

*Proceedings*

# Investigation and Assessment of the Management of Natural Resources in the State of California Using the Conceptual Framework of Water–Energy–Food Nexus <sup>†</sup>

Georgia Manou <sup>\*</sup>, Georgios Bariamis and Evangelos Baltas

Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, 5 Iroon Polytechniou, 157 80 Athens, Greece; bariamis@chi.civil.ntua.gr (G.B.); baltas@chi.civil.ntua.gr (E.B.)

<sup>\*</sup> Correspondence: georgia.manou@outlook.com

<sup>†</sup> Presented at the 4th EWaS International Conference: Valuing the Water, Carbon, Ecological Footprints of Human Activities, Online, 24–27 June 2020.

Published: 18 August 2020

**Abstract:** The current analysis attempts to quantify the interlinkages between the water, energy and food sectors of California covering the period 2002–2015. The results reveal that 25% (60,696 GWh) of the annual energy consumption is attributed to agriculture, while 75% (174,709 GWh) is used for water supply purposes. The agricultural sector consumes 77% (32,629 m<sup>3</sup>) of the irrigation water, and the energy sector is vulnerable to water availability fluctuations, because many hydroelectric facilities are connected to its grid. Considering the water scarcity and the uneven geographical distribution of water in the state, its central role in California’s water–energy–food (WEF) Nexus becomes apparent.

**Keywords:** water resources; California; food; energy; Nexus

---

## 1. Introduction

The water–energy–food (WEF) Nexus has emerged over the last few years as a conceptual framework for natural resource management [1,2]. The concept of the WEF Nexus arose in the sentience of the global community as a reaction to climate change and several social changes that humanity has been witnessing in recent years, such as population growth, globalization, economic development and urbanization [3]. These phenomena put a lot of pressure on water, energy and food systems, and as a result, many communities in different parts of the world are called upon to confront possible “conflicts” between the three sectors [1].

The WEF Nexus was introduced as a conceptual framework for the monitoring and achievement of the Sustainable Development Goals (SDGs) that the United Nations have set [4]. In order to achieve water, energy and food safety for everybody at the same time, governments and the different stakeholders that, occasionally, take part in the decision making should consider broader influences and cross-sectoral impacts [5,6].

Often in the nexus literature, only two components are taken into account such as in the case of the water–energy nexus [7–9]. Sometimes, the impact of external factors such as climate change on the nexus between two resources is investigated [10]. The nexus concepts have also been examined for urban environments [11,12] and on a household scale [13,14]. In spite of researchers having approached the nexus perspective, the data and knowledge gaps and the lack of systematic analytical tools prevent, in many cases, the effective application of nexus thinking [15]. Moreover, according to

[16], the current literature focuses more on understanding the nexus rather than governing and implementing it.

In the current analysis, we attempted to quantify the interlinkages of three nexus components and subsequently assess how water, energy and food resources are managed in the state of California. The scale of the analysis was the state administration, which is perceived as a generally large scale for a nexus investigation. Nevertheless, it was considered adequate in order to reveal the bigger picture of natural resource management in the state.

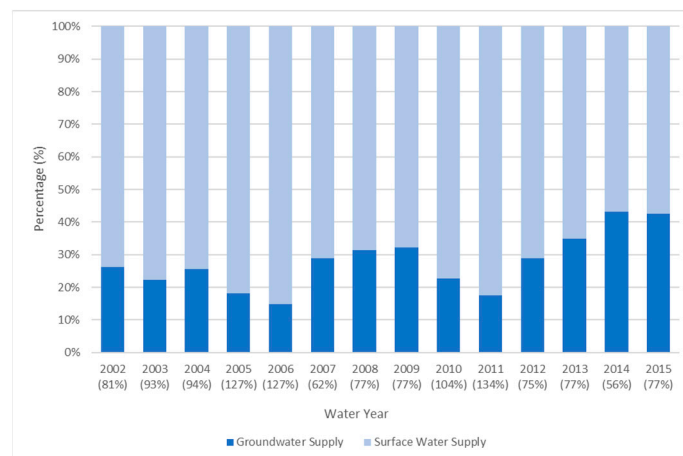
## 2. Materials and Methods

### 2.1. Study Area

California is the third largest state in the USA (423,970 km<sup>2</sup>) and by far the most populous one. On the first of July 2019, its population was estimated at 39,000,000 people [17]. In the third quarter of 2019, its Gross Domestic Product (GDP) was estimated at USD 3,155,224 million[18]. On one hand, the geographical area of California influences the management of its natural resources, while on the other hand, its economic status and large population affect the demand for natural resources and the consumption patterns.

