058		12,058	0
Geothermal		65,323		65,323
Hydro	8,760,777	133,529	6,280,250	2,614,056
Solar	16,892			16,892
TOTAL	**104,944,156**	**14,541,893**	**30,750,700**	**88,735,349**

Obtaining data is more challenging when there is no reporting requirement. SRP, a quasi-municipality, provided its water-use data, but it was the only unregulated power producer to do so. For the others, so-called "merchant plants," we used vetted data from nearby regulated plants. The values for the consumptive use of water to generate electricity in Arizona (minus hydro dams) ranged from a high of 785 gallons per megawatt hour (gal/MWh) for nuclear energy to a low of less than 1gal/MWh for solar photovoltaic. Of the fossil-fuel power plants, the combined-cycle natural gas used the least (see Figure 2, below).

FIGURE 2.[59] **Average water consumption for electrical power generating facilities supplying Arizona.**[60] (*Note: The actual value for the single, 1 MW, experimental, concentrating solar power facility in Arizona is 311 gal/MWh, but this is seen as unrepresentative of the true water obligations of solar-trough technology. More realistic values, based on experience in California and discussion with industry representatives, is at least 1,000 gal/MWh, unless dry-cooling is employed.*)



These numbers prompt at least two questions. Considering the relatively high water demands of nuclear power plants, why was the Palo Verde Nuclear Generating Station (PVNGS) sited 50 miles west of downtown Phoenix, in one of the driest places on the continent? The creative solution was to use treated effluent from the nearby 91st Avenue wastewater facility for most of its needs.[61] Because of the source of this

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59. PASQUALETTI & KELLEY, *supra* note 58, at 8.

60. Electricity from geothermal power plants is imported from one plant in Imperial Valley. Solar thermal is based on one facility near the Saguaro fossil plant, northwest of Tucson, but should be expected to be higher when more data are available. Larger solar-thermal plants in California use between 800–1,000 gal/MWh.

61. VEIL, *supra* note 56, at 36. Veil identifies 57 power plants around the United States that use reclaimed water for cooling purposes, with most concentrated in Florida, California, Texas, and Arizona where the availability of freshwater constrains the options. The Palo Verde Nuclear Generating Station outside of Phoenix is the plant with the single highest volume (55 million gal/day) of reclaimed water use. This plant makes no subsequent releases of blowdown water to the environment and, instead, evaporates poor quality

water, some might suggest we exclude its consumptive water totals use from the state tally. We argue, however, the opposite. Prior to the completion of PVNGS, water discharged from the 91st Avenue facility flowed into the Gila River, which courses toward a confluence with the Colorado River near Yuma, 170 miles southwest of Phoenix. Diverting this water in an enclosed pipeline to PVNGS precludes it from recharging local aquifers or meeting any other use. Because it is no longer available for any other use, we count the water used at Palo Verde in the same manner that we count water used at any other plant.

The other question of particular interest in Arizona pertains to solar energy. If Arizona has the best solar energy resource in the United States, shouldn't state development of solar energy be leveraged by its low water requirement? While solar photovoltaic (and wind) use little water in the generation phase, concentrating solar power (CSP) installations are a different case entirely. Figure 2 presents two water consumption values for CSPs, one about three times greater than the other. This discrepancy comes from the examples used. The largest CSP in Arizona is a 1 MW pentane vapor Organic Rankine Cycle installation adjacent to the 450 MW gas-fired Saguaro power plant, 30 miles northwest of Tucson. Until the last quarter of 2008, APS did not measure the total amount of water they add to compensate for evaporation when electricity is generated at their solar facility. However, they had been measuring blowdown (the saline water that is drained off from the cooling towers). The Saguaro solar facility is the only CSP operating in the state. We estimated its water consumption as 311 gal/MWh by taking into account water lost to blowdown, the water used to wash the solar panels, and an estimate of the makeup water for the cooling tower.[62] Saguaro is a test facility whose water use is not typical of CSP installations. This preliminary 311 gal/MWh value was corroborated once APS began monitoring makeup water use more closely.[63]

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residual water in open ponds. States that are not water-scarce—including Massachusetts, Maryland, and New Jersey—also make use of reclaimed water for power-plant cooling. In some instances, reclaimed water is used for air pollution control equipment, including scrubbers. This latter use within power plants is expected to increase. *See also* VEIL, *supra* note 56, at 28.

[62] Blowdown at the Saguaro solar facility amounts to about 2,500 to 3,000 gal/week during the summer and 2,500 to 3,000 gal/10 days during the lower temperature months. PASQUALETTI & KELLEY, *supra* note 58, at 11 n.2 (2008).

[63] Approximately 3800 gallons of RO/DI (reverse osmosis, deionized) water is used per "deluge" wash. Labor-intensive, "full–contact," cleaning requires twice as much water per washing. Between 4,000 and 6,000 gal/day are used for makeup and blowdown, according to Saguaro operator Jeff Lee of APS. We assume 5,000 gallons are lost to produce 10 MWh, which is 500 gal/MWh. Four thousand gallons to produce 12 MWh would yield 333 gal/MWh, remembering that the plant does not run on a steam cycle.

However, the 1 MW Saguaro facility is intended primarily for research and development, and other data estimates might be more applicable. For example, operating experience for the 350 MW Solar Energy Generating Stations (SEGS) in California's Mojave Desert, all of which operate on a steam cycle, are in the range of 800 to 1,000 gal/MWh.[64] Engineering estimates for a similar facility, the 280 MW Solana project proposed by Abengoa Solar for a site a few miles west of Gila Bend, Arizona,[65] are in the same range.[66] These water requirements would presumably present a public concern, if not an actual barrier, to the proliferation of CSP installations in the arid Southwest.[67] The current strategy that bypasses this concern is to buy agricultural land, complete with its existing water rights. This approach is limited to the availability of such land, just as it tempts increased public opposition to CSP facilities based on their water needs. In effect, water-intensive energy development in the region creates an energy-water-land nexus.

