Cleaner Engineering and Technology 8 (2022) 100504

Contents lists available at ScienceDirect

Cleaner Engineering and Technology

journal homepage: www.sciencedirect.com/journal/cleaner-engineering-and-technology

International circular economy strategies and their impacts on agricultural water use

Maurício Dziedzic [a,*], Priscila Rodrigues Gomes [b], Marco Angilella [c], Abdelghani El Asli [d], Pia Berger [e], Adilia Januario Charmier [f,g], Ying-Chu Chen [h], Ranahansa Dasanayake [i], Rebecca Dziedzic [j], Filipa Ferro [g,k], Donald Huising [l], Michael Knaus [m], Faezeh Mahichi [n], Fouad Rachidi [o], Cândida Rocha [g], Kevin Smith [d], Shunso Tsukada [p]

[a] *School of Engineering, University of Northern British Columbia, 3333 University Way, Prince George, V2N 4Z9, Canada*
[b] *Post-doctoral Fellow. Graduate Program in Environmental Management, Universidade Positivo. Professor Pedro Viriato Parigot de Souza St., 5300, Curitiba, PR, Brazil*
[c] *Project Manager-Sustainable Water Management, Dipl. Betriebswirt (FH), Marco Angilella, Institute for Applied Material Flow Management, Environmental Campus Birkenfeld, Trier University of Applied Sciences, Campusallee, Building-9926, Room-131, 55768, Neubrücke, Germany*
[d] *Al Akhawayn University in Ifrane, School of Science & Engineering Ifrane, 53000, Morocco*
[e] *Universidad Panamericana. Facultad de Ingeniería. Josemaría Escrivá de Balaguer 101, Aguascalientes, Aguascalientes, 20296, Mexico*
[f] *CQE, Centro de Química Estrutural, Instituto Superior Técnico, Universidade de Lisboa, Av.Rovisco Pais, 1049-001, Lisboa, Portugal*
[g] *DREAMS, Universidade Lusófona de Humanidades e Tecnologias, Campo Grande 376, Lisbon, 1749-024, Portugal*
[h] *Department of Civil Engineering, National Taipei University of Technology, Taipei City, 106, Taiwan, ROC*
[i] *Institute for Applied Material Flow Management, Environmental Campus Birkenfeld, Trier University of Applied Sciences, Campusallee, Building-9926, Room-127, 55768, Neubrücke, Germany*
[j] *Building, Civil and Environmental Engineering, Concordia University, S-EV 6.126, Engineering, Computer Science and Visual Arts Integrated Complex, 1515, St. Catherine W. Montreal, Quebec, Canada*
[k] *MARE – Marine and Environmental Sciences Centre, Faculdade de Ciências e Tecnologia, Universida de Nova de Lisboa, Departamento de Ciências e Engenharia do Ambiente, Campus de Caparica, 2829-516, Caparica, Portugal*
[l] *The Institute for a Secure and Sustainable Environment, University of Tennessee, Knoxville, 37996, USA*
[m] *Head-International Department, Institute for Applied Material Flow Management, Environmental Campus Birkenfeld, Trier University of Applied Sciences, Campusallee, Building-9926, Room-132, 55768, Neubrücke, Germany*
[n] *College of Asia Pacific Studies (APS), Ritsumeikan Asia Pacific University (APU), Japan*
[o] *Ecole Nationale d'Agriculture Meknès, BIOVEPE Research Team, Morocco*
[p] *Financial Analyst (Master of Business Administration), Visiting Professor, College of Asia Pacific Studies (APS), Ritsumeikan Asia Pacific University (APU), Japan*

ARTICLE INFO

Keywords:
Agricultural sector
Environmental impacts
Legislation
Water resources
Water security

ABSTRACT

The concept of Circular Economy (CE) is becoming increasingly important in the pursuit of more sustainable societies. CE strategies are being applied in the sustainable management of a plethora of areas, such as energy, water, food and eco-industrial parks. The present paper focuses on the question of how CE principles can support the sustainable management of water in the agricultural sector around the world, considering different legislative environments, water resources management guidelines, environmental stressors, and CE practices. Considering these practices and circumstances, seven countries were compared: Brazil, Germany, Japan, Mexico, Morocco, Portugal, and Taiwan. Together, CE experts in the seven countries developed a set of 44 criteria to assess each of these areas. Broader establishment and respect of water resources legislation was found to be strongly correlated with lower agricultural water use. While the application of CE practices was found to not be correlated with lower consumption, this is still novel in most countries. Based on the studied countries, it can be concluded that a global CE agenda has not been reached for water resources. Further application and variety of practices is required to better represent the impact of CE on a national scale, but local success stories could support the wider

---

* Corresponding author.

E-mail addresses: Mauricio.Dziedzic@unbc.ca (M. Dziedzic), priscilarodgom@gmail.com (P.R. Gomes), m.angiella@unwelt-campus.de (M. Angilella), a.elasli@aui.ma (A.E. Asli), pberger@up.edu.mx (P. Berger), januarioadilia@gmail.com (A.J. Charmier), ycchen@mail.ntpu.edu.tw (Y.-C. Chen), hansjr2@yahoo.com (R. Dasanayake), rebecca.dziedzic@concordia.ca (R. Dziedzic), filipatmferro@gmail.com (F. Ferro), dhuisingh@utk.edu (D. Huising), m.knaus@umwelt-campus.de (M. Knaus), fmahichi@apu.ac.jp (F. Mahichi), fourac2008@gmail.com (F. Rachidi), candidalprocha@gmail.com (C. Rocha), K.Smith@aui.ma (K. Smith), stsukada@apu.ac.jp (S. Tsukada).

https://doi.org/10.1016/j.clet.2022.100504
Received 9 December 2020; Received in revised form 11 April 2022; Accepted 3 May 2022

application of CE in agriculture. The findings and the framework of the study can be applied to other countries in directing CE strategies for more sustainable water use in agriculture. Increasing CE implementation, motivated by legislation and better management can help ensure water security throughout nations.

1. Introduction

Agriculture is the most water-intensive economic activity in the world. Even though irrigated agriculture is generally more resilient to short-term drought than rain-fed agriculture, it is uniquely vulnerable, as the productivity and sustainability of irrigated agricultural areas depend on available water, crop water use, and transport losses (Winter et al., 2017). Considering that the current world population of 7.9 billion is expected to reach 9.7 billion in 2050 and 11.2 billion in 2100 (UNDESA - United Nations Department of Economic and Social Affairs, 2015), there is a pressing need to increase agricultural production, with a potentially dramatic rise in water consumption and environmental impacts. Among these impacts is climate change, with varying temperature and precipitation effects.

These challenges represent an opportunity for the implementation of circular economy (CE) strategies, with the adoption of closed cycle systems to improve sustainability (Toop et al., 2017). This can help transition agriculture from linear production, which converts natural resources into products and wastes, to CEs designed to reduce resource use and waste generation by closing food production materials and energy loops. Additionally, considering that the Earth is composed of interconnected subsystems (e.g., hydrosphere, biosphere, anthroposphere and technosphere), changes to one subsystem affect others. Thus, sustainable strategies should account for these interconnections. A holistic water resources management approach should be circular and integrated with other systems.

Winter et al. (2017) proposed a framework for water-agriculture interactions in irrigated agricultural areas. Scenarios depend on climate, economic and land use, technological development and adaptation, diet, and bioenergy trends. Decisions are driven by water costs; public and private water rights and management; local, national, and international laws and policies; and management infrastructure. The system interactions define, among other aspects, local and global food security, environmental impacts and water and agricultural trade flow. This systematization exemplifies how complex and holistic the water-agriculture system is, highlighting how important it is to evolve from a mechanistic, reductionist view to an integrated one, considering system's perspectives and procedures.