#### 2.1.1. Water Sector

The adequacy or shortage of water resources in California has always been a determining factor not only for its economic but also for its cultural development. Its agricultural production and its population have flourished in parallel with the development of its water resources facilities. It is true that 75% of its rainfall and snowfall takes place in the north part of the state, which barely constitutes one third of its area, while 80% of the water demand comes from the two thirds in the south of the state [19]. Numerous large hydraulic works have been constructed in order to manage the state’s surface water resources and bring them to South California and the Central Valley [20]. California constructed the world’s largest water system and, therefore, has been reasonably characterized as the most hydrologically altered landmass on the planet [21,22]. Considering the groundwater reserves of the state, they are ten times more than the ones of surface water (rivers, lakes, reservoirs). Groundwater acts as a safety net in years with low precipitation (Figure 1) and offers California the flexibility of extracting more of it in order to cover the demand, especially the agricultural demand, and avoid economical and other crises [23].



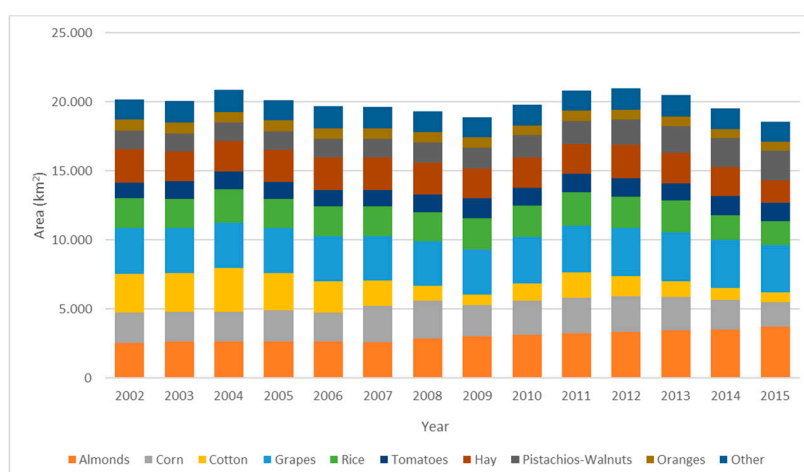
**Figure 1** Contribution of surface and groundwater to the total water supply. In the horizontal axis the numbers in brackets represent percentages of normal precipitation (average of the annual precipitation values) from 1981 to 2010.

### 2.1.2. Energy Sector

California is the state with the second largest total energy consumption, which is justifiable by its large population and its extended geographic area as well as by its thriving economy. Nevertheless, its per capita energy consumption is one of the lowest in the USA, due, in part, to the mild climate and its energy efficiency programs [24]. Indicatively, according to calculations based on data provided from the California Energy Commission (CEC) in the period 2002–2015, the average power generation from renewable energy sources was almost 30%. The CEC breaks down the energy sector of the state into three categories: electricity, natural gas and crude oil. According to our calculations based on the commission’s databases, each one of them contributes to the total energy mix of the state by 17%, 22.5% and 60.5%, respectively.

### 2.1.3. Agriculture and Food Sector

The agricultural sector of California is by far the most profitable in the United States, with revenues up to 50 billion dollars in 2017 [25]. On account of the large variety of the state’s agricultural products (more than 400 different crop types), in the current analysis, a manageable number of them was selected by taking into account the following criteria: (a) the economical profit that these products provided from 2009–2015; (b) their exports from 2011–2015. The time periods that we chose were not random, rather, they were mandatory because of the lack of data for the previous years. The planted area of the selected crops between 2002 and 2015 is represented in Figure 2. It should be noted that livestock products were not considered. Dairy products and the areas cultivated for animal grazing, except for alfalfa and some other types of hay, were, also, excluded from the analysis.



