Solar Photovoltaic Energy Generation on Aqueducts of California

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ABSTRACT: Passage of the California Global Warming Solutions Act of 2006 (AB 32) set the stage for a transition to a low-carbon economy. In addition to greenhouse gas action, drought in California is ushering in an era of unprecedented advances in water resource management. For example, Congressman Jared Huffman's pending assembly bill would expand investments to reduce evaporative losses in the Bureau of Reclamation water conveyances. Due to the simultaneous demand for greenhouse gas and water action, it is imperative that emerging solutions create synergies and avoid tradeoffs at the energy-water nexus. Photovoltaic structures constructed over aqueducts have been proposed as one novel solution to energy and water management. The objective of this study is to address knowledge gaps on the environmental and economic performance of these solar canals.

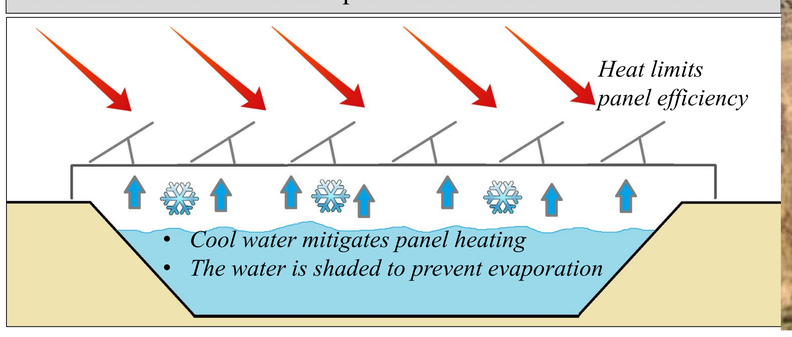

Figure 1. Schematic of a solar canal depicting the basic concepts behind the proposed benefits of increased photovoltaic efficiency and reduced evaporation.

Figure 2. Renderings of a solar canals using tensioned cables (Source: Citizen Group).

METHODS: Evaporation rates were calculated using the Penman method, pan evaporation method and CIMIS data. Evaporative savings were calculated based on evaporation rates and previous shading experimentation. The water intensity of electricity production was compared to the potential for electricity generation from photovoltaics on California canals to estimate water savings from diverting the current energy mix to solar power. We used the following metrics to evaluate the impact of the solar canals: 1) energy intensity, 2) greenhouse gas emissions intensity, 3) energy costs for water distribution, and 4) water costs (including project capital costs. We used the information in our analysis to compare the financial feasibility of solar canals to a ground-mounted system considering a steel truss system and a tensioned cable system

Water Savings

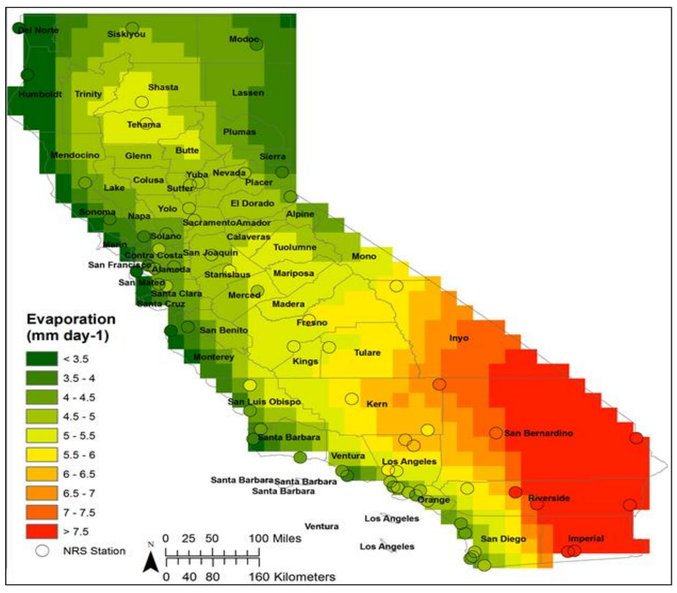

Figure 4. Annual mean evaporation estimates (mm day1) using the modified Penman equation at National Solar Radiation (NSR) weather stations indicated by circles overlaid onto a thin plat spline interpolated evaporation rate grid.