V. ARIZONA AND SONORA ENERGY-WATER NEXUS CASES AND IMPLICATIONS

In Arizona and Sonora, electrical power and water development are largely decoupled yet have immediate and long-term policy implications. We illustrate these below through consideration of the following cases of critical infrastructure and economic development: (1) growth in Phoenix, Tucson, and Mexican cities, including Ambos Nogales on the border; (2) water consumed in electrical power generation and the "virtual water" implications of regional interstate power grids; (3) the irrigation-electrical power nexus in agriculture; and (4) coastal desalination and proposed transboundary transfer schemes that have advanced to concept-level studies. In our concluding comments in Part VI, we at-

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[64] DEP'T OF ENERGY, ENERGY DEMANDS ON WATER RESOURCES, REPORT TO CONGRESS ON THE INTERDEPENDENCY OF ENERGY AND WATER, Table V-1 (2006).

[65] *See Utility-Scale Solar Power: Opportunities and Obstacles*, *Field Hearing before the H. Subcomm. on Energy & Env't* (2008) (statement of Kate Maracas, Vice President, Arizona Operations, Abengoa Solar).

[66] Engineering estimates for that facility are about 928 gal/MWh of withdrawn water. "With wet cooling, the cooling tower represents approximately 90 percent of a Rankine parabolic trough power plant's raw water consumption. The other 10 percent of water consumption includes the steam cycle makeup cycle (8 percent) and mirror washing (2 percent)." Nat'l Renewable Energy Lab., *Parabolic Trough Power Plant System Technology*, http://www.nrel.gov/csp/troughnet/power_plant_systems.html (last visited Jan. 4, 2011).

[67] Air-cooled CSP facilities are expected to use much less water. *See* BrightSource Energy, *BrightSource Energy's Environmental Commitment*, http://www.brightsourceenergy.com/about_us/environmental_stewardship/ (last visited Oct. 21, 2010).

tempt to synthesize findings of the four cases that are more broadly relevant to the policy and operational considerations posed in previous parts of this article.

A. Electrical Power for Urban Water Supply and Wastewater Reclamation

Rapidly expanding urban centers can place increasing demands on water supply.[68] Per capita consumption of water is declining in cities throughout the U.S. Southwest, so that the growing population is not by itself the driver of demand. Yet making the best use of available sources of water remains a challenge that has important implications for energy use. In Arizona, Phoenix[69] is relatively better positioned than Tucson[70] with respect to a diversified portfolio of water sources. The energy intensity difference for water service provision between Phoenix and Tucson is a function of geography and water supply options (see Figure 3, below).

More than 50 percent of Phoenix's drinking water is supplied by a major local water distribution company, the SRP, whose operation is gravity-based and requires minimal energy input. By contrast, the Tucson metropolitan area relies heavily on the CAP canal to transport Colorado River water over 300 miles to the area. Such pumping requires large amounts of energy. Municipal areas located within an AMA will rely less on groundwater mining and increasingly on renewable supplies. Tucson will increasingly rely on the CAP, and as a result more energy will be used for water service. In contrast, municipalities in the Phoenix metropolitan area with access to SRP water will experience greater water demand with less energy impact due to the minimal amounts of energy required to deliver SRP water to the municipalities.

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[68] *See* GRADY GAMMAGE, JR., ET AL., MORRISON INST. FOR PUB. POLICY, MEGAPOLITAN: ARIZONA'S SUN CORRIDOR (2008), *available at* http://morrisoninstitute.asu.edu/publications-reports/Mega_AzSunCorr (downloadable pdf at site).

[69] *See* Jan C. Bush, Subhrajit Guhathakurta, John L. Keane & Judith M. Dworkin, *Examination of the Phoenix Regional Water Supply for Sustainable Yield and Carrying Capacity*, 46 NAT. RESOURCES J. 925 (2006).

[70] *See generally* CITY OF TUCSON & PIMA COUNTY, PHASE 2 FINAL REPORT, WATER AND WASTEWATER: INFRASTRUCTURE, SUPPLY AND PLANNING STUDY (2009), http://www.tucsonpimawaterstudy.com/Reports/Phase2FinalReport/PHASE2report.12-09FINAL_lg.pdf; CITY OF TUCSON WATER DEP'T, WATER PLAN: 2000–2050 (2004), http://www.tucsonaz.gov/water/docs/waterplan.pdf; CITY OF TUCSON WATER DEP'T, UPDATE TO WATER PLAN: 2000–2050 (2008), http://www.tucsonaz.gov/water/docs/wp08-update.pdf.

Energy intensities for Mexican cities[71] similarly vary by source of supply, conveyance topography, and so forth (see Figure 4, below); however, it should be noted that the border cities of Nogales (Sonora) and Tijuana (Baja California) require higher energy intensities for water supply than numerous other (non-border) cities.

The city of Phoenix and Tucson metropolitan area's consumption of electricity for water and wastewater service amounts to less than 2 percent of statewide total electricity.[72] The 2 percent electricity-use number represents a portion of total electricity for water use statewide due to the focus on Phoenix and Tucson. In the Tucson metropolitan area, electricity use for water and wastewater service accounts for approximately 5 percent of metro area total electricity consumption. Therefore, the Tucson metropolitan area uses slightly more electricity for water and wastewater service than the national average, which is 3–4 percent.