**Figure 2.** Planted area of the agricultural crops with most exports (2011–2015) and most GDP profit (2009–2015).

## 2.2. Interconnections of the Nexus Components

Following the collection of the required data, the quantification of the interconnections of the nexus components was conducted. For each of the three interconnections of a WEF Nexus (water–energy, water–food, energy–food), two “flows” can be identified. Nevertheless, in the case of California, the food–energy flow, mainly the biofuels’ sector, is not very developed, and relative data were not found. Therefore, this flow was excluded from the analysis. Suitable factors of intensity were explored for each of the nexus components. In some cases, there was no need for quantification at all, because there were already available data. In general, the acquisition of data for each year from 2002 to 2015 was attempted; although, for some flows, only average estimates of a single number were attained for the whole period examined.

### 2.2.1. Water for Energy

Water is required for the mining, transporting, processing and refining of fossil fuels, for disposing the waste that is produced during the aforementioned procedures, for cooling of thermoelectric facilities as well as for hydroelectric stations [3,26]. Factors of water consumption in  $\text{m}^3/\text{L}$  for every stage of the crude oil production line (mining, production, recovery, refining and other operations of a crude oil facility) are provided by [27]. By multiplying these factors by the amounts of oil used in each one of the stages mentioned before, the total water consumption of the crude oil sector for the examined time period was calculated. For the calculation of water used from the electrical sector, [26] provided water withdrawal and water consumption factors in  $\text{m}^3/\text{MWh}$  for the entire life cycle of a facility. These factors were used for coal, natural gas, nuclear, geothermal and solar electric generation facilities. As for the biomass/waste-to-energy facilities that produce electricity, the water withdrawal and consumption factors were acquired from [28].

A different methodology was followed for the calculation of the water that the large and small hydroelectric facilities used and consumed. On one hand, every hydroelectric facility operates because an amount of water passes through its turbines and returns to the river flow that it was diverted from, downstream the dam or to another reservoir (non-consumptive water usage). On the other hand, in the cases of hydroelectric stations accompanied by reservoirs, large amounts of water are lost through evaporation and seepage from porous foundations underlying the reservoirs (consumptive water usage) [3,27]. An estimation of the non-consumptive water use of hydroelectric stations in 1995 was provided by [29]. By using this estimation, the hydroelectric power generation of 1995 and the average hydroelectric power generation of the period 2002–2015, we applied the rule of three and calculated a factor of intensity in  $\text{m}^3/\text{kWh}$ . We multiplied this factor by the energy produced each year of the examined period from each hydroelectric station of the state, except for the pumped-storage, and we calculated the non-consumptive water use of hydroelectric stations. Factors of evaporation and seepage in  $\text{m}^3/\text{kWh}$  specifically for California's reservoirs were provided by [27]. These factors were multiplied by the annual energy produced from each hydroelectric station of the state, except for the pumped-storage and the run-of-river, followed by the aggregation of all the results of the consumptive water use of hydroelectric stations from 2002 to 2015.

### 2.2.2. Energy for Water

Energy is consumed in all stages of the water use cycle, during which the water is, at first, diverted, collected or extracted from a water resource, then, it is transported to water treatment facilities and finally, it is distributed to end users. Afterwards, wastewater from urban and industrial uses is collected, treated and discharged back to the environment, while wastewater from agricultural uses is common not to be treated before being discharged back to the environment, either as runoff to natural waterways or into groundwater basins [30]. Desalination is another water-related activity that consumes energy. In California in 2001, 19% of the total electricity and 32% of the total natural gas consumed were used for water-related activities. In addition, an amount of diesel related to irrigation water pumping was consumed in the same year [30]. The aforementioned percentages as well as this specific amount of diesel were assumed to be constant for the whole time period examined, due to the lack of annual data. The percentages were multiplied by the consumed electric energy and natural gas, respectively, of each year from 2002 to 2015. In order to be able to aggregate all these amounts to a single total, natural gas and diesel were converted to their electrical equivalent. For the conversion of natural gas, we considered that  $1 \text{ m}^3$  equals approximately  $10.73 \text{ kWh}$  [31]. For the conversion of diesel, the factor  $3.72 \text{ kWh/L}$  [32] was used, which refers only to irrigation water pumping. Factors of intensity in  $\text{kWh}/\text{m}^3$  of each type of desalination station (sea/brackish) [33] were multiplied by the amount of sea and brackish water, respectively, that was desalinated in 2010 [23]. The total energy consumption for water desalination was, thus, estimated for the corresponding year. This amount of energy was considered constant for the whole period of 2002–2015 as well, due to the lack of annual information.