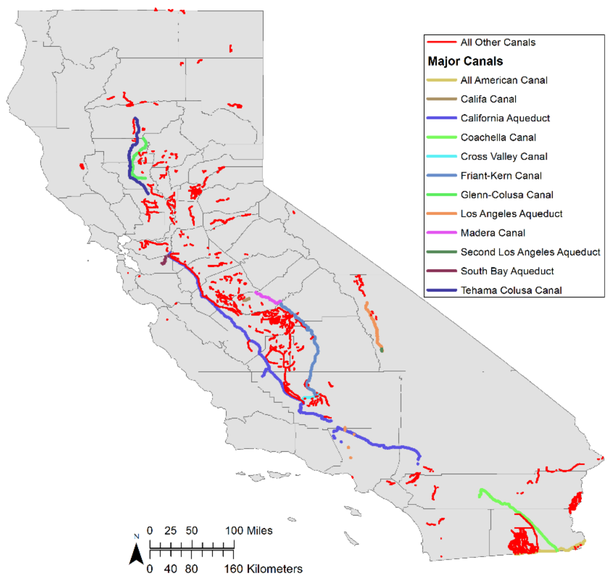

Figure 5. : National Hydrography Dataset major open canals and aqueducts considered in this study. Approximately 4,000 miles of canals and aqueducts.

Table 1. Statewide Deployment

Method	Lower Estimate	Baseline Estimate	Upper Estimate
	billion gallons yr^{-1} (thousand acre-feet yr^{-1})		
Simplified Penman	45 (138)	84 (258)	92 (283)
Pan evaporation	36 (112)	68 (209)	75 (229)
CIMIS	37 (114)	69 (212)	76 (232)

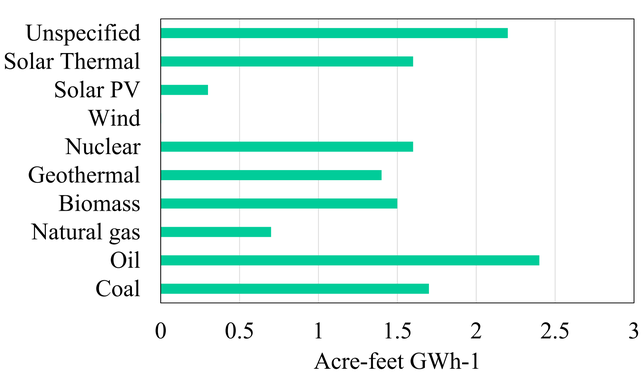

Figure 6. The water intensity of electricity production in California. Statewide, water savings estimate 90-320 TAF y^{-1}

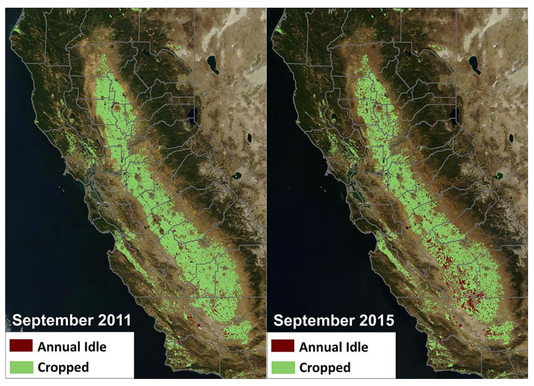

Figure 7. Spatial extent of annual idle and irrigated cropland in the Central Valley, California for the year 2011 compared to the year 2015. Source: NASA Landsat.

Water Savings in Context

- Combined water savings 200-600 TAF y^{-1}
- Approximately 1.03 million acres idle in Central Valley due to drought
- 7 million irrigated acres in Central Valley
- Statewide average, 2.9 AF $acre^{-1}$ for irrigation
- Approximately 7-20% of fallowed land could be put back in production