CE strategies seek to keep materials in the eco-sphere and the technosphere for as long as possible, rather than "discarding" them. This should help reduce resource use and energy demand, within a product's life cycle (Ritzén and Sandström, 2017).

Accordingly, the objective of CE is to transform unsustainable into sustainable business models. By applying CE strategies companies can increase revenues, promote value for their customers, and reduce resource consumption and environmental impacts. The main principles of CE are:

(i). To preserve and improve natural capital by controlling finite stocks and balancing flows of renewable resources;
(ii). To optimize the yield of resources by circulating products, components, and materials in use at the highest level of utility, in the technical and biological cycles;
(iii). To stimulate the effectiveness of the CE system by revealing and excluding negative externalities from the outset (Homrich et al., 2018).

Agriculture, in particular, faces many challenges associated with population growth, food security, climate change, and resource scarcity. In recent years, agriculture has become intensive and extensive, dependent on fossil fuels and synthetic fertilizers, and with a high rate of water use. In this context, the principles of CE offer opportunities to make agriculture more efficient. By focusing on water resources used in agriculture, CE can help reduce water scarcity problems, by reducing consumption and increasing water reuse. Wastewater transformed into useable agricultural input represents added value and promotes CE, thereby minimizing waste and pollution.

The effectiveness of this scheme depends, to a large extent, on the capacity to ensure the benefits of wastewater reuse and to implement appropriate strategies to adapt to changes in the regulatory framework for wastewater and sludge reuse (Grundmann and Maaβ, 2016).

Those wishing to implement CE must also address the scale of application, to avoid the exploitation of resources in one area to satisfy demands in another area. Agro-industrial production facilities, in water scarce areas, being relocated to places without water shortages, may induce shortage at the new locations.

The objective of the present study is to compare international circular economy strategies and their impacts on agricultural water use. National practices are compared for seven countries: Brazil, Germany, Japan, Mexico, Morocco, Portugal, and Taiwan. Information on national practices was collected from local CE experts, all co-authors of the paper, and part of the International Material Flow Management (IMAT) Network. Local legislation, water resources management, environmental stressors, and circular economy practices were compared for each country. Thus, circular economy strategies were assessed according to three axes: normative, environmental, and practical. Context on each country's agricultural water use is provided in the next section.

2. Materials and methods

2.1. Case study countries agriculture water use characteristics

Agribusiness, as a major user of natural resources, is responsible for wide environmental impacts, especially on water resources. The study examines practices of seven countries, where the authors are located, i.e. Brazil, Germany, Japan, Mexico, Morocco, Portugal, and Taiwan. These countries represent 8% of Earth's land and various policy approaches, circular economy maturity levels, and climates.

Understanding their issues and solutions can highlight important strategies and contribute to improvements in food security, globally. The main characteristics of agricultural water use in each of these countries are presented in the subsequent sections, followed by a detailed comparison of legal, environmental and practical aspects.

2.1.1. Brazil

With an area of 8,547,403.5 km^2 and about 208 million inhabitants (IBGE. Instituto Brasileiro de Geografia e Estatística, 2017), Brazil stands out in the world scenario of freshwater availability, representing 12% of the world total (1488 million m^3.s^{-1}). More than 90% of the territory is subject to a rainfall rate between 1000 and 3000 mm.year^{-1} (REBOUÇAS, 2015). With about 80% of the average flow of fresh water available in the Amazon basin, parts of the territory may be subject to water scarcity, even though the average water stress in the country is low (1.76%) (ANA, 2020). Brazil's climate is as diverse as its territory is broad, including, for instance, semi-arid regions in the Northeast, tropical rainforests in the Amazon and along the Atlantic coast, and savannah-like conditions in the central region.

Around 33.8% of the land is used for agriculture (World Bank, 2015) and 21% of this is irrigated. A significant increase in irrigated agriculture has occurred in Brazil in recent decades, surpassing the growth rates of total planted areas (ANA, 2020).

Agriculture is responsible for the withdrawal of 32.7 km^3 and the use of 23.5 km^3 of freshwater annually. These values correspond to 49.8% of the overall withdrawal (65.7 km^3 year^{-1}) and 66.1% of the overall use (35.5 km^3 year^{-1}) (ANA, 2020).

The main opportunity for improvement in Brazil in this theme is to decrease the demand for irrigation water, both by matching crop type to local water availability, and also by improving irrigation efficiency.

2.1.2. Germany

The German territory has a land area of 348,900 km^2 (The World Bank, 2017) of which 47.9% percent is used for agriculture (Federal Ministry of Food and Agriculture, 2015; The World Bank, 2017). Located in Central Europe, Germany's climate is characterized as temperate and marine, belonging to the 'temperate cool' Global Agro-Ecological Zone [GAEZ] (FAO, 2017). With a mean annual precipitation of ca. 706 mm (WBG, 2017), Germany receives an average of 307 km^3 of precipitation annually. The total renewable water resource in Germany is ca. 1909 m^3.person^{-1}.year $^{-1}$ (FAO, 2014).

Despite being a 'water-rich' country, water scarcity does occur in certain regions. Geo-climatic variations, the rate of withdrawal of water, and contamination/pollution of water have been identified as the principal reasons for this variability.

A report by the Associations of the Water Industry of Germany indicates that, as of 2010, of the 188 km^3 of available water, 154.9 km^3 were left unused, whereas, 5.1 km^3 and 28 km^3 of water was distributed annually through public and non-public water supply systems, respectively (WVGW, 2015). Power generation uses 21 km^3 of water annually in Germany (BMELofand, 2014), and is the largest consumer of water in the country. Industry uses 7 km^3, households 4 km^3, and agriculture 0.3 km^3. The public water extraction is mainly (61%) from groundwater (DESTATIS, 2017).

Despite its low water demand for agriculture, Germany still suffers with diffuse pollution from agricultural sources, which increases pressure on rivers and groundwater bodies. This can be viewed as an opportunity to improve farming techniques and promote better pollution control at the source.

2.1.3. Japan

The Japanese Archipelago is characterized by steep mountains, which cover three quarters of the land. With an average annual availability of renewable water resources of 430 km^3 (Aquastat, 2015), and a relatively high average annual precipitation of 1684.3 mm (1975–2003) (Kim, 2010), Japan is still considered a non-abundant water country. The country has a relatively narrow surface area and the mountainous features of the land lead to rapid precipitation run-off (The World Bank, 2006). Agricultural land represents only 12% of the territory (World Bank, 2015). The amount of water resources available per year per capita in Japan (3300 m^3.hab^{-1}) is less than half of the world average (7800 m^3.hab^{-1}) (MLIT, Ministry of Land and Tourism, 2015).

The seasonal and yearly fluctuations of rainfall, as well as the increases in industrial and municipal water use as the economy grew rapidly, caused Japan to face some water shortage incidents, such as the severe water shortage at the time of the Tokyo Olympic Games in 1964 (MLIT, Ministry of Land and Tourism, 2015). Recent analyses of long-term changes in average annual surface temperatures in Japan from 1898 to 2016 revealed an increase of 1.19 °C in the past century (JMA, 2017).

While Japan receives relatively abundant annual precipitation, regional droughts have been reported every year (Xu et al., 2019). The incidents have forced the drought coordination council, organized by river basin communities, to impose joint water restrictions as a result of collective decisions in water resource management during droughts (Tembata and Takeuchi, 2018).