### 2.2.3. Water for Food and Food for Water

As far as the water–food flow is concerned, the California Department of Water Resources (CDWR) provided data for the annual irrigation water applied in the period 2002–2015 as well as for the depleted amount of water because of irrigation for the same period [23,34]. Depletion is the quantity of water consumed within a service area and no longer available as a source of supply. It includes evaporation, evapotranspiration and outflow to a salt sink [35]. As far as the food–water flow is concerned, the acquisition of data for the kinds and amounts of agricultural products that California imported annually between 2002 and 2015 was attempted, in order to multiply them by their respective virtual water coefficients. Since there were no such data available, the alternative of a water footprint was chosen. The water footprint of a product or service is defined as the volume of water that is consumed for the production of this product or service in the same place it is produced and not necessarily in the place it is consumed [36]. More specifically, California’s external water footprint is associated with goods that are produced outside of California but are imported into and consumed within the state. In fact, agricultural goods account for most of the state’s external water footprint. California’s external agricultural water footprint was acquired from [37]. It should be noted that an imbalance arose between the food–water flow, where livestock was included in the agricultural sector and the water–food flow, where it was excluded from the same sector.

### 2.2.4. Energy for Food

Present-day agriculture is very “high-input” [38], modernized and intensified. In order to explore how and to what extent the energy sector of California affects food production, we calculated the energy consumed for irrigation water (conveyance/supply), the application of chemicals (fertilizers, pesticides) and the operation of agricultural machinery.

As mentioned before, in 2001, 19% of the total electric energy consumed in California was attributed to water-related activities. In the same year, 22% out of the aforementioned percentage, corresponding to about 4.18% of the total electricity consumption, was consumed for irrigation purposes [30]. This percentage—in addition to a certain amount of diesel used for the pumping of irrigation water [30]—was considered constant for the consecutive years 2002–2015. For the calculation of the energy used annually during the entire life cycle of fertilizers, the tons of nutrients (nitrogen-N, phosphate-P<sub>2</sub>O<sub>5</sub> and potash-K<sub>2</sub>O) that were used on an annual basis were multiplied by different factors of intensity in kWh/ton [39]. For the calculation of the energy used annually for pesticides, the amounts of pesticides applied on an annual basis at all the different stages of the food production line were multiplied by an average factor of intensity in kWh/ton [39]. The required energy for the operation of agricultural vehicles (primarily tractors) and other equipment was estimated by multiplying both the planted and harvested area of the selected crops of California by the electrical equivalent of an average amount of diesel per agricultural area [40].

## 3. Results

Considering all the different aspects of the nexus and integrating all the components at a common temporal resolution and spatial level, California’s WEF Nexus was quantified. The standard triangular format was used in order to represent the interlinkages of the nexus components in annual average values for the years ranging from 2002 to 2015, as presented in Figure 3. It should be clarified that in the water–energy and the water–food flows, the numbers represent total water withdrawals for the production of energy and food, respectively, while the numbers in brackets represent the amount of water consumption. Hence, it is revealed that the average water consumed by the energy sector of California in the examined period was less than 2% of the water withdrawn. Additionally, the water depletion through the irrigation of agricultural crops was almost 77%.

Furthermore, in Figure 3, two main “nexus paths” are identified—the water–energy–food and the energy–water–food. The first path highlights the central role that water plays in the nexus and depicts that if the available water for the energy sector was less than 128,362 hm<sup>3</sup>, except for the disturbances that would have been caused to the energy sector, the food sector would either

experience shortages in irrigation water and chemical/agricultural machinery or compete with other sectors such as the urban sector for the distribution of the available energy. The second path sets the energy resource as the determinant factor of the nexus analysis. Likewise, if 174,709 GWh of energy was not available each year for the water sector, then, the water would be impossible to extract, convey and distribute to end users, among which is irrigated agriculture, which is used to acquire an annual amount of 42,446 hm<sup>3</sup>.

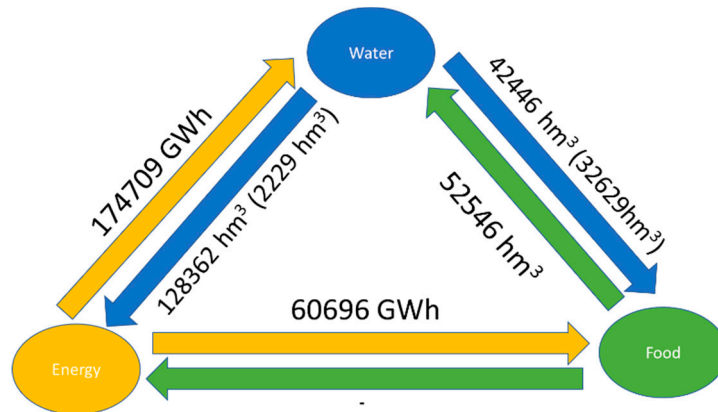


Figure 3. California’s water–energy–food (WEF) Nexus schema.

