Barriers in Implementation of Circular Economy Approach with the Consumption of Oilfield Produced Water

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Research Article

Keywords: Wastewater, Sustainability, Circular Economy, Wastewater Management, Barriers

Posted Date: March 14th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1439745/v1

Abstract

A circular economy approach within wastewater consumption for agriculture has gained relevance in recent years. Extreme climate conditions (e.g., megadrought in California) have resulted in severe water shortages, yet there seems to be a reluctance to accept alternative water sources. Despite the numerous local initiatives towards oilfield water reuse, barriers remain to its implementation in practice. This study identifies the barriers towards widespread adoption of Oilfield Produced Water (OPW) for crop irrigation. Semi-structured interviews were conducted with five major stakeholder groups of the OPW: oil and gas managers/ business owners, farmers, entrepreneurs, water district managers, and water board personnel. This study used qualitative data analysis to identify factors influencing the beneficial uses and barriers to reusing OPW. The findings highlighted three macro-categories: water shortages, costs of treatment Vs. the expected benefits, and public perceptions vs. scientific studies based on thematic relevance and coherence. The interviews revealed the need for a tighter collaboration among the various stakeholder groups in this ecosystem that involves public-private partnerships and shared governance in managing the environment—addressing these barriers aids the development of a circular economy for wastewater.

1. Introduction

A linear economy is based on the principles of take-make-use-destroy (Govindan and Hasanagic, 2018). On the other hand, the circular economy is based on reducing-reuse and recycling principles (Genovese et al., 2017). The final nature of natural resources leads to resource efficiency and resource management, where the circular economy becomes essential paradigms in the research of industrial activities (Genovese et al., 2017). The circular economy can serve as a viable solution to the need for long-term sustainable management of natural resources. Rising costs of raw materials, environmental impacts of by-products, and non-sustainable waste management make circularity a logical approach for resource efficiency and resource management (Batista et al., 2018).

Projection of increased water stress and shortage make water management a critical paradigm emerging in the research of industrial activities (European Commission, 2020; UNESCO World Water Assessment Program, 2019; UNESCO, 2017). According to an estimate, by 2030, more than 160 percent of the total available water in the world will be required for global water needs (Lavrnić et al., 2017). The water shortage increases the provisioning and regulatory pressures for industries with high water use, like food industries (UNESCO World Water Assessment Program, 2019).

There are examples of water reuse in agriculture, brewing, and textile (Schaltegger et al., 2012; Hagenvoort et al., 2019; Núñez et al., 2019). However, a widespread adaptation of such practices has not been demonstrated partly due to the requirement for collaboration from regulators and policymakers, business leaders, and consumers. Similarly, a need for technological capacity to roll out these solutions on a broader scale has not been evaluated (UNESCO World Water Assessment Program, 2019).

Since the drought of 2011–2016, the entire state of California has been struggling with freshwater availability, creating tensions between water users across the state (Meng, Chen & Sanders, 2016). A significant source of wastewater in California is oil and gas drilling. However, most of it is disposed of through underground injection, where that water can no longer be accessed nor used (EPA.GOV, 2019). OPW, however, is more complex than seawater. OPW will require multiple steps of treatment to make it suitable for consumption in industry or agriculture. The adaptability of reclaimed OPW is probably a 'chicken and egg' problem. Lack of interest or fear in reclaimed water use has discouraged treatment technologies from being implemented in the US. On the other hand, there is no incentive for oil and gas companies to treat OPW and supply water to neighbors when they can pump it underground. It is coupled with a lack of a regulatory framework to discourage returning OPW to the ground.

With a projected megadrought in California in the coming years, this may be the right time to incentivize reclaiming OPW. It will be easier to choose available reclaimed water to continue agribusiness once faced with a choice of fallow the land or using reclaimed water. In addition, US government efforts to domestically produce critical materials may be one of the vehicles to spur the recovery of OPW as OPW can be a rich source of several materials considered necessary for the hi-tech industry. Furthermore, recovery of critical materials will provide a domestic supply chain, develop infrastructure and subsidize the cost of water treatment.

2. Research Design

This study conducted Twenty-four semi-structured interviews with the different stakeholders in the OPW. To implement projects for using OPW for farming would require collaboration between these stakeholders as public-private partnerships to offset the cost of infrastructure. A qualitative analysis was performed using the most recent version of the NVivo software. After editing each and processing the interview data, each extracted quotation was coded with a unique code linking each quotation to each respondent. The qualitative analysis of the 24 interviews identified three macro-categories that capture the significant stakeholders' perceptions about and factors influencing: water shortage and OPW, barriers to widespread adoption of OPW for crop irrigation, and how to overcome these barriers.