Future water management choices regarding water supply and treatment techniques, such as desalination, may result in increasing overall electricity use. In addition, as technological advances enable re-

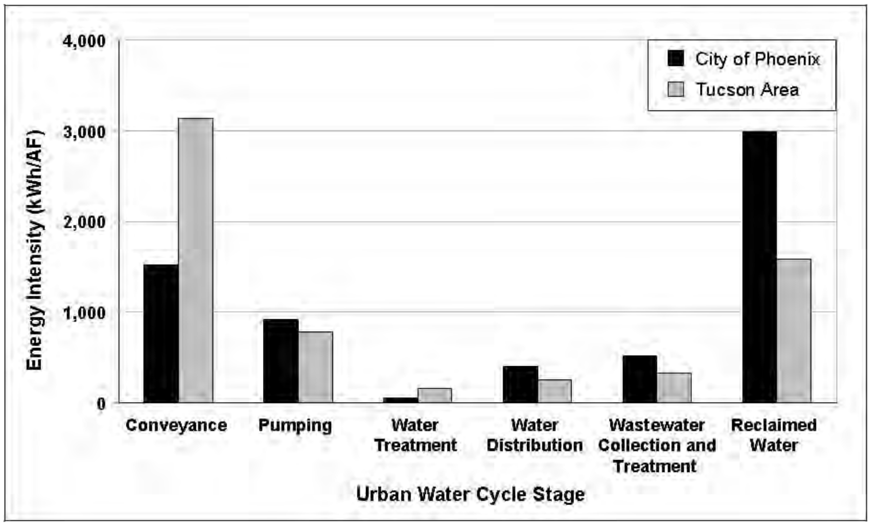

FIGURE 3. Energy intensity of the urban water-use cycle for the city of Phoenix and the Tucson metropolitan area.

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[71] Arturo Pedraza, Engineer, Alliance to Save Energy, Proyecto de Eficiencia Física, Operación Hidráulica y Electromecánica, Para la Ciudad de Nogales, Son., Address to the Nogales, Sonora Water Board (2008).

[72] CHRISTOPHER SCOTT, MARTIN PASQUALETTI, JOSEPH HOOVER, GREFF GARFIN, ROBERT VARADY & SUBHRAJIT GUHATHAKURTA, WATER AND ENERGY SUSTAINABILITY WITH RAPID GROWTH AND CLIMATE CHANGE IN THE ARIZONA-SONORA BORDER REGION 10 (2009).

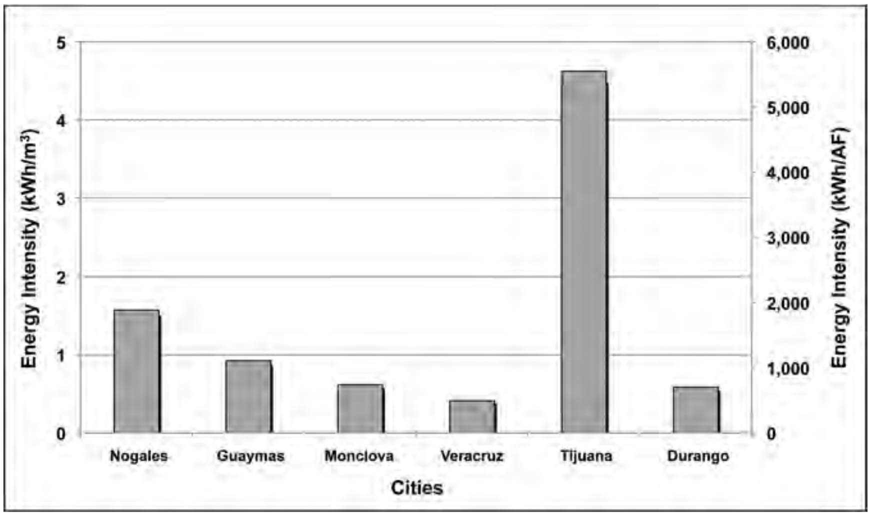

FIGURE 4. Energy intensity of the urban water-use cycle in selected Mexican cities.

searchers and water agencies to test for contaminants of emerging concern, the energy intensity of water service could increase. Simultaneous consideration of water and electricity resources will be necessary to maintain the current low overall electricity use for water and wastewater services. Long-distance conveyance options, particularly from high-energy water sources like coastal desalination described below, significantly increase the energy requirements of critical water infrastructure.

B. Trading Virtual Water in Grid Power Sales

Generating electricity in thermal power plants requires water for cooling, and this has the effect of embodying the water into the electricity in the same "virtual water"[73] sense that all agricultural products embody water. As we transport lettuce, wine, and strawberries, water used in their preparation effectively moves with them. The same is true of the transfer of water with the movement of electricity. Just as it moves with trucked food, such "virtual water" moves wherever the electricity goes. Because Arizona trades electricity across state lines, in effect, water is

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[73] *See* J. Anthony Allan, *Virtual Water: Invisible Solutions and Second–Best Policy Outcomes in the MENA region*, INT'L WATER & IRRIGATION J. (2001); Ashok K. Chapagain & Arjen Y. Hoekstra, *The Global Component of Freshwater Demand and Supply: An Assessment of Virtual Water Flows Between Nations as a Result of Trade in Agricultural & Industrial Products*, 33 WATER INT'L 19 (2008).

traded between states as well. Of the 105 million MWh of electricity generated in Arizona annually between 2002 and 2006, about 31 million MWh (approximately 30 percent) were exported. Moving in the other direction, about 14.5 million MWh were imported annually (see Figures 5 and 6, below).