In Figure 4, the percentage change of the water–energy, energy–water, water–food and energy–food flows considering 2002 as the baseline year is depicted. According to Figure 4, the water–energy flow presented several extremes, which are explained by the close interrelation of this flow with annual precipitation and snowfall levels (water availability), possible extreme natural phenomena etc. The declining trend in this specific flow was caused by the reduced power generation of the large hydroelectric stations after 2011. The production of hydroelectric facilities reduced because of the severe drought that started in California in 2012 [41] and was accompanied with very high temperatures and, therefore, high evaporative losses from the state’s reservoirs. Conversely, the irrigation water supply (water–food flow) remained relatively stable. The groundwater reserves made a significant contribution to this, which, as usual in water years with low precipitation, ensured the provision of a large part of the required, valuable resource, so that California could cover its water demands. The energy–water flow remained in stable levels, because of the ability of the energy mix to recover the inefficiency of hydroelectric stations with the supplementary production of the natural gas-fired facilities. The application of chemicals and energy inputs to agriculture (energy–food flow) also did not present serious fluctuations.

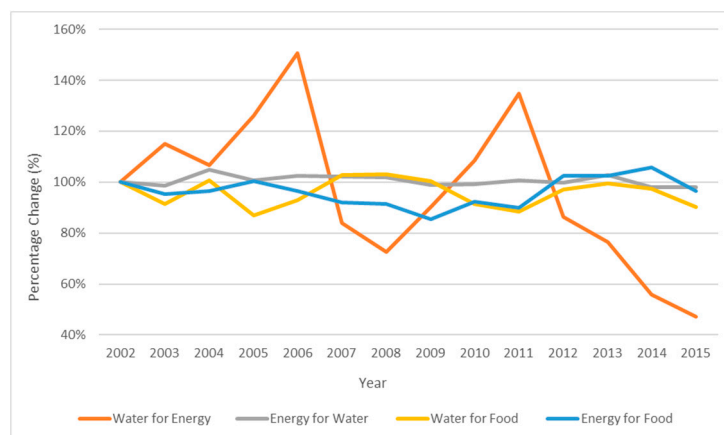


Figure 4. The percentage changes (2002 baseline year) of nexus interconnections.

#### 4. Conclusions

The WEF Nexus is a multifactorial conceptual framework, and there are so many elements involved in a nexus analysis that often, it is hard to set the boundaries of the analysis system or other subsystems. More specifically, California is a large state characterized by an equally large number of descriptors (with regard to population, economy, energy etc.), which made the analytical process more challenging with more data availability issues to overcome. An in-depth understanding of the conceptual framework and a clear distinction between definitions are particularly important when carrying out a WEF Nexus analysis. With the plethora of databases that exists from different information sources, it is crucial that the parameters of the analysis are distinctly defined, so that any usage of overlapped data is avoided. This was a challenge that had to be surpassed as well. A WEF Nexus approach to the management of natural resources in California presents complexity due to the fact that all three sectors are developed and there are many stakeholders that share interests in specific governance decisions. Nevertheless, any governance decision that is made influences the whole nexus system of the state.

**Author Contributions:** Conceptualization, G.M. and G.B.; methodology, G.M.; software, G.M.; validation, G.M. and G.B.; formal analysis, G.M.; investigation, G.M.; resources, G.M.; data curation, G.M.; writing—original draft preparation, G.M. and E.B.; writing—review and editing, G.M. and G.B.; visualization, G.M.; supervision, E.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflict of interest.