3. Water Shortage And Wastewater Reuse

Extreme climate conditions that result in water shortage are among the most critical challenges facing many countries today (Savchenko, Kecinski, Li & Messer, 2019). Owing to population growth, urbanization, climate change, and the economic prosperity of nations, freshwater suppliers are rapidly dwindling. Different countries have come up with innovative solutions to mitigate their water scarcity issues. For instance, many countries in the Middle East rely on water harvesting from oceans using Reverse Osmosis (RO) systems. These large-scale RO plants produce almost all of the water needed for human consumption – Israel, Saudi Arabia, UAE, etc., have mega RO plants installed capacity and brought the price of potable water down. This is mainly funded by the local governments.

Studies, including that by Environmental Protection Agency (EPA) have been conducted in the past to assess the feasibility of using produced water for beneficial purposes and provide data about its quantity and quality. However, there continues to be a shroud of mystery around using produced water for irrigating crops. Among the factors is the lack of a unified message from the major players (stakeholders) that comprises the oil and gas producers, water districts and water boards, farmers, local community representatives, environmental group representatives, scientists, and academics. The purpose of this study is to achieve a better understanding of the underlying resistance factors for using produced water by conducting semi-structured comprehensive interviews with these different stakeholders.

Several studies investigate the psychological and functional barriers to using recycled wastewater (Rice, Stotts, Wutich, White, Maupin, & Brewis, 2019). In addition, other studies examined factors for their influence on the public and regulatory authorities about the adoption of recycled wastewater, which is not necessarily oilfield-produced water. Those factors include consumer education campaigns (Moon, Bergey, Bove, & Robinson, 2016), information sharing

4. Oilfield Produced Wastewater

Although prior research examined the barriers to using other types of wastewaters, studies investigating opinions and public perceptions about using OPW are scarce. OPW has been used for farming for decades in few water districts of Kern County, which produces 70% of California's oil production (KGET, Sep 23, 2020) but has not seen its widespread use. To unravel the barriers to widespread adoption and the possibility of commoditizing it, the authors conducted interviews to solicit perceptions and opinions of the major stakeholders (which include water districts and state board, oil and gas producers, food producers, entrepreneurs, water professionals, environmentalists, and academics). What strategies would promote the widespread adoption of produced water for irrigation? What are the barriers impeding widespread adoption? What information could assist the general public and other stakeholders within the produced water production/treatment/ distribution/user to effectively promote the reuse of available produced water? The typical assumption is that producers (both food, oil, and gas) are profit-maximizers and choose technologies based on a cost-benefit analysis (Savchenko, Kecinski, Li & Messer, 2019) without due importance to the well-being of consumers, agricultural field workers, or the environment.

The synthesis of the literature is structured in four strands:

1. Water shortages and oilfield produced water.
2. Technologies available to treat oilfield-produced water and their limitations.
3. Use and barriers to use of produced water in irrigation.
4. How to overcome those barriers.

4.1 Water shortages and OPW in Kern County:

With a megadrought being predicted this year in California, and Kern County, identifying alternate water streams has assumed paramount importance in agricultural farming. Although reclaimed water has been identified as a viable option for crop irrigation, the lack of public acceptance for foods grown with reclaimed water remains a significant hurdle. Reclaimed water is generated by treating wastewaters of various types such as industrial, black, gray, brackish, and others. Oilfield Produced Water, which is treated wastewater from oil and gas drilling operations, is a type of reclaimed water. If suitably treated, some of the water shortages could be offset by using reclaimed produced water for agriculture. It can be produced consistently in reasonably large volumes (almost 0.2 million acre-ft of water annually while producing oil per CA DOGGR, 2012). As per the study of CALFLOWS (2017), around 150,000 acre-feet per year (3.4 million barrels/day) of produced water is potentially available for reuse in Kern County. Overall, California is the third-highest oil and gas producing state in the USA, and Kern County has 70% of the oil and gas in California. Kern County is also the top agricultural-producing county in the USA, making it an ideal laboratory for the many scientific challenges at the nexus of agriculture, energy, and water.