Agriculture is responsible for the withdrawal of 54 km^3 of freshwater yearly (Federal Ministry of Food and Agriculture, 2015). Variations in the magnitude of tropical storms are another concern of Japanese farmers because too much rain can decimate a crop, making agriculture a particularly high-risk business. There are infrastructural mechanisms used in many parts of Japan to combat this problem, such as pipes installed at a paddy's capacity level which redirects water back to irrigation channels, but some regions still struggle with mudslides. In the early summer of 2017, Hita, a city in the Oita prefecture, endured considerable damage from mudslides and overflowing river channels and had to rely on volunteers to help clean up the damage (Hita Social Welfare Council, 2017).

Thus, Japan could improve its water situation by promoting groundwater recharge, thus decreasing the uncertainty of water supply associated with seasonal precipitation. Soil conservation techniques could also be employed to decrease the risk of mud slides, such as increasing vegetation cover.

2.1.4. Mexico

Mexico has a total area of 1,959,248 km^2: 54% of which is used for agriculture (World Bank, 2015). The central-northern region is semi-arid and arid. Rainfall is scarce in the north and northeast of the country and in the Peninsula of Baja California, extending to the northwest of Mexico. Rainfall is abundant in the southeast and in the southwest, near the Gulf of Mexico, the Pacific coast, and south of the Tropic of Cancer. The rains come mainly between June and September (68% of the mean annual precipitation), except in the peninsula of Baja California, where rain falls predominantly during the winter (CONAGUA, 2014).

The mean annual precipitation is 760 mm (CONAGUA, 2014). 72.4% of this water returns to the atmosphere as evapotranspiration, 21.2% runs off into rivers and lakes and 6.4% naturally recharges aquifers. Taking into account the water outflows to and inflows from neighboring countries, every year the country has 447.26 km^3 of freshwater available (CONAGUA, 2015).

Mexico's utilization of its water resources, as a percentage of the total extracted volume, is: 77% for irrigation, 14% for public-urban usage and 9% for self-supplied industries and thermoelectric plants (CONAGUA, 2014). Agriculture is responsible for the withdrawal of 65 km^3 of freshwater each year (Federal Ministry of Food and Agriculture, 2015).There are 731 watersheds mapped in Mexico, 104 of which are subject to water availability problems (CONAGUA, 2015). Groundwater is relied upon to supply much of the industrial demand and about 65% percent of urban demand - sixty million people live in cities, about half of Mexico's population. Aquifers are the main source of water supply for the rural population and for irrigating approximately two million hectares, which is about 35% of Mexico's total irrigation.

Mexico had 25.8 million inhabitants in 1950, compared to 118.4 million in 2013 (population figures measured in mid-2013, projection by Conapo) and 127 million in 2016 (UNDP, 2017). The mean per capita natural water availability in Mexico in 1950 was 18,035 m^3.hab^{-1}.year^{-1} and in 2013 it dropped to 3982 m^3.hab^{-1}.year^{-1}. The National Water Plan states that 30% of the Mexican population has poor water availability in terms of both quantity and quality (CONAGUA, 2014; UNDP, 2017).

The growing population is causing overexploitation of the aquifers, and this is becoming more alarming each year (CONAGUA, 2014; INEGI, 2017). The National Population Council (Conapo) estimates that the pressure on water resources will increase in the future, due to a steady annual population growth (rate of 1.3 for 2000–2005 and 1.4 for 2010–2015) (FAO, 2016).

The main issue here is the high percentage of the available water used for irrigation. Better irrigation techniques should be implemented, as well as selecting crops according to water availability in a region.

2.1.5. Morocco

Morocco is located on the upper North-West region of the African continent with an area of 710.850 km^2 and a population of approximately 36.5 million inhabitants. The average annual rainfall of the country is low, ranging from more than 800 mm per year in the western and central Rif and the peaks of the Middle and High Atlas, to less than 100 mm in the South and the Sahara region (PNUE, 2007).

The country's total internal renewable water resources are close to 32 km^3 per year (22 km^3 of surface water and 10 km^3 of underground water). Agriculture uses 90% of the water (9.156 km^3 $year^{-1}$), and domestic and industrial water supply requires 1.275 km^3 $year^{-1}$ (GWP, 2012). Despites its arid climate, Moroccan agricultural production has been compared favorably to water-rich, but cooler climate countries, using a life cycle assessment approach (Payen et al., 2014).

Irrigated agriculture has emerged as a component of the national and regional economy and acts as a lever for generating wealth and creating jobs. Agricultural land covers 68.5% of the country (World Bank, 2015). Irrigated agriculture, although occupying only 16% of the cultivated area (1.5 million ha), contributes to about 45% of agricultural benefit and accounts for 75% of agricultural exports. The irrigated sector is also responsible for 100% of citrus fruits production, 99% of sugar, 82% of vegetable crops, and 75% of fodder and milk. In terms of employment, the agricultural sector provides nearly 120 million working days a year, which equates to 1.65 million jobs including 250,000 permanent ones (Conseil Economique, 2014).

In 2009, Morocco adopted an innovative and ambitious national water strategy that has enabled the country to have a global roadmap for water resources management, and targets for 2030. This strategy is based on water demand management and water resource development; management and development of supplies; preservation and protection of water resources; reduction of water vulnerability to water-related risks; adaptation to climate change; pursuit of regulatory and institutional reforms; modernization of information systems; and strengthening of means and skills (Ministère de l'Agriculture et de la Pêche Maritime, 2013).

Demand management in agriculture is addressed through the introduction of incentive mechanisms for irrigation modernization and the adoption of water-efficient technologies, the rehabilitation of irrigation networks and strengthening of the maintenance of irrigation networks (Burak and Margat, 2016).

2.1.6. Portugal

Portugal has 92,226 km^2, 3124 km^2 in the archipelagos of Madeira and Azores in the Atlantic Ocean (INE, 2018). Most of its river basins are shared with Spain, therefore hydrological plans and programs are coordinated between the two countries (APA, 2015).

Portuguese water resources are very heterogeneous, being characterized by an average annual precipitation of 950 mm, with an irregular spatial distribution, seasonal variability and inter-annual irregularity (APA, 2015). For instance, in the Guadiana river basin the average annual precipitation is 580 mm (the lowest registered in the mainland), and in the Minho and Lima river basins it is above 2000 mm (GODINHO, 2016).

Agricultural holdings cover 40.4% of the national territory (World Bank, 2015). Annual freshwater withdrawals for agriculture are 8 km^3. This accounts for 74.7% of the water used in the mainland, while the urban sector uses 19.6%, followed by industry (5%) and tourism (0.7%). Water from the northern river basins is mainly used to produce hydroelectricity, whereas the water from the southern river basins is mainly used for agriculture. Both are used for public water supply (APA, 2015).

The annual demand for water in Portugal is about 7.5 km^3, combining the needs of the agricultural, urban, and industrial sectors. Additionally, distribution is highly inefficient with 40% losses in 2000, and 37.5% in 2009 (APA, 2012).

Decreasing the amount of water used for irrigation, and improving water distribution efficiency should be prioritized in Portugal.

2.1.7. Taiwan

Taiwan is a small island (approximately 36,000 km^2) with short and fast-flowing rivers. Piped water reaches 93.80% (in 2017) of the country population (about 24 million people) and 22 million people have a clean and safe water supply (Water Resources Agency, 2017).