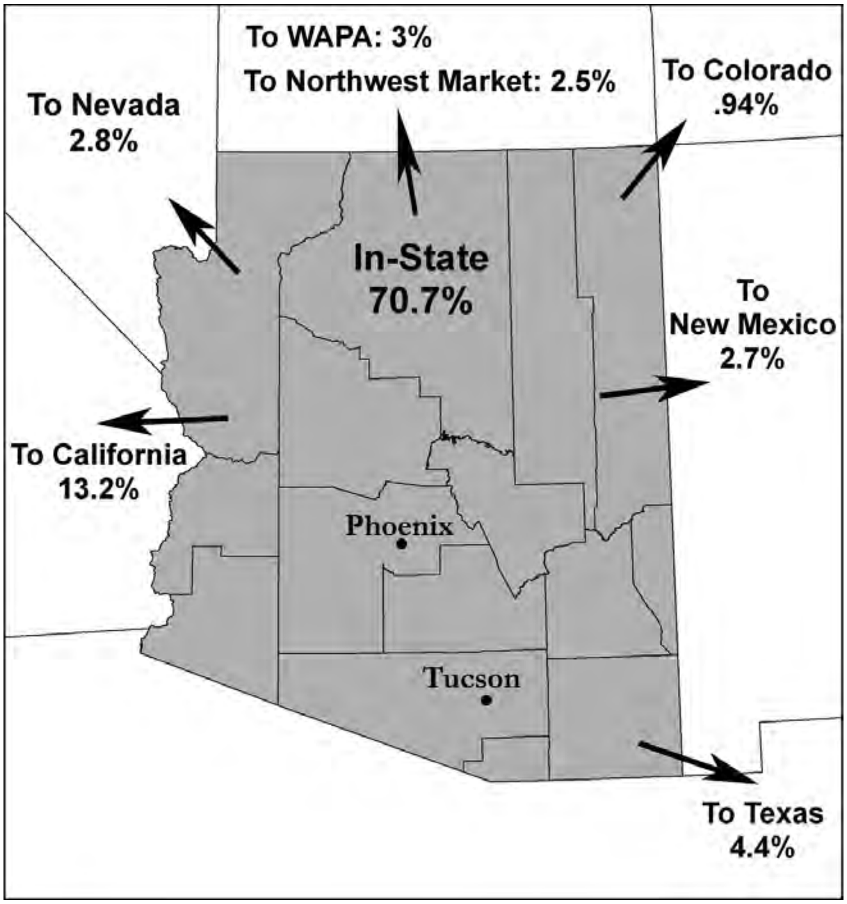

FIGURE 5. Destination of Arizona's exported electricity.[74] (*Note: Of the average of about 105 million MWh generated in Arizona for the years 2002–2006, about 71 percent is used within the state. WAPA is the acronym for Western Area Power Administration.)*

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[74] About 71 percent of the electricity generated in Arizona remains in the state.