4.2 Technologies available to treat oilfield produced water, and their limitations

In general, treatment of OPW for reuse involves the removal of oil and grease, dissolved organics, bacteria, suspended particles, dissolved gas, dissolved salts, contaminants, softening, and so forth. The choice of and different stages of technology depends on the quality of the OPW and the choice of the cheapest technology that could achieve the targeted standards. Depending on the location of oil and gas drilling, the produced water quality varies, and so does the treatment technology and its cost. The characteristics of oilfield-produced water depend on the geological formation and location, the lifetime of the reservoir, and the hydrocarbon produced (Fakhru'l-Razi 2009). Depending on the quality and quantity of produced water, different filtration technologies such as walnut shell media filter, ion exchange, dissolved air flotation, reverse osmosis, and so forth are available as traditional treatment plants, modular or mobile water treatment solutions. As per the Produced Water Report: Regulations, Current Practices, and Research Need by the GWPC (Ground Water Protection Council, 2019), there are various technologies available or are being researched and developed at academic, industrial, and governmental institutions. A comprehensive discussion of various technologies available to treat oilfield-produced water could be found in these literatures (Nasiri et al., 2017; Igunnu & Chen, 2014; Veil, 2011; Arthur, Langhus & Patel, 2005).

To suitably treat oilfield-produced water for reuse in irrigation purposes, the concentration of the different components found in this wastewater must be decreased to the given standard limits. Conventional technologies normally target the removal of dispersed contaminants present in the OPW. This could involve a 3-stage separation method involving hydrocyclone, induced or dissolved gas flotation, and nutshell or multi-media filter for the polishing treatment. However, the conventional technologies do not render the treated OPW suitable for beneficial use outside of the O&G industry. Emerging technologies are targeting the removal of dissolved contaminants in the OPW to seize the opportunity of beneficial use (such as agriculture) for the treated produced water. Removal of the dissolved components such as TDS require evaporative technologies which are energy intensive requiring high maintenance, or reverse osmosis which is sensitive to the presence of oil and oxidants. Removal of dissolved organic compounds involve advanced treatment technologies using UV-oxidation, ozone injection, nano filtration and so forth.

One of the first stages to treat produced water is to remove the dispersed and dissolved oil components. Electrochemical oxidation is frequently used for the removal of organic compounds from the OPW as well as disinfecting and killing microorganisms in this water. After oil removal, if the water contains total dissolved solids (TDS) higher than the prescribed limits for agricultural use, reverse osmosis is used to reduce the TDS values as well as reduction of metalloids such as boron. A technology under development is focused on improving the efficiency of the electro-oxidation technology so that presence of organic contaminants in the OPW could be eliminated, which, in turn, would not foul the membranes of the reverse osmosis reactor, if any.

The treatment facilities are varied – centralized, near-field, or mobile treatment units. re are various treatment facilities. Transporting PW to a large central facility is cost-intensive as constituents of PW may be corrosive and or lack transportation infrastructure. A modular distributed network of water treatment plants can save transportation costs. To offset the high cost of small water treatment plants, a byproduct recovery in critical materials extraction will encourage investment in such technologies. Essential materials demand is increasing, and the hi-tech industry is relying on increased imports to meet such demand. Imports bring about their uncertainties in terms of scheduling, transportation, and geopolitical events.

Extracting critical materials using modular processing units and distributed water treatment facilities seems like a good fit to solve both problems. In a study, M Yang et al. (2018) developed detailed process simulation models for shale gas processing and methanol manufacturing with different scales using raw shale gas extracted from the Marcellus, Eagle Ford, and Bakken shale plays. Techno-economic analyses and environmental impact analyses were conducted for the four shale gas monetization options to systematically compare their economic and ecological performances based on the same conditions. The results show that modular methanol manufacturing is more economically competitive than conventional shale gas processing. Besides, modular methanol manufacturing is better than large-scale methanol manufacturing for raw shale gas produced from distributed, remote wells from economic and environmental perspectives. Transportation costs sometimes offset the cost savings that come from the economy of scale of a large installation. A modular design of a critical material extraction process and a distributed water treatment approach is better financially. It also brings about economic revitalization and job creation benefits to a broader region.

In sum, the treatment of produced water is costly to businesses. However, in the face of severe water scarcity, there is an imminent need to develop new technologies to treat it to levels required for crop irrigation. In addition to the infrastructure requirements' monetary cost, there is an emotional or psychological cost of using produced water for growing foods. The reluctance to use oilfield-produced water could be partially due to the "disgust factor" associated with the use of recycled wastewater, which reflects the risk and image liabilities of water that could contain higher concentrations of hydrocarbons, heavy metals, and other pollutants. It could also be due to cognitive limitations to viewing produced water as a product independent of its origins. Alternatively, it could be due to uncertainties surrounding the long-term economic and social consequences of produced water usage. Therefore, the purpose of this paper is to identify the reasons for resistance to the widespread adoption of produced water in the California agricultural sector.