#### References

1. Endo, A.; Tsurita, I.; Burnett, K.; Orenco, P.M. A review of the current state of research on the water, energy, and food nexus. *J. Hydrol. Reg. Stud.* **2017**, *11*, 20–30, doi:10.1016/j.ejrh.2015.11.010.
2. Roidt, M.; de Strasser, L. *Methodology for Assessing the Water-Food-Energy-Ecosystems Nexus in Transboundary Basins and Experiences from Its Application*; United Nations: New York, NY, USA; Genova, Italy, 2018; p. 66.
3. Hoff, H. Understanding the Nexus. In *Proceeding of the Nexus Conference: The Water, Energy and Food Security Nexus*, Bonn, Germany, 16–18 November 2011, pp. 1–52.
4. Biggs, E.; Bruce, E.; Boruff, B.; Duncan, J.M.; Horsley, J.; Pauli, N.; McNeill, K.; Neef, A.; Van Ogtrop, F.F.; Curnow, J.; et al. Sustainable development and the water–energy–food nexus: A perspective on livelihoods. *Environ. Sci. Policy* **2015**, *54*, 389–397, doi:10.1016/j.envsci.2015.08.002.
5. WWAP. United Nations World Water Assessment Programme. *World Water Dev. Rep.* **2003**, *1*.
6. Weitz, N.; Strambo, C.; Kemp-Benedict, E.; Nilsson, M. Closing the governance gaps in the water–energy–food nexus: Insights from integrative governance. *Glob. Environ. Chang.* **2017**, *45*, 165–173, doi:10.1016/j.gloenvcha.2017.06.006.
7. Tsolas, S.D.; Karim, M.N.; Hasan, M.M.F. Optimization of water-energy nexus: A network representation-based graphical approach. *Appl. Energy* **2018**, *224*, 230–250, doi:10.1016/j.apenergy.2018.04.094.
8. Hussey, K.; Pittock, J. The Energy–Water Nexus: Managing the Links between Energy and Water for a Sustainable Future. *Ecol. Soc.* **2012**, *17*, 31, doi:10.5751/es-04641-170131.
9. Vilanova, M.R.N.; Balestieri, J.A.P. Exploring the water-energy nexus in Brazil: The electricity use for water supply. *Energy* **2015**, *85*, 415–432, doi:10.1016/j.energy.2015.03.083.
10. Stang, S.; Wang, H.; Gardner, K.; Mo, W. Influences of water quality and climate on the water-energy nexus: A spatial comparison of two water systems. *J. Environ. Manag.* **2018**, *218*, 613–621, doi:10.1016/j.jenvman.2018.04.095.
11. Zhang, P.; Zhang, L.; Chang, Y.; Xu, M.; Hao, Y.; Liang, S.; Liu, G.; Wang, C. Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review. *Resour. Conserv. Recycl.* **2019**, *142*, 215–224, doi:10.1016/j.resconrec.2018.11.018.
12. Romero-Lankao, P.; Bruns, A.; Wiegleb, V. From risk to WEF security in the city: The influence of interdependent infrastructural systems. *Environ. Sci. Policy* **2018**, *90*, 213–222, doi:10.1016/j.envsci.2018.01.004.
13. Hussien, W.A.; Memon, F.A.; Savic, D. An integrated model to evaluate water–energy–food nexus at a household scale. *Environ. Model. Softw.* **2017**, *93*, 366–380, doi:10.1016/j.envsoft.2017.03.034.