The average annual rainfall in Taiwan is 2722 mm (averaged from 2003 to 2012). However, only 17.7 km^3 of water are useable each year after deducting water lost to evapotranspiration (21%) and runoff that reaches the ocean (Yang, 2010). The useable water comes from rivers (56%), reservoirs (24%), and groundwater (20%). Freshwater use in agriculture accounts for about 72%, 12.7 km^3, while domestic use corresponds to 19%, and industrial use to 9%.

Water resources in Taiwan are limited by the uneven spatial and temporal distribution of precipitation and the special topographical conditions. About one third of Taiwan consists of mountains higher than 1000 m, while another third is between 100 and 1000 m. These north-south mountains cause water resources to flow quickly down the east-west slopes into the ocean and cannot be easily stored. The dry season extends from November to April and the wet season extends from May to October. Total rainfall in these two seasons is significantly different, leading to water shortage in the dry season and water excess in the rainy season. The capacity of reservoirs in Taiwan is approximately 1.9 km^3, which is insufficient to supply the 4.3 km^3 of water used each year. Additionally, only 37.2% of Taiwan's land area is flat (below 100 m) (Yang, 2010), and 21% of the national territory is used for agriculture.

Extreme events due to climate change are causing increased deposition of sand and rocks in rivers and reservoirs, thereby reducing their storage volumes and increasing water turbidity. Additionally, the groundwater in southern Taiwan has been overexploited for years due to the development of agricultural and aquacultural industries. The over-pumping of groundwater has caused land subsidence and seawater intrusion in these areas. Measurements and strategies to sustainably manage water resources are challenges in Taiwan, and could include structural measures to promote aquifer recharge.

2.2. Database and study design

In order to compare the strategies of each country, eighteen water management and circular economy specialists, co-authors of the present study, brainstormed analysis areas and criteria. Based on their experience and discussion, the criteria were clustered in three axes:

- Normative, focused on national laws and regulations;
- Environmental, related to local environmental stressors, i.e. water availability and demand;
- Practical, focused on applied circular economy practices.

In total, 44 analysis criteria were compiled (Table 1), and grouped into four categories:

a. Water Resources Management (WRM);
b. Water Resources Legislation (WRL);
c. Environmental Stressors (ES);
d. Circular Economy Practices (CEP).

WRM and WRL are related to the normative axis and include the most criteria, eighteen and eleven, respectively. WRM comprises water resources planning and management at various levels, from local to national. WRL embraces principles and laws focused on water resources. ES includes nine criteria that represent different pressures on water resources. Lastly, CEP comprises six criteria related to actions taken to implement a circular economy in the management of water resources.

2.3. Statistical methods

These criteria were investigated and compared among the seven countries (Brazil, Germany, Japan, Mexico, Morocco, Portugal, and Taiwan). Associations among the criteria and their categories were investigated by Multiple Correspondence Analysis (MCA), a multivariate

Table 1
Criteria employed to compare circular economy strategies for agricultural water use.

Categories	Criteria	
WRM	X1	Water as a public good.
	X2	Strict quality, quantity and sustainability regulatory aspects.
	X3	Strict regulatory aspects of shared and cross-border water resources.
	X4	Water supply and wastewater disposal as public services.
	X5	Legitimate agencies and representatives of civil society make strategic decisions.
	X6	Water catchment rights and discharge rights are subject to strict control by the governments.
	X7	Existence of permitting (authorization and payment) for specific uses of water.
	X8	Rates and prices determined by regional and local contexts.
	X9	Management is based on river basins.
	X10	High wastewater treatment index (greater than 80%) of the total collected.
	X11	Losses in distribution networks are low (less than 10%).
	X12	Existence of sectoral initiatives to improve performance and sustainable management of water resources.
	X13	Water resources management is articulated among several actors (managers and society), that is, it is integrated and decentralized.
	X14	Actions for planning and water resources management at various levels: national, state and local (river basin).
	X15	Actions for planning and water resources management among member states (different countries) that constitute a river basin district.
	X16	The use of water resources is based on a water quality framework to meet each type of specific use.
	X17	The regulation of water resources use is made through mandatory user registration, regardless of the type of resource (surface or ground) and the domain of use (area).
	X18	Water use fees are intended for water resources conservation and recovery.
WRL	X19	Water resources laws are elaborated and implemented at three levels: national, state (regional) and local.
	X20	Water resources use monitoring is done at the river basin level.
	X21	Water resources use monitoring depends on the amount withdrawn by the user.
	X22	Water resources use monitoring depends on the type of use.
	X23	Monitoring of water resources use is preventative.
	X24	Monitoring of water resources use is corrective/repressive (eg. in addition to fines there are restrictions for some users.)
	X25	There is a substantial framework of principles and laws focused on water resources (e.g. specific and integrated policies, management systems, policy instruments and regulations, information systems, policies, plans and programs at various levels: national, regional, local, etc.)
	X26	There are separate and specific laws for surface and groundwater management.
	X27	The law prohibits direct monetary trade of water rights.
	X28	There is specific regional legislation for agricultural use of water.
	X29	There is a legal framework for seawater desalination.
ES	X30	There is agricultural crop production in areas with water deficit.
	X31	Due to agro-climatic reasons and crop requirements, the crop is irrigated.
	X32	When irrigation is used, the pressure on freshwater resources, due to the high rate of “water extraction” for crop production, is significant.
	X33	Of the area of cultivated land irrigated in the country, the greater part is occupied by the main crop in the country.
	X34	The water fraction used in agriculture is high compared to other sectors of the water economy.
	X35	The pressure exerted on water resources (surface and groundwater) by the transport of agricultural pollutants, such as nitrates due to the use of organic fertilizers, chemicals and pesticides, is significant.
	X36	Uneven spatial and temporal precipitation distribution and special topographic conditions limit the availability of water resources.
	X37	Use of inefficient irrigation systems and technologies.
	X38	There are situations of water crises in the country (water scarcity).
CEP	X39	There are “closing loops” practices, aimed at the reuse of waste water.
	X40	Recovery of material and energy from sludge/biomass obtained from the waste water treatment (closing the energy cycle, and also the material cycles, by digestion).
	X41	It is economically advantageous to recycle water for reuse (or Agricultural return flow) compared to the use of the non-recycled resource.
	X42	There are soil management practices aimed at soil moisture retention, decreasing irrigation water demand.
	X43	There is information/education about Circular Economy in agriculture.
	X44	There are policies, laws and/or regulations directly related to Circular Economy, including aspects in the agricultural sector.

data analysis method, which was developed in the 1960s by Le Roux and Rouanet (2010), whose objective was to develop a graphical representation of data in as few dimensions as possible (Hoffman and Franke, 1986), and to explore their relationship.

In this analysis the categorical variables (nominal qualitative variables) were the countries, whereas their water usage practices in agriculture were the analysis criteria. A scattergram was used to depict the categories, while the results were presented in a perceptual map. This map allowed comparisons among variables and categories. It enabled calculation of statistically significant associations between categorical variables, by their coordinates defined by symmetric normalization.

Distance between map elements reveals the degree of association. A higher association is indicated by greater proximity, meaning that the elements appear more frequently together (Le Roux and Rouanet, 2010; Parchomenko et al., 2019). Here, country proximity indicated the similarity among their water practices, while country-practice proximity indicated how strong a practice was in that country.