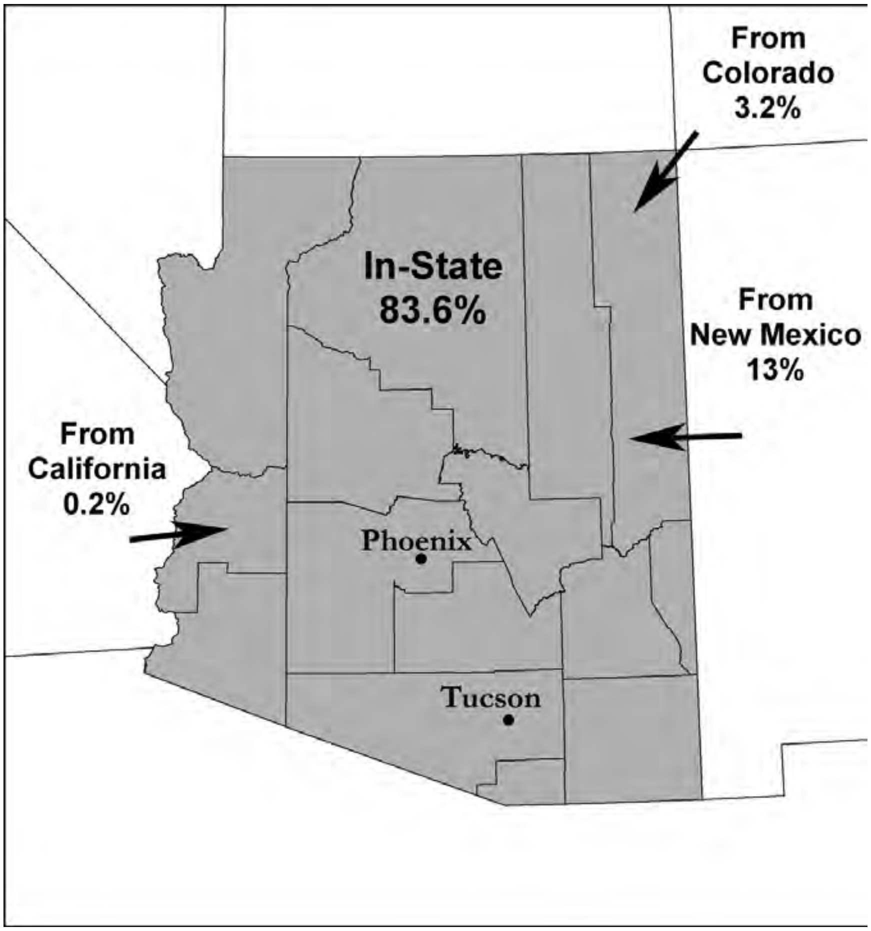


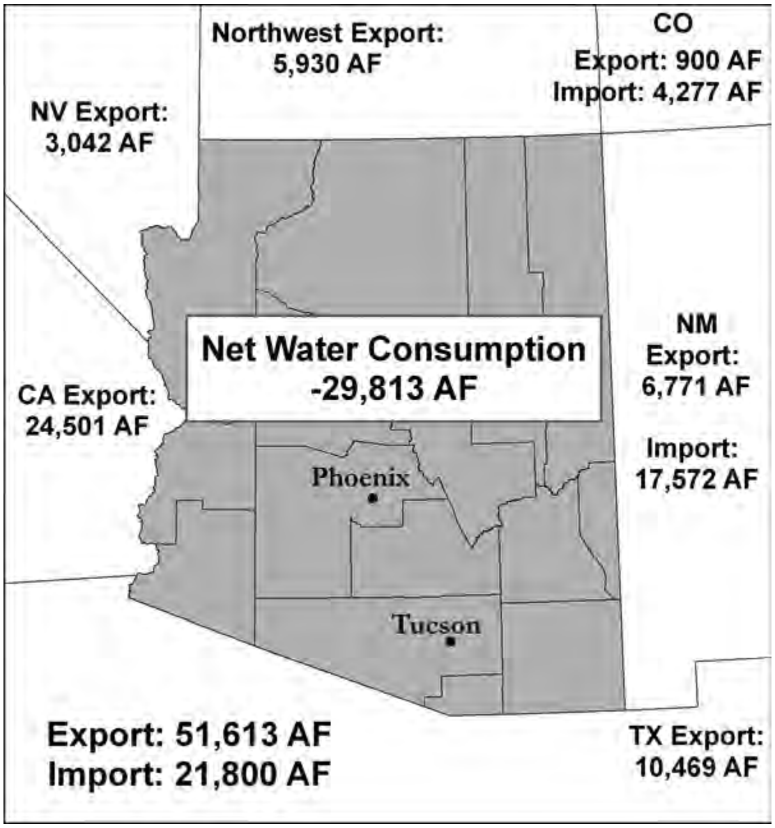
FIGURE 6. Sources of Arizona's imported electricity. (*Note: Of the average of about 89 million MWh used in Arizona, about 84 percent is generated within the state.)*

Knowing the total electricity generated by each fuel, plus the amount of electricity exported, and the consumptive use of water per megawatt-hour of electricity for each energy resource, we can calculate the amount of virtual water that crosses state borders. The total water exported is annually about 52,000 acre-feet (see Table 2, below). Counterbalancing some of this loss, the total imported virtual water is about 22,000 acre-feet per year. The net loss of water to Arizona from thermoelectric plants is about 30,000 acre-feet per year, enough to supply the annual needs of 150,000 people at current rates of use in Arizona (see Figure 7, below). While it is not possible to identify the exact origin of the

TABLE 2. Exported electricity and virtual water (2002–2006 annual average).

	MWh	MWh Percent	Gal/ MWh Average	Acre-feet consumed
Coal	9,308,761	32.60%	548	15,643
Natural Gas	165,506	0.09%	492	250
Natural Gas (combined-cycle)	303,164	1.77%	350	326
Nuclear	14,680,961	51.42%	785	35,381
Biomass	12,058	0.04%	351	13
TOTAL	**24,470,450**		**687**	**51,613**

FIGURE 7. Net water consumption by Arizona for thermoelectrical generation (imports minus exports), 2002–2006. *(Note: About 30,000 acre-feet (AF) of water is "exported" from the state, embodied within the electricity.)*



generated electricity, two sources—nuclear and gas-fired merchant plants—are most likely responsible for generating most of this exported electricity; PVNGS transmits about 31 percent of its electricity to California and almost all of the electricity from the merchant plants is sold to California.

Several policy implications are associated with these findings. The most salient is that decisions by the Arizona Corporation Commission (ACC) to approve permit applications for new power plants are tantamount to approval to send Arizona water to other states. In other words, when the ACC grants a permit for the construction and operation of a new generating station that will be primarily selling electricity to other states, they are also approving the transfer of any water used in the generation of that electricity. This is true for fossil fuel and nuclear plants, and it will also be true of any of the proposed CSPs that in the future will be generating electricity for sale across borders. Such additional generation capacity within Arizona will add to the infrastructure costs because there will be a need for additional transmission capabilities for this electricity.

C. The Irrigation-Electrical Power Nexus in Agriculture

Agriculture is the largest consumer of water in Arizona and Sonora, estimated at 68 percent and 85 percent of total water resources, respectively.[75] The combination of year-round growing conditions, productive soils, plentiful sunshine, and location with respect to markets makes farming in the region highly competitive. The arid climate makes irrigation essential. We focus on Sonora's energy-water nexus in agriculture as a "critical sector," given that groundwater pumping for irrigation currently represents a tenth of Sonora's total electrical power consumption[76] and the farming sector accounts for 8–9 percent of the state's economic output. Because water availability has constrained irrigated agriculture, the state's cropped area witnessed continual declines over

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[75] *See* Jeffrey C. Silvertooth, Professor and Head, Dep't of Soil, Water & Envtl. Science, Univ. of Ariz., Managing Agricultural Systems in a Non-Stationary World, Address at the Ninth SAHRA Annual Meeting (Sept. 23, 2009), http://chubasco.hwr.arizona.edu/am2009/sites/chubasco.hwr.arizona.edu.am2009/files/presentations/Session%204/Silver_SAHRA%20Annual%20Meeting%202009.pdf; COMISIÓN NACIONAL DEL AGUA, ESTADISTICAS DEL AGUA EN MEXICO, 167 (2008), http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/EAM_2008.pdf.