Economic Performance

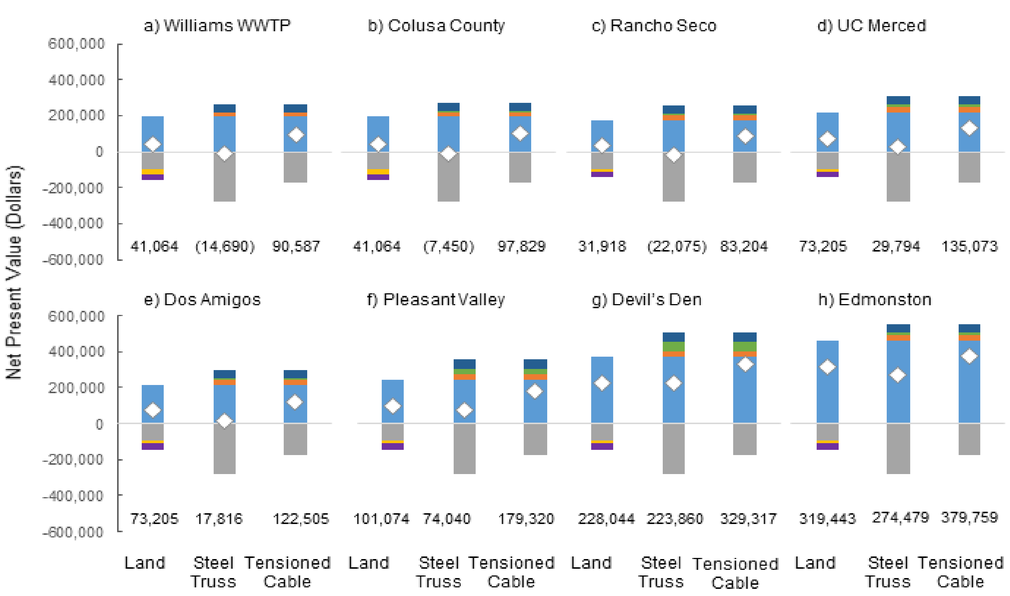

Figure 8. The incremental net present value at eight different locations for three different PV systems: conventional ground-mounted, steel truss over canal, and tensioned cable over canal.

Figure 9. The three solar panel support structures considered in our economic analysis. Left: ground-mounted systems. Middle: Steel truss system (Jena, 2015). Right: Tensioned cable system.(Ave, 2015)

Energy production and GHG savings

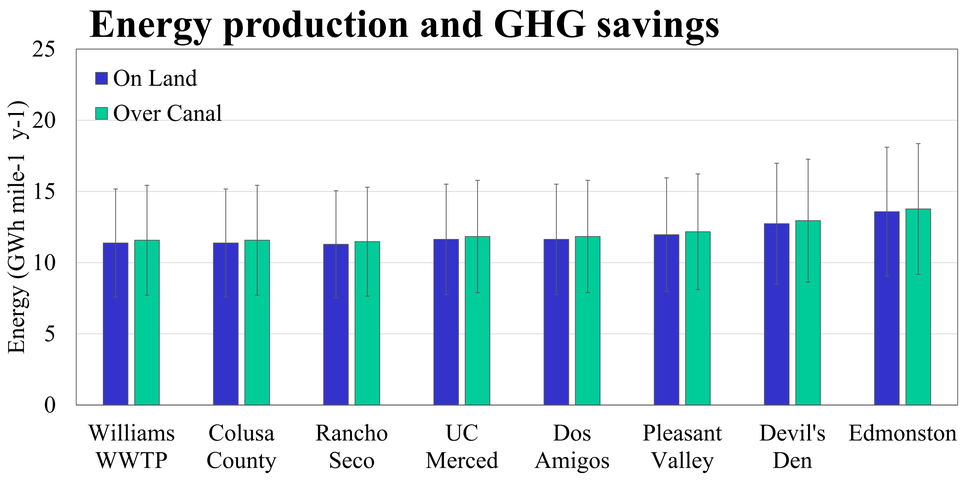

Figure 10. The net energy produced at eight different locations for ground-mounted "on land" systems and solar canal systems. For the solar canal energy production, the assumption is a 4% increase in panel efficiency.

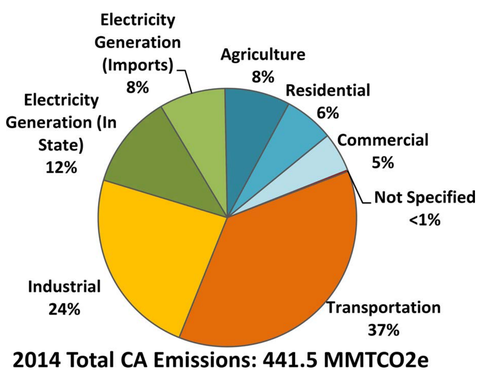

Figure 11. Greenhouse gas emissions by economic sector reported by the California Air Resources Board.

Energy Production Results

- Mean (across sites considered) baseline estimate "over canal" energy production 12 (± 4) GWh $mile^{-1}$ y^{-1}
- Statewide estimate, 49 (± 16) TWh y^{-1}

GHG savings

- Mean (across sites considered) baseline estimate "over canal" greenhouse gas offsets 3,400 (± 1,100) mt CO_2e mi^{-1} y^{-1}
- Statewide, 14 (± 5) million mt CO_2e y^{-1} based on assumptions:
  - 4,000 miles of open canal in California
  - Canal span 75 (± 25) ft.
  - Panel efficiency increased 4% for "over canal" compared with "on land" scenario
  - 279 mt CO_2e GWh^{-1} offset (includes both fuel combustion and upstream emissions)

GHG Savings in Context

Potential to offset between displace between 9 – 19 million mt annual CO_2e grid electricity emissions or between 26 – 54% of the emissions from the imported electricity sector.

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