The association intensity among the variables was obtained from a contingency table in which the absolute frequencies observed for each pair of two-variable categories were arranged, where a given cell ij contained the quantity n_{ij} (i = 1, …, I e j = 1, …, J) of observations. The total number of observations N can be obtained by equation (1) or equation (2).

$$N = \sum_{i=1}^{I} \sum_{j=1}^{J} n_{ij} \tag{1}$$

which is the same as,

$$\mathrm{N} = \sum c_1 + \sum c_2 + \sum c_J + \sum l_1 + \sum l_2 + \sum l_I \tag{2}$$

Where,

$$\sum l_i = row\ sum$$

$$\sum c_j = column\ sum$$

To investigate a statistically significant association among variables and categories, a χ^2 test and a residue analysis of the contingency tables were performed using statistical software R.

The following hypotheses were tested:

H0. The association among the variables and their respective categories occurs randomly;

H1. There is a non-random association between at least one variable and one category.

The χ^2 test (equation (3)) makes it possible to verify the distance between expected values and observed values, under the independence hypothesis.

$$\chi^2 = \sum_{i=1}^{I}\sum_{j=1}^{J}\frac{\left[n_{ij}-\left(\frac{\sum c_j \, . \, \sum l_i}{N}\right)\right]^2}{\left(\frac{\sum c_j \, . \, \sum l_i}{N}\right)}\text{, with } (I-1)\,(J-1) \text{ degrees of freedom} \tag{3}$$

Where:

$n_{ij} = observed\ frequency\ on\ row\ i\ column\ j$

$\frac{\sum c_j \, . \, \sum l_i}{N} = expected\ frequency\ in\ each\ cell$

$n_{ij} - \left(\frac{\sum c_j \, . \, \sum l_i}{N}\right) = residual\ statistics$

If the χ^2 value is greater than its critical value, it can be stated that there is a statistically significant association among the categorical variables.

Furthermore, to compare all national practices, a normalized index, I_C, was defined for each category (equation (4)) and in total (equation (5)).

$$I_C = \sum_{i=1}^{I}\frac{l_i}{I} \tag{4}$$

$$I_T = \sum_{j=1}^{J} I_C \tag{5}$$

Accordingly, the maximum index for each category, I_C, (WRM, WRL, ES and CEP) is 1, and for the total, I_T, is 4. However, because ES represent stressors that increase water use, while all other categories are related to strategies that decrease water use, the index for ES is instead calculated as one minus the normalized sum of categorical variables.

2.4. Uncertainties and shortcomings

Varying realities may exist within a country, and the aspects related here reflect the most prevalent conditions in each of the countries analyzed. Additionally, the existence of legal frameworks is, at best, an indication of how the agricultural sector is regulated in each country, but verifying whether such regulations are enforced is beyond the scope of the present work. Also, the conditions reported portray the reality for the main crops cultivated in each country, and important deviations might be observed if more crops were considered.

Furthermore, the proposed criteria are not an exhaustive list of circular economy strategies. They were based on the current experience of the selected case study countries. The importance of each criterion is also not explored. The statistical analyses assume all categories are equally important as are all criteria within each category. However, because each category has a different number of criteria, those with more criteria inherently assume each individual criterion is less important.

3. Results and discussion

3.1. Analysis categories

3.1.1. Water resources management

Information gathered on water resources planning and management at various levels indicated that, for the countries analyzed, all waters are public property for common use with stringent regulations on quality and quantity. There is no regulation on shared and cross-border water resources in Japan, which is not surprising since the country is made up of a group of islands. There are also no regulations of that sort in Mexico and Morocco, where there is tension with neighboring countries. In Portugal, despite the strict regulations stipulated by the EU Water Framework Directive, there are issues that need to be addressed concerning the quality of waters and tributary flows (quantity and modeling) in almost all river basins shared with Spain (APA, 2015).

In all seven countries, water supply and wastewater disposal are the responsibility of the public sector, but treatment may be public or private. Water management is decentralized, and strategic decisions are made considering the forms of organization, participation, and cooperation, by legitimate agencies and representatives of civil society. Taiwan is the exception, where strategic decisions are an exclusive government responsibility.

Water catchment rights and discharge rights, in all countries analyzed, are subject to strict government control and there is permitting (authorization and payment) for specific uses of water. The rates and prices are determined by the regional/local context. Taiwan, again, differed from the other countries: prices are determined by the national government and are the same in different regions.

Germany and Portugal have high wastewater treatment indices (greater than 80% of the total collected). Losses in distribution networks are low in Germany and Japan (less than 10%). In other countries, losses are high due to leaks in abstraction and distribution systems. Lastly, all countries present sectoral initiatives to improve performance and sustainable management of water resources, most notably by organizations representing the agro-industry.

3.1.2. Water resources legislation

All seven countries have a substantial framework of principles and laws focused on water resources (e.g., specific and integrated policies, management systems, policy instruments and regulations, information systems, policies, plans, and programs) at various levels: national, regional, and local. Mexico and Taiwan only have national level legislation. In Brazil, Germany, Japan, Mexico, and Portugal there are separate and specific laws for surface and groundwater management. The use of rainwater is regulated only in Morocco and Brazil, the latter focusing on domestic use.

There is specific regional legislation for agricultural use of water in Brazil, Japan, Morocco, and Taiwan. Germany and Portugal follow EU regulations. Seawater desalination is regulated in Brazil (Regional Programs in the Brazilian semi-arid region focusing on human consumption), Mexico (desalination plants in the northwestern states Baja California and Baja California Sur), and Taiwan (there are 22 water desalination plants in the islands). Monitoring water resources use depends on the amount withdrawn by the user and the type of use (agricultural, industrial or household) and is corrective/repressive in most of these countries, i.e., in addition to fines there are restrictions for some users.

3.1.3. Environmental stressors

This category focuses on the pressure exerted on water resources. In all seven countries there are crops in water deficit areas, requiring irrigation, and the pressure on freshwater resources is significant. Except for Germany, in all other countries the percentage of agricultural water use is high compared to other sectors of the water economy.

In Mexico, for example, there are 13 Hydrological Administrative Regions: One region is under very high stress (139%), seven regions are under high stress (40.5–81.5%); one under medium stress (20.8%); one under low stress (15.17%); and three regions experience no water stress (1.45–8.6%) (CONAGUA, 2017, 2016, 2015, 2014, 2013).

Still in Mexico, agriculture is dominated by inefficient irrigation systems (CONAGUA, 2014). Only 8.8% percent of the Mexican farmland is watered by drip irrigation, while 77.7% is irrigated by much less water efficient practices such as flood-irrigation, and overhead irrigation (center pivot systems); and 17.3% is irrigated by sprinkler systems (INEGI, 2017). Efforts have been started to improve that situation (Sainz-Santamaria and Martinez-Cruz, 2019).

The pressure exerted on water resources, both surface and groundwater, goes beyond irrigation. Contamination by agricultural pollutants, such as nitrates due to the use of organic fertilizers, chemicals, and pesticides, is significant in Germany, Mexico, Portugal, and Taiwan.

3.1.4. Circular economy practices

Some evidence was found of actions aimed at implementing a circular economy in the management of water resources. There are “closing loop” practices, focused on the reuse of wastewater in industrial cycles and crop irrigation, in Brazil, Germany, Japan, Mexico, and Taiwan.

In Brazil, it is economically advantageous to reuse water in agriculture, as there is reuse in irrigation and in the industrial cycle of sugarcane washing.