[76] Unless otherwise specified, electrical power data for the state of Sonora used in this analysis were accessed from the Federal Electricity Commission.

the 1996–2005 period,[77] a trend that continues to the present. Aquifer depletion is a serious and growing challenge.[78]

Federal and state authorities in Mexico are concerned about the causal links between power supply to agriculture and groundwater overdraft. Coupled energy-water policies and programmatic initiatives have only been partially effective in addressing resource scarcity challenges. The National Water Commission initiated the Efficient Use of Water and Electrical Energy Program[79] nationwide to implement water and energy efficiency improvements at the farm level on a cost-share basis (typically 50 percent of the cost is met using federal support, but it is up to 90 percent for small-scale farmers). Some state governments in Mexico have covered part of the farmers' share of the improvements, though not Sonora due to inadequate financial resources. The program seeks to improve electrical power and water-use efficiency through pump and electrical equipment upgrades and the promotion of efficient irrigation technologies, including drip and sprinkler irrigation. The program's coverage has been incomplete, and due to stringent criteria for approved technical studies prior to the release of cost-share funds, many farmers are excluded. This has important equity implications, with large commercial growers being more able to meet the requirements while small-scale growers have tended to find themselves out of compliance.

In a coordinated policy initiative, the Federal Electricity Commission and the Federal Agricultural Department (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, or SAGARPA, whose mandate also covers livestock, rural development, fisheries, and food security) have examined various means to defray the rising costs of power supply to agriculture while promoting economic productivity, if not physical efficiency explicitly. In April 2002, the CFE estimated that the average cost of energy for groundwater pumping[80] in Mexico was Mex$0.3133 (US$0.033) per kWh, representing a total subsidy of Mex$5.62 billion (US$592 million) at the national level in 2000. The energy rationalization plan established a pump power-tariff of Mex$0.30 (US$0.0316) per kWh that was adjusted for regional purchasing power

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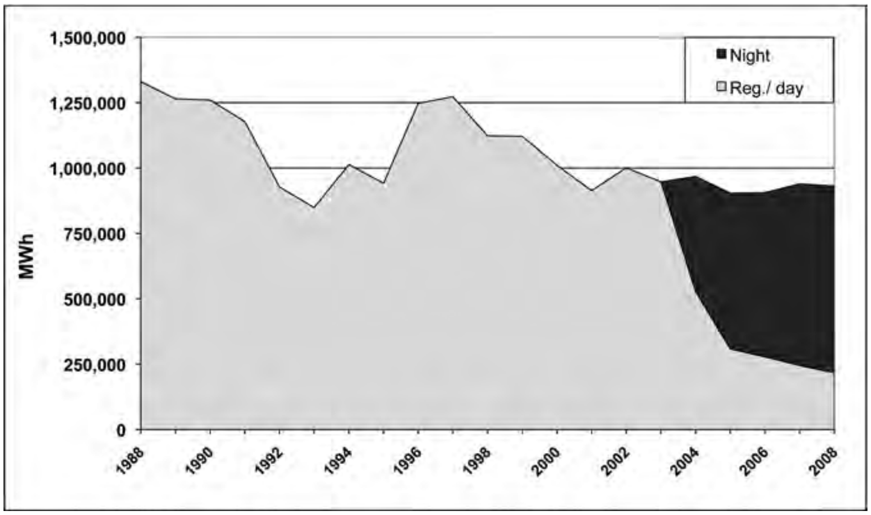
[77] *See* Alvaro Bracamonte Sierra, Norma Valle Dessens & Rosana Mendez Barron, *La Nueva Agricultura Sonorense: Historia Reciente de un Viejo Negocio*, 19 REGION Y SOCIEDAD 51 (2007), *available* at http://redalyc.uaemex.mx/pdf/102/10209903.pdf.

[78] *See* Christopher A. Scott, Sandy Dall'erba & Rolando Díaz Caravantes, *Groundwater Rights in Mexican Agriculture: Spatial Distribution and Demographic Determinants*, 62 PROF. GEOGRAPHER 1 (2010).

[79] *Uso Eficiente del Agua y la Energía Eléctrica*.

[80] Tariff category 09 is "exclusively for low tension power to pump water used to irrigate cropped fields and to light the pump house." Other farm-level power uses are separately metered at different tariff rates. Scott et al., *supra* note 2.

FIGURE 8. Electrical power energy consumed to pump groundwater for irrigation in Sonora, 1998–2008.



parity and increased nominally to account for inflation. Increasing slab-tariffs for pumping were eliminated, except in relation to the proposed annual power quota described below. SAGARPA provided the subsidies to users who consumed less than 15,000 kWh annually, while CFE subsidized those consuming more than this level. Incentives were proposed to further stimulate irrigation "technification," i.e., the adoption of drip and sprinkler technology, and for the shift to higher-value production.

In December 2002, the Mexican Congress unanimously passed the Rural Energy Law (Ley de Energía para el Campo) to regulate market mechanisms and incentives for petroleum-based energy sources and electricity use in agriculture. The law mandated a Rural Energy Program with an annual budget and implementation plan that must be included in the federal budget. The intent of the law was to level the playing field with Mexico's principal competitors—United States and Canadian agricultural producers—who enjoyed similar energy subsidies. The law also purported to cap groundwater extractions through an annual power consumption quota fixed to the volume of groundwater a grower was concessioned to pump. Once the quota was exceeded, CFE would steeply increase power tariffs for pumping until the end of the annual billing cycle, at which point the meter would start over again. However, this provision has not been enforced as CFE does not have sufficient personnel in rural areas to enforce the quota, and it was concerned about further bill payment delinquency, which is a growing concern with rising tariffs and falling groundwater levels.