4.3 Barriers to use oilfield produced water:

Rogers (2003) outlined four types of risk barriers or resistance to adopt to any product innovation across industries (Korjonen-Kuusipuro et al., 2017; Kuisma, Laukkanen & Hiltunen, 2007) as shown on Fig. 2 and described in detail below:

4.3.1 Psychological Barrier.

This has to deal with a product's incompatibility with consumers' perception of practices or habits. For example, "oi1 is for machines; food is for people." Research has shown three antecedents that drive consumer rejection of foods grown using any reclaimed water. These are disgust, neophobia, and safety concerns (Savchenko et al., 2019). The policy literature has found that owing to disgust, most people prefer reuse of reclaimed water (not necessarily produced water) for activities that involve little or no human contact (Lease et al., 2014; Kecinski & Messer, 2018). Neophobia is associated with the fear of trying new foods such as genetically modified foods (Townsend 2006). Safety concerns can be another barrier to the use of produced water for irrigating crops. For instance, consumers' aversion to purchasing potato chips and French fries decreased after rumors spread that these could contain a carcinogenic compound (McFadden & Huffman, 2017). These concerns play a critical role for products that are directly ingested, such as various foods and beverages. These fears could be exacerbated by media or environmentalist groups (e.g., negative backlash following LA Times 2015 news reporting of Chevron's use of produced water for beneficial uses. Trust in food safety and producing various foods can play an essential role in consumers' purchase decisions. A study by Fielding et al. (2015) found that trust in authorities such as government agencies was positively correlated to the acceptance of reclaimed water for potable and non-potable uses.

4.3.2 Value or Economic Barrier.

This has to deal with a product's inability to produce economic- or performance-based benefits. For example, what is the cost-benefit analysis for using produced water for widespread irrigation of crops? OPW production volume in the USA ranges from 7–10 barrels per 1 barrel of oil. In California, it is 5–40 barrels per barrel of oil depending on the location and age of the site. Actions required to maximize the opportunities for beneficial use of OPW are: laws and regulations at the state level that support the beneficial reuse of OPW; improvements in cost-effective technologies to treat OPW to increase feasibility of OPW reuse; entities such as food producers interest to accept the treated OPW; increased transparency for improved relationships amongst various stakeholders in the OPW ecosystem. OPW is considered as a "non-revenue" fluid with treatment costs ranging from $0.05 to .0.30/ barrel and could rise to $5 per barrel if truck transportation is involved. The facilities cost ranges from anywhere between $100–500 per daily barrel of treatment capacity (SPEC Services, Inc.). Any value that could be derived is post-treatment and its suitability for beneficial uses such as irrigation.

4.3.3 Physical Risk Barrier.

This deals with any physical damage that the usage of a product might cause. In the case of produced water use in farming, the risk is that contaminants in the water might hurt the crops, the soil quality and hurt the people who eat those crops.

4.3.4 Social Risk Barriers

to innovative adoption of produced water might have to deal with long-term increases in the willingness of agricultural producers and regulators to "blur the lines" between mineral products and edible products in society.

In reclaimed water, including produced water, the perceived risks of *both* farmers and consumers are essential. There is no point in farmers growing crops using produced water if the produce is not going to be bought by the consumers and vice versa — consumers cannot buy food products that farmers refuse to cultivate (Po et al., 2005; Menegaki et a1., 2007).

5. Methodology

5.1 Study Design

The study method resembles a case study. It focuses on a contemporary event of using produced water in Kern County while seeking to understand the barriers to its widespread adoption for crop irrigation and what could be done to overcome these barriers. A literature review using the words "recycled water," "reclaimed water," "produced water," and "food production," "beneficial uses," "barriers" have been conducted to determine the availability of research about beneficial uses of OPW and public reluctance thereof. The selection process did yield relevant articles dealing with various types of wastewater, but not necessarily oilfield-produced water.