In some countries it is common to use wastewater for irrigation, such as in Brazil, Germany, Mexico, and Taiwan. However, the economic advantages depend on local circumstances, and it is usually better to save water, by optimizing irrigation systems and irrigation times, for instance, before recycling the water. Soil management practices also contribute to decreasing irrigation water demand. However, they are not common in Mexico and Taiwan. Material recovery occurs in Brazil, Mexico, and Taiwan with sludge/biomass recovered from wastewater treatment and used in agricultural fertilization.

Finally, policies, laws and regulations directly related to CE, including aspects in the agricultural sector, are promoted in Germany, Portugal, Morocco, and Taiwan. Germany is the only country where there is information/education about CE in agriculture, with a well developed platform for CE education in all sectors.

3.2. Association levels among countries and water use practices

The critical χ^2 rejection value for H0 at a 0.05 significance level with 18 degrees of freedom is 28.869. The result obtained was 9.013, and it was, therefore, not possible to reject the null hypothesis, and the relationship among variables and categories may occur randomly.

The authors also concluded that there was no statistically significant relationship among countries and their practices. However, Table 2 and Fig. 1 revealed some trends.

A simple correspondence plot (Fig. 2) showed that it was not possible to associate a category with a specific country. Proximities among countries indicated similarities in their respective practices. Taiwan’s isolated position revealed that its practices were the most divergent among the countries analyzed.

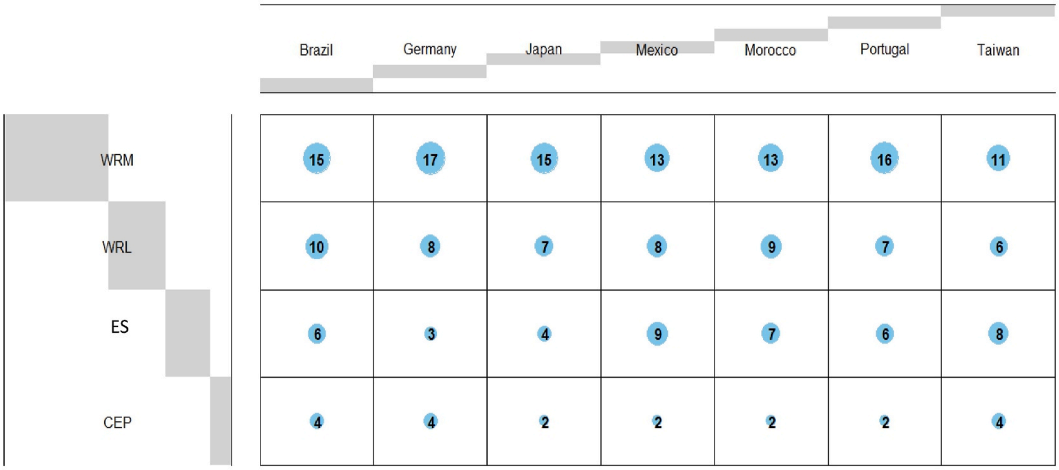
Among the seven countries and the 44 criteria analyzed, the WRL category represents the most homogeneous criteria group due to its proximity to the origin of the graph (Fig. 2). Although the results indicated an association with no statistical significance, it was possible to

Table 2
Binary matrix of practices adopted, by country.

Country	Brazil	Germany	Japan	Mexico	Morocco	Portugal	Taiwan
x1	1	1	1	1	1	1	1
x2	1	1	1	1	1	1	1
x3	1	1	0	0	0	0	1
x4	0	1	1	0	0	1	1
x5	1	1	1	1	1	1	0
x6	1	1	1	1	1	1	1
x7	1	1	1	1	1	1	1
x8	1	1	1	1	1	1	0
x9	1	1	1	1	1	1	0
x10	0	1	1	0	0	1	0
x11	0	1	1	0	0	0	0
x12	1	1	1	1	1	1	1
x13	1	1	1	1	1	1	0
x14	1	1	1	1	1	1	1
x15	1	1	0	1	0	1	1
x16	1	1	1	1	1	1	1
x17	1	1	1	1	1	1	1
x18	1	0	0	0	1	1	0
x19	1	1	1	1	1	1	0
x20	1	1	1	1	1	1	1
x21	0	1	0	1	1	1	0
x22	1	1	1	1	1	0	1
x23	1	1	1	1	1	1	1
x24	1	1	0	1	1	1	1
x25	1	1	1	0	1	1	0
x26	1	1	1	1	0	1	0
x27	1	0	0	0	1	0	0
x28	1	0	1	0	1	0	1
x29	1	0	0	1	0	0	1
x30	1	1	0	1	1	1	1
x31	1	1	1	1	1	1	1
x32	0	0	0	1	1	0	1
x33	1	0	1	1	1	0	1
x34	1	0	1	1	1	1	1
x35	0	1	0	1	0	1	1
x36	1	0	1	1	1	1	1
x37	0	0	0	1	0	0	0
x38	1	0	0	1	1	1	1
x39	1	1	1	1	0	0	1
x40	1	0	0	1	0	0	1
x41	1	0	0	0	0	0	1
x42	1	1	1	0	1	1	0
x43	0	1	0	0	0	0	0
x44	0	1	0	0	1	1	1

1 - The criterion/practice is adopted/observed by the country.

0 - Otherwise.



	Brazil	Germany	Japan	Mexico	Morocco	Portugal	Taiwan
WRM	15	17	15	13	13	16	11
WRL	10	8	7	8	9	7	6
ES	6	3	4	9	7	6	8
CEP	4	4	2	2	2	2	4

Fig. 1. Country matrix and number of practices per category.
The maximum possible for each category is WRM (18), WRL (11), ES (9), CEP (6).

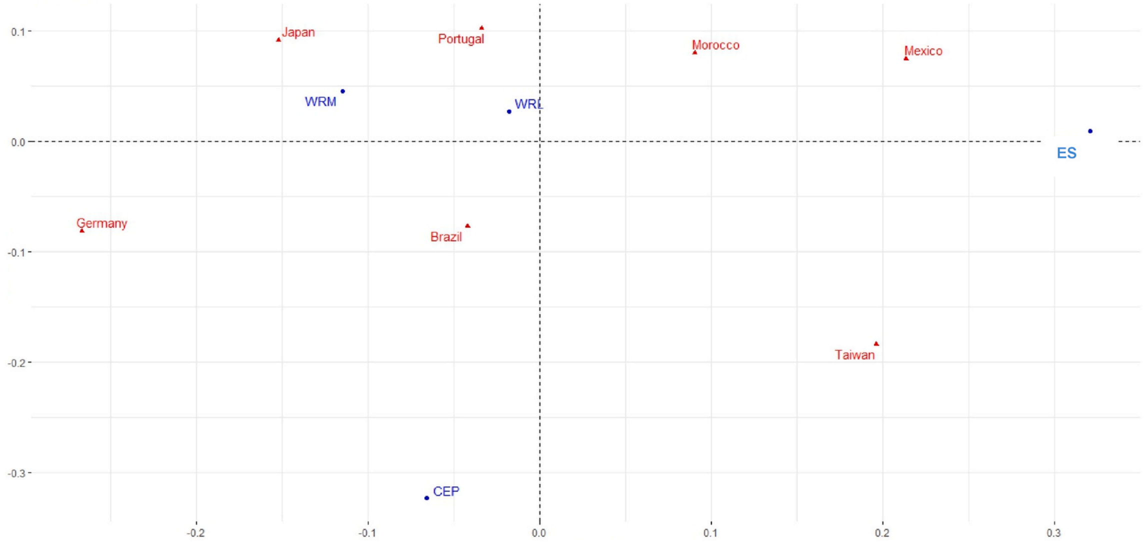


Fig. 2. Simple correspondence analysis of water use practices in seven countries.

detect similarities, among countries. Japan and Portugal showed evidence of common practices in WRM; Morocco and Mexico showed a close relationship in ES; Brazil and Germany showed similar practices in CEP, and Taiwan showed unique practices.