Two years later in 2004 and into 2005, nighttime tariffs were introduced for agricultural groundwater pumping; they were initially 13 percent lower than daytime tariffs. As this difference increased (up to 22 percent in 2008), farmers in all major groundwater-pumping states (including Sonora, Chihuahua, and Coahuila along the U.S. border, as well as Guanajuato in central Mexico) have rapidly shifted to pumping at night. Sonora's total power consumption for groundwater pumping has declined marginally from 2000 to the present (see Figure 8, above); however, with efficiency improvements being made by an increasing number of farmers, the groundwater conservation gains are likely negated by falling groundwater levels and on-farm operations.[81]

Groundwater levels in Sonora continue to fall. The irrigation-power nexus in the state has reduced peak daytime power demand for CFE as well as unit costs of power for farmers; however, without further reductions in pumped volumes and irrigated acreage, the long-term groundwater overdraft challenge remains unaddressed.

D. Coastal Desalination and Proposed Transboundary Water Transfers

Desalination of seawater is receiving increasing attention in many parts of the world, and in some parts of the United States, especially California. The linked energy-water dimensions of desalination have long been recognized.[82] In the mid-1960s under the auspices of the International Atomic Energy Agency, the United States and Mexico explored the technical and economic feasibility of using nuclear power for desalination at Golfo de Santa Clara on the Sea of Cortez, near San Luís Río Colorado in Sonora.[83] These plans gave way to the Yuma Desalting Plant,[84] in part due to the recognition of the significant risk posed by the

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[81] Falling groundwater levels require more power to pump water to the surface. Additionally, where farmers use ponds to temporarily store water pumped at night, until daytime farm laborers distribute water to the crops, additional power may be required. These effects, which tend to reduce the volume of water that each unit of power delivers to crops, are offset by efficiency improvements.

[82] Technology advances have reduced the energy demand of conventional seawater desalination from 20 kWh/m3 in the mid-1970s to less than 2 kWh/m3 (under 2,500 kWh/acre-foot) in 2005.

[83] *See* INT'L ATOMIC ENERGY AGENCY, NUCLEAR POWER AND WATER DESALTING PLANTS FOR SOUTHWEST UNITED STATES AND NORTHWEST MEXICO (1968).

[84] Constructed from 1975 to 1992 at a cost of $258 million.

site's proximity to the San Andreas Fault.[85] The diplomatic challenges associated with the U.S. role and influence in managing facilities and physical infrastructure located within Mexico, and with transboundary water transfers, were not fully appreciated; these challenges remain and should not be discounted.

More recently, in view of limitations foreseen in California's interest and willingness to use or make available water desalinated along its coastline for purposes other than its own, an Arizona-Mexico Water Augmentation Consortium has been proposed to pursue desalination in Mexico (using non-nuclear power) to help address Arizona's increasing demand for water.[86] Plans for desalination within Mexico to serve U.S. demands for water have advanced to concept-level planning.

In a recent 2009 study "to provide conceptual-level information and opinion of cost data," a desalination facility would be located at Puerto Peñasco (some 60 miles east of the Golfo de Santa Clara site proposed in the 1960s).[87] Two options were developed for transboundary transfer of desalinated water that could be exchanged with other upstream users of Colorado River water. Both options are based on membrane reverse osmosis technology (with details retained in confidence by the clients who commissioned the report) resulting in product water of 750 mg/L of total dissolved solids. This is acceptable for agricultural and environmental uses but leaves salinity in the detectable taste range for potable water.

In the "Arizona-Sonora Scenario," 120,000 acre-feet per year requiring 50 MW of power would cost $995 per acre-foot to desalinate and an additional $1,732 per acre-foot to convey via a 168-mile pipeline to the Imperial Dam within the United States. These costs are currently higher than for other water sources, e.g., water rights purchased from agriculture, although it is unfeasible to consider purchasing such volumes. The energy intensity per acre-foot delivered to the Imperial Dam is approximately the same as Tucson's combined conveyance (at significantly higher lift), pumping, treatment, and distribution shown in Figure 3, above. In other words, desalinated water in this scenario remains an expensive proposition though not out of the question for potable uses.

In the "Regional Scenario" (potentially benefiting California, Nevada, and locations within Mexico), 1.2 million acre-feet requiring 500

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[85] *See generally* Evan R. Ward, "*The Politics of Place*"*: Domestic and Diplomatic Priorities of the Colorado River Salinity Control Act (1974)*, 6 J. POL. ECOLOGY 31 (1999).

[86] *See generally* Karl Kohlhoff & David Roberts, *Beyond the Colorado River: Is an International Water Augmentation Consortium in Arizona's Future?*, 49 ARIZ. L. REV. 257 (2007).

[87] *See* HDR ENG'G, INC., INVESTIGATION OF BINATIONAL DESALINATION FOR THE BENEFIT OF ARIZONA, UNITED STATES, AND SONORA, MEXICO, FINAL REPORT ES–1, ES–7 (2009).

MW would cost $905 per acre-foot at the plant plus $278 per acre-foot in a combined canal (143 miles) and pipeline (25 miles) conveyance system to the United States. The study acknowledges "simplifying assumptions" were made on the availability of power at $0.10/kWh, and cautions that risks associated with environmental permitting, and archaeological and cultural concerns remain unexplored. The intergovernmental coordination challenges receive cursory attention, and in our view, are an important area for more detailed review and assessment. The local acceptability of siting a desalination facility in Puerto Peñasco would be aided by the addition of a municipal facility that is currently being planned.