14. Hussien, W.A.; Memon, F.A.; Savic, D. A risk-based assessment of the household water–energy–food nexus under the impact of seasonal variability. *J. Clean. Prod.* **2018**, *171*, 1275–1289, doi:10.1016/j.jclepro.2017.10.094.
15. Liu, J.; Yang, H.; Cudennec, C.; Gain, A.K.; Hoff, H.; Lawford, R.; Qi, J.; De Strasser, L.; Yillia, P.; Zheng, C. Challenges in operationalizing the water–energy–food nexus. *Hydrol. Sci. J.* **2017**, *62*, 1714–1720, doi:10.1080/02626667.2017.1353695.
16. Dai, J.; Wu, S.; Han, G.; Weinberg, J.; Xie, X.; Wu, X.; Song, X.; Jia, B.; Xue, W.; Yang, Q. Water-energy nexus: A review of methods and tools for macro-assessment. *Appl. Energy* **2018**, *210*, 393–408, doi:10.1016/j.apenergy.2017.08.243.
17. U.S. Census Bureau QuickFacts: California; United States. Available online: <https://www.census.gov/quickfacts/fact/table/CA,US/PST045218> (accessed on 27 January 2020).
18. *Gross Domestic Product by State: Third Quarter 2019*; Bureau of Economic Analysis: Suitland, MD, USA, 2019.
19. The California Water System. Available online: <https://water.ca.gov/Water-Basics/The-California-Water-System> (accessed on 27 January 2020).
20. Infrastructure. Available online: <https://water.ca.gov/What-We-Do/Infrastructure> (accessed on 27 January 2020).
21. California’s Water Systems—MAVEN’S NOTEBOOK | Water news. Available online: <https://mavensnotebook.com/the-notebook-file-cabinet/californias-water-systems/> (accessed on 27 January 2020).
22. California Water 101—Water Education Foundation. Available online: <https://www.watereducation.org/photo-gallery/california-water-101> (accessed on 27 January 2020).
23. Water Plan Update 2013: Investing in Innovation & Infrastructure; Bulletin 160-13 of the Department of Water Resources of Natural Resources Agency: Sacramento, CA, USA, 2013.
24. California - State Energy Profile Analysis—U.S. Energy Information Administration (EIA). Available online: <https://www.eia.gov/state/analysis.php?sid=CA> (accessed on 27 January 2020).
25. *California Agricultural Statistics Review 2017–2018*; California Department of Food and Agriculture: Sacramento, CA, USA, 2018.
26. Meldrum, J.R.; Nettles-Anderson, S.; A Heath, G.; Macknick, J. Life cycle water use for electricity generation: a review and harmonization of literature estimates. *Environ. Res. Lett.* **2013**, *8*, 015031, doi:10.1088/1748-9326/8/1/015031.
27. Gleick, P.H. Water and Energy. *Annu. Rev. Energy Environ.* **1994**, *19*, 267–299, doi:10.1146/annurev.eg.19.110194.001411.
28. *Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production-The Next Half Century*; Technical Report of the Electric Power Research Institute: Palo Alto, CA, March 2002.
29. Arimoto, T. Science in a changing world. *Phys. World* **2018**, *31*, 17–18, doi:10.1088/2058-7058/31/3/23.
30. Klein, G.; Krebs, M.; Hall, V.; O’Brien, T.; Blevins, B. B. *California’s Water—Energy Relationship*; Final Staff Report for the California Energy Commission: Sacramento, CA, USA, November 2005.
31. Energy conversion calculators—U.S. Energy Information Administration (EIA). Available online: <https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php> (accessed on 27 January 2020).
32. Kranz, W. Updating the Nebraska Pumping Plant Performance Criteria. In Proceedings of the 2010 Central Plains Irrigation Conference, Kearney, Nebraska, 24–25 February 2010; pp. 51–57.
33. Pinzon, J. *Energy Efficiency in Water Reuse and Desalination: Five Individual Projects which Address Energy Efficiency in Both Water Reuse and Desalination: Final Project Report*; California Energy Commission: Sacramento, CA, USA, 2013.
34. California Department of Water Resources. *Disaster Prev. Manag. Int. J.* **2000**, *9*, 10–5–10–48, doi:10.1108/dpm.2000.07309aag.019.
35. Glossary. Available online: <https://water.ca.gov/Water-Basics/Glossary> (accessed on 29 January 2020).
36. Chapagain, A.K.; Hoekstra, A.Y. *Water Footprints of Nations; Research Report No. 16*; Unesco-IHE Institute for Water Education: Delft, The Netherlands, November 2004.
37. Fulton, J.; Gleick, P.H.; Cooley Heather. *California’s Water Footprint*; Report of the Pacific Institute: Oakland, CA, USA, December 2012.
38. Giampietro, M. Energy Use in Agriculture Energy Flows in Agriculture: Solar—Powered Natural Processes and Fossil Energy-Based Technical Inputs. *Agric. Ecosyst. Environ.* **1997**, *65*, 231–243.



39. Helsel, Z.R. Energy and Alternatives for Fertilizer and Pesticide Use. *Energy Farm Produc.* **1992**, *2*, 177–201.
40. *Analysis of California's Diesel Agricultural Equipment Inventory According to Fuel Use, Farm Size, and Equipment Horsepower*; Report of the California Air Resources Board: Sacramento, CA, USA, October 2018.
41. Lund, J.; Medellin-Azuara, J.; Durand, J.; Stone, K. Lessons from California's 2012–2016 Drought. *J. Water Resour. Plan. Manag.* **2018**, *144*, 04018067, doi:10.1061/(asce)wr.1943-5452.0000984.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).