The largest distances were seen between Germany and Mexico, and Germany and Taiwan. The smallest distance was observed between Portugal and Japan, meaning that these countries are the most similar in this group. Regarding the categories of analysis and the countries, the greatest distance was between Germany and ES, meaning that this country has few stressors, and those that do occur are dissimilar to those observed in other countries. The shortest distance was seen between Japan and the WRM category, followed by Portugal and WRL, and Brazil and WRL.

3.3. Correlation between circular economy strategies and agricultural water use

Comparing the calculated indices and water use per km^2 for all countries highlights their differences (Table 3). Japan and Taiwan have the highest consumption rates, potentially due to their wide production of rice, which is a water-intensive crop. On the other hand, Germany and Morocco have the lowest consumption rates and their agriculture

Table 3
National indices and agricultural water use.

	Brazil	Germany	Japan	Mexico	Morocco	Portugal	Taiwan
I_{WRM}	0.83	0.94	0.83	0.72	0.72	0.89	0.61
I_{WRL}	0.91	0.73	0.64	0.73	0.82	0.64	0.55
I_{ES}	0.33	0.67	0.56	0	0.22	0.33	0.11
I_{CEP}	0.67	0.67	0.33	0.33	0.33	0.33	0.67
I_T	2.74	3.01	2.36	1.78	2.10	2.19	1.93
Water Use m^3.km^{-2}	15.9	1.3	1210.8	266.8	6.9	236.9	1612.8

focuses on grains and citrus, respectively. Morocco has a high number of environmental stressors, which could also explain the drive for lower consumption.

In order to assess the impact of different types of strategies on water use, indices were correlated to water use (Table 4). Based on this analysis, the highest correlated index was that of WRL. Thus, greater application of water regulations and legislation was strongly correlated to lower water use in the studied countries. WRM is moderately correlated to water use, and ES and CEP had no relation to water use. The results suggest regulations and management strategies can lead to greater reduction in water use. However, stressors and popular crops may be the drivers for these practices. For example, an agriculture inherently based on water-intensive crops may have less incentives to shift production to other crops and less openness to strict water regulations.

The correlations provide insight into the importance of local customs, as well as the institution of circular economy minded legislation, regulations, and management. However, more research is still needed to assess what specific types of legislation or practices would lead to the most impact. And this could also depend on local culture, crop production, and environmental factors. It should be noted that all analyses in the present study assumed equal importance of each criteria, as well as equal importance of each category. This is a simplification that also requires further study. Lastly, while circular economy practices were shown to be generally not correlated to lower use at a national level, these are still novel. Further application and variety of practices is required to better represent the impact of CE on a national scale, but local success stories could support the wider application of CE in agriculture.

3.4. Discussion

The CE principles presented in the Introduction, above, may be rephrased to the use of water in agriculture, as the following tenets:

(i) Preserve and improve natural capital by controlling finite stocks and balancing flows of water for use in agriculture;
(ii) Optimize the yield of water by circulating products, components, and materials in use at eh highest level of utility, in the technical and biological cycles;
(iii) Stimulate the effectiveness of the CE system by revealing and excluding negative externalities.

Thus, considering the diverse characteristics of the countries analyzed, including land extension and topography, climate and water availability, crop diversity, CE may be used to promote the sustainable management of water in the agricultural sector both in the local and the international scales.

At a local scale, the main focus must be on reducing consumption and increasing reuse, but may also include increasing the volume of water sustainably available. Consumption may be lowered, for instance, by adopting drip irrigation, when irrigated crops are unavoidable, or switching crops when possible. Reuse may be augmented by implementing closed loop irrigation systems, relying on energy supplied by renewable sources, such as wind and solar. Increasing the volume of available water may be achieved by adding storage in regions where precipitation varies significantly along the year, by creating and protecting aquifer recharge areas, and by harvesting water from novel sources, such as the seas or the atmosphere. Financing of these systems may be done by local governments or by international agencies.

Table 4
Pearson correlation between indices and agricultural water use.

Index	Correlation
I_{WRM}	−0.538
I_{WRL}	−0.784
I_{ES}	+0.135
I_{CEP}	+0.092
I_T	−0.395

At a global scale, international cooperation, promoted and regulated by agencies such as the United Nations (UN) and the World Trade Organization (WTO), could lead to the cultivation of crops in regions with the best climate, making more water available for public consumption in water scarce regions. Issues of fair trade, national independence and sovereignty would have to be regulated before such arrangements could be put into place.

Educating and informing the agricultural sector and its work force about the principles and advantages of CE is also of paramount importance, as well as creating incentives to promote its use. This needs to be done at the local level, but may be initiated globally, with CE education programs developed by international agencies and implemented locally, as part of the Sustainable Development Goals (SDG) (United Nations, 2016). Local policy makers can aid by subscribing to the SDGs, and facilitating the implementation of initiatives to achieve these goals.

4. Conclusions

Agriculture faces many challenges in the pursuit of greater sustainability. These are associated with dependence on fossil fuels and synthetic fertilizers, resource scarcity, food security, population growth, climate change, and water scarcity and/or overuse. As one of the largest consumers of water resources, agriculture should promote sustainability by implementing efficient water use practices, combined with integrated agricultural practices designed to improve soil quality and plant health. CE practices aimed at a systemic view of water-agriculture interactions are still novel in some countries and not yet initiated in others.

The comparison of the seven countries reported herein showed regulation remains a challenge in many areas, mainly related to cross-border water resources management and basic infrastructure level of service, such as low percentage of wastewater treatment and high losses in distribution networks in most countries. Water resources legislation is abundant and there are integrated policies, management systems, policy instruments and regulations at various levels. However, they are often not adequately implemented, monitored and improved, significantly impacting water use.

Water recycling and reuse are practiced, especially in industry, and are based on immediate financial benefits, not considering long-term goals such as natural capital preservation, and climate change. The integration of CE concepts in practice is in its infancy in most countries analyzed herein, except Germany. Awareness, commitment and laws and regulations on CE are generally non-existent or are in the early phases of discussion, especially in the agricultural sector.

In order to compare the seven studied countries, strategies and practices impacting agricultural water use were categorized as either management, legislation, environmental stressors, or CE practices. Criteria under each category were defined and can be used to analyze other countries, as well as promote good water practices, stewardship, and holistic water governance, especially in the implementation of closed-cycle systems.

The MCA analyses herein did not reveal statistically strong correlations among the different countries and among the categories and each country. Nevertheless, the correlation between indices and water use showed the wider establishment and respect of water resources legislation was strongly correlated to lower water use. Thus, legislation should be a focus for countries seeking to improve sustainability in agricultural water use. Water resources management was found to be moderately correlated to lower water use. Future studies should explore which specific practices have the most impact on consumption, and the effect of local culture, crop production, and environmental factors. Also, the variation of conditions for different crops and different regions within the same country may be exploited to provide a more detailed depiction of the reality.

The list of criteria proposed in the study can provide a useful framework for other countries to assess their agricultural practices and identify more sustainable actions. The analyses performed can be used by policy makers and stakeholders to direct improvements in water quantity and quality management, consumption risk mitigation, availability, regulation, and planning. And by implementing more circular practices that leverage symbiotic relationships between businesses and improved water resources management, broader financial benefits could be realized.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

ANA, A.N. de Á. e S.B., 2020. Conjuntura de Recursos Hídricos 2020.