The rapidly expanding resort town of Puerto Peñasco is chronically water-scarce and has largely depleted aquifer water-resources in the surrounding area. Under a planning grant from the U.S. Trade and Development Agency, which seeks to advance the competitiveness of U.S. companies abroad, Puerto Peñasco has contracted to investigate the feasibility of a modular-design desalination plant. The first phase would desalinate 11.5 million gallons per day (500 liters per second) to an output quality of 200 mg/L of total dissolved solids, considered pure drinking water. To supply the 50 MW of power required in the first phase, solar generation alternatives are under consideration. Currently, using alternative energy sources for desalination can be as much as three times more expensive than using conventional energy sources, but if improvements continue, it may be possible to use solar energy to power desalination facilities along the coasts of the Sea of Cortez.

VI. CONCLUSIONS

The insufficiency of conventional energy and water resources in Arizona and Sonora has been exacerbated by growth, climate change, and the need to mitigate GHGs. In this context, critical energy and water infrastructure and core economic activities like agriculture must be reassessed to address future challenges. Policy initiatives are required that view energy and water in joint management terms, and that more fully unlock the potential of conservation, efficiency, and renewable energy sources. This is not simply a question of planning for optimal resource use. Following from the conceptual observations on predictable surprises, water-intensive power generation and energy-intensive water supply technologies must be redesigned to reduce mutual impacts. Collaborative policymaking that involves public decision-makers, private initiative, and a range of stakeholders will be needed to counter special-interest groups' influence over infrastructure development and energy and water policy. Part of the industry's persuasive rationale is based on the very concept of *scarcity*, which has been portrayed as inhibiting development. These interests have extensive reach with elected leadership in states like Arizona, where tax revenues and campaign contributions are strongly linked to real estate development.

Regulatory institutions are part of the answer. However, such regulations within the energy and water sectors separately are already quite complicated.[88] This makes the complex legal and institutional context in which joint energy and water policy must be pursued appear ever more daunting. Energy and water provisioning through extensive distribution networks require coordination among multiple political and administrative units. Decentralized energy and water provisioning (certain renewable energy generation systems and water harvesting and greywater systems) are subject to more localized management and oversight.

Consideration of the water demand for power in the U.S.-Mexico border region and the four energy-water nexus cases presented in this article offers lessons learned that have wider implications. While wind and geothermal energy sources exist in the broader border region, solar represents the most promising renewable energy potential for Arizona and Sonora. Given the increasing electricity demand for water service provision, the challenge of storing solar energy can be partially addressed by storing water. Raw water conveyance and subsequent aquifer storage and recovery are less time-sensitive, and hence more suitable for solar power applications than 24-hour needs for in-line water treatment and distribution. Solar photovoltaic systems, which consume little water during the generation phase, should be installed in preference over concentrating solar-power technology that involves a steam cycle. The bulk of the region's power requirements will continue to be met using conventional generation. In this context, nuclear generation stands out as especially water consumptive. Urban effluent is also suitable for other power generation technologies.

Policy and decision-making frameworks that can help guide technology choices and their social and environmental implications must be widened from the current focus on large infrastructure to include energy and water conservation as well as added renewables and off-grid water provisioning. Expanding the definition of "critical infrastructure" in this manner will aid in meeting the very real challenges posed by growth and climate change in the region, while better offsetting the mutual energy-water impacts of infrastructure development than current planning models are able to. This is a predictable outcome of coupling energy and water policy.

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[88] *See generally* Sanya Carleyolsen, *Tangled in the Wires: An Assessment of the Existing U.S. Renewable Energy Legal Framework*, 46 NAT. RESOURCES J. 759 (2006).

All the cases considered in this article display operational and policy dimensions of the energy-water nexus. Beyond simply characterizing their mutual resource dependencies, we have sought to present evidence of the decision-making choices and future opportunities that each case presents. The power used for urban water supply and wastewater reclamation is strongly influenced by the pumping requirements of conveyance. Long distance, interbasin transfers account for the largest share of cities' power-for-water footprint. This raises the appeal of water conservation as a means to save energy in addition to water. And although reclaimed water has a relatively high per-unit energy requirement, this is water that already has embedded energy as a result of its conveyance, treatment, and distribution. It would be ill-advised to lose these sunk costs by not viewing reclaimed water as an important resource, including for power generation itself.

Power grids are an essential component of the region's critical infrastructure; however, the way in which they may distort energy-water nexus relations requires further attention. In other words, power sales have the (perhaps inadvertent) effect of exporting virtual water from Arizona, which is simultaneously coping with scarcity in trying to meet its own water needs. More localized power generation and consumption patterns can partially offset these effects.

Agricultural sector water is often viewed as the buffer for growth and climate adaptation under the assumption that growing needs for water for power generation and urban supply will be met by purchasing or otherwise transferring water from farms. Sonora's power-irrigation nexus suggests that coupled energy-water programmatic and policy initiatives have been partially successful in reducing power requirements for groundwater pumping, although program penetration and social-equity effects require additional attention. Groundwater depletion, exacerbated by irrigation water demand that is influenced in turn by power supply and pricing, remains the principal unresolved energy-water nexus challenge in Sonora.

Much promise exists for coastal desalination as a unique case of energy and water coupling, particularly to meet local demand of coastal settlements. It appears that current costs for membrane technology and associated power requirements, as well as conveyance infrastructure and pumping place desalination are out of reach for agricultural and environmental water needs. The degree to which power requirements for desalination can be met by renewable energy sources is subject to further technology research and development and appropriate siting and environmental impact regulations.

Joint energy and water policymaking that seeks to achieve the broadest possible set of societal and environmental outcomes for the region will require coordination among binational, federal, and local decision-making processes that exist or are underway in various guises, but that will require clear articulation. Leadership by elected representatives combined with private initiative and stakeholder priority-setting will be underpinned by improved understanding of coupled energy-water policy opportunities.