APA, A.P. do A., 2015. Plano Nacional da Água.

APA, A.P. do A., 2012. PROGRAMA NACIONAL PARA O USO EFICIENTE DA ÁGUA-Implementação 2012 - 2020.

Aquastat, G.W.I.S., 2015. Japan Country Fact Sheet [WWW Document]. FAO, Food Agric. Organ, United Nations.

BMEL, F.M. of E. and R., 2014. Everything Flows: A German Water Balance [WWW Document].

Burak, S., Margat, J., 2016. Water management in the mediterranean region: concepts and policies. Water resour. OR Manag. 30, 5779–5797. https://doi.org/10.1007/s11269-016-1389-4.

CONAGUA, C.N. del A., 2017. Estadísticas DEL AGUA EN.

CONAGUA, C.N. del A., 2016. Estadísticos Agricolas de los Unidades de Riego, Año agrícola 2014-2015 ([WWW Document]).

CONAGUA, C.N. del A., 2015. Statistics on Water in Mexico 2015 (Mexico).

CONAGUA, C.N. del A., 2014. National Water Plan 2013-2018 (Mexico).

CONAGUA, C.N. del A., 2013. Estadísticas Agrícolas de las Unidades de Riego.

Conseil Economique, S. et E., 2014. La gouvernance par la gestion intégrée des ressources en eau au Maroc.

DESTATIS, S.B., 2017. Field Crops and Grassland [WWW Document].

FAO, F. and A.O. of the U.N., 2017. Global Agro-Ecological Zones [WWW Document].

FAO, F. and A.O. of the U.N., 2016. COUNTRY FACT SHEET ON FOOD AND AGRICULTURE POLICY TRENDS. Mexico.

FAO, F. and A.O. of the U.N., 2014. AQUASTAT: Germany [WWW Document].

Federal Ministry of Food and Agriculture, 2015. Agriculture at the Heart of Society Taking Stock of Agricultural Policy: Selected Facts and Figures on Agriculture.

GODINHO, J.P.M.E.F.N., 2016. A Água da Escola Portuguesa. Lisboa.

Grundmann, P., Maaß, O., 2016. Wastewater Reuse to Cope with Water and Nutrient Scarcity in Agriculture-A Case Study for Braunschweig in Germany. In: Competition for Water Resources: Experiences and Management Approaches in the US and Europe, pp. 352–365. https://doi.org/10.1016/B978-0-12-803237-4.00020-3.

GWP, G.W.P., 2012. Water Demand Management: the Mediterranean Experience [WWW Document].

Hita Social Welfare Council, 2017. Letter from Hita Social Welfare Council. Hita.

Hoffman, D.L., Franke, G.R., 1986. Correspondence analysis. Graphical of Categorical Data 23, 213–227.

Homrich, A.S., Galvão, G., Abadia, L.G., Carvalho, M.M., 2018. The circular economy umbrella: trends and gaps on integrating pathways. J. Clean. Prod. 175, 525–543. https://doi.org/10.1016/j.jclepro.2017.11.064.

IBGE. Instituto Brasileiro de Geografia e Estatística, 2017. Banco de Dados Agregado 2016 [WWW Document].

INE, I.N. de E., 2018. Portugal Em Números - 2016.

INEGI, 2017. Espacios Y Datos [WWW Document].

JMA, J.M.A., 2017. Annual Report on the Climate System 2016 [WWW Document].

Le Roux, B., Rouanet, H., 2010. Multiple Correspondence Analysis. SAGE Publications, Inc., p. 2455. https://doi.org/10.4135/9781412993906. Teller Road, Thousand Oaks California 91320 United States of America.

Ministère de l'Agriculture et de la Pêche Maritime, 2013. Note stratégique n°97.Note de veille secteur agrumicole.

MLIT, Ministry of Land, I., Tourism, T., 2015. WHITE PAPER ON LAND, INFRASTRUCTURE, TRANSPORT AND TOURISM. JAPAN.

Parchomenko, A., Nelen, D., Gillabel, J., Rechberger, H., 2019. Measuring the circular economy - a Multiple correspondence analysis of 63 metrics. J. Clean. Prod. 210, 200–216. https://doi.org/10.1016/j.jclepro.2018.10.357.

Payen, S., Basset-mens, C., Perret, S., 2014. Ac Sc. J. Clean. Prod. 87, 139–148. https://doi.org/10.1016/j.jclepro.2014.10.007.

PNUE, U.N.E.P., 2007. Water Demand Management in the Mediterranean.

REBOUÇAS, A.C., 2015. Água doce no mundo e no Brasil. In: BRAGA, B., TUNDISI, J.G., TUNDISI, T.M., CIMINELLI, V.S.T. (Eds.), Água Doces No Brasil: Capital Ecológico, Uso e Conservação. Escrituras Editora, São Paulo, p. 729.

Ritzén, S., Sandström, G.Ö., 2017. Barriers to the circular economy - integration of perspectives and domains. In: Procedia CIRP, pp. 7–12. https://doi.org/10.1016/j.procir.2017.03.005.

Sainz-Santamaria, J., Martinez-Cruz, A.L., 2019. How far can investment in efficient irrigation technologies reduce aquifer overdraft? Insights from an expert elicitation in Aguascalientes, Mexico. Water Resour. Econ. Times 25, 42–55. https://doi.org/10.1016/j.wre.2017.10.003.

Tembata, K., Takeuchi, K., 2018. Collective decision making under drought: an empirical study of water resource management in Japan. Water Resour. Econ. 22, 19–31. https://doi.org/10.1016/j.wre.2017.11.001.

The World Bank, 2017. Data - Land Area [WWW Document. T. W. Group, Prod.

The World Bank, 2006. Water Resources Management in Japan. Washington, D.C.

Toop, T.A., Ward, S., Oldfield, T., Hull, M., Kirby, M.E., Theodorou, M.K., 2017. AgroCycle - developing a circular economy in agriculture. In: Energy Procedia, pp. 76–80. https://doi.org/10.1016/j.egypro.2017.07.269.

UNDESA - United Nations Department of Economic and Social Affairs, 2015. World Population Projected to Reach 9.7 Billion by 2050.

UNDP, U.N.D.P., 2017. Human Development Reports 2016.

United Nations, 2016. Transforming Our World: the 2030 Agenda for Sustainable Development, A/RES/70/1. https://doi.org/10.1201/b20466-7.

Water Resources Agency, 2017. Official Statistic Report.

WBG, W.B.G., 2017. Country historical climate - Germany. Clim. Chang. Knowl. Portal Dev. Pract. Policy Makers [WWW Document].

Winter, J.M., Lopez, J.R., Ruane, A.C., Young, C.A., Scanlon, B.R., Rosenzweig, C., 2017. Representing Water Scarcity in Future Agricultural Assessments. Anthropocene. https://doi.org/10.1016/j.ancene.2017.05.002.

WVGW, 2015. Profile of the German Water Sector 2015. DWA, Bonn.

Xu, Z., Chen, X., Wu, S.R., Gong, M., Du, Y., Wang, J., Li, Y., Liu, J., 2019. Spatial-temporal assessment of water footprint, water scarcity and crop water productivity in a major crop production region. J. Clean. Prod. 224, 375–383. https://doi.org/10.1016/j.jclepro.2019.03.108.

Yang, W.F., 2010. Development of Water Resources in Taiwan.