5.2 Study Participants

The respondents were selected based on purposive sampling (Oliver, 2006). Twenty-six key individuals were selected based on the major stakeholder groups of produced water usage for agricultural irrigation. These groups were: oil and gas producers, farmers, and local community representatives/general entrepreneurs. Several of the respondents were attendees of the Water Conference held at CSUB in February 2020. The respondents were initially contacted through email with the consent form and purpose of the study sent to them. Following is the respondent category and their organization:

- O&G Managers in established companies 5

- O&G Business Owners 1
- Water District Managers, Water Board 5
- Food Producers/ Ag industry 4
- Water Resource Managers/Experts/Consultants 5

Entrepreneurs 4 *5.3 Data Collection*

The data was gathered through twenty-six video interviews given COVID-19 social distancing requirements in Bakersfield. The interviews were semi-structured, using open-ended questions to allow the participants to elaborate on the subject matter as they perceive them. Five broad interview questionnaires were developed with slightly different questions for the five major stakeholder groups in the OPW. The ecosystem is a public-private partnership endeavor and requires entrepreneurial motivations and insights of ‘collective entrepreneurship.’ The interview guides were pilot tested and refined in several stages to estimate the interview questions' length, pacing, and comprehensibility. The interviews lasted from 30–45 minutes, depending on each individual and their responses. Follow-up questions were asked as and when necessary. The interviews were digitally recorded via Zoom and transcribed using Otter.ai transcribing software. The authors manually edited the interviews in the NVivo software, which was used for qualitatively analyzing the interviews and identifying the main themes and patterns.

5.4 Content Analysis

A qualitative analysis was performed using the most recent version of the NVivo software. After editing and processing the interview data, each extracted quotation was coded with a unique code linking each quotation to each respondent. The qualitative analysis of the 26 interviews identified three macro-categories that capture the stakeholders’ perceptions about and factors influencing: water shortage, OPW, barriers to widespread usage of OPW for crop irrigation, and how these barriers could be overcome. In addition, several micro categories (or sub-codes) of importance within each macro category were identified that aligned with the themes of relevance.

The following discussion presents the macro and micro categories of importance that emerged from the interviews conducted on oilfield-produced water and treatment technology.

5.5 Ethical Considerations

At the onset of the interviews, the respondents were once again briefed about the purpose of the interview, the strict confidentiality of their responses, and their signature on the informed consent form as required by the CSUB’s IRB (Institutional Review Board), which duly approved this study.

6. Results And Discussion

The study revealed that there are only three water districts in Kern County that support produced water programs. In the current model, the oil and gas companies (the larger established ones) treat the produced water generated at the site and sell it to their respective water district. The district facility blends the produced water with fresh water and puts the blend into the canal from where the farmers tap their requirements. The usage of produced water depends on drought conditions. E.g., in a wet year like 2017, there was little requirement for the farmers to use OPW as freshwater was readily and cheaply available. This ecosystem for using produced water to use in irrigation exists only on the east side of Kern County, where the quality of produced water is good, to begin with, regards to the salt content such that its treatment at the oil site is not prohibitive. In contrast, the produced water quality on the West side of Kern is not good.

6.1 Barriers to widespread adoption of OPW

To develop a circular framework involving wastewater use in practice, a full range of opportunities, drivers, and barriers can be identified. The following sections discuss and barriers to the successful implementation of oilfield water reuse and the possibilities for extending these techniques towards a circular economy.

6.1.1 Economic, Financial and Legal Drivers and Barriers

Kirchherr et al. (2018) highlight how technological feasibility can be a driver and prerequisite for transitioning the circular economy. Nevertheless, other factors, including economic and regulatory barriers, hampering circular economy transition. Economic barriers include long-term economic viability and short-term financial barriers (Ormazabal et al. 2018; Ranta et al. 2018). Upfront investment costs and capital-intensive infrastructure can deter potential first movers in wastewater use, especially when freshwater sources are cheaper than reusing wastewater. Therefore, in addition to financial viability, a successful transition towards the circular use of water needs to consider the long-term economic feasibility of deploying circular economy practices (Ruiz-Rosa, 2020).

Political and regulatory feasibility involving wastewater use can act as drivers and barriers to hampering circular water use. Small firms can be incentivized to enact circular activities in response to a favorable legal requirement (Ormazabal et al. 2018). In addition, well-designed regulations can be used as drivers to address environmental and social challenges that could arise from promoting wastewater reuse. However, the lack of supportive policy framework, over regulations, and poorly developed legal frameworks can impede the uptake of wastewater use Ranta et al. 2018).

6.1.2 Existing and Future Technologies

The main concerns that emerged across the stakeholder groups are: capital-intensive infrastructure (treatment plants, pipelines, storage etc.) required to treat especially desalinate produced water and then to distribute it, handling of the brine and wastes generated, high variations in produced water quality that demands differing technologies to be reasonably cost-effective, moratorium against oil drilling in Kern County such as to render produced water insignificant as an alternative water source (given that the available produced water could meet around 5% only of the farmers’ total water needs).

One manager of a prominent O&G company opined that one way to commoditize produced water is to have an aggregator to create scale for all oil companies to participate and ensure a large volume of produced water at a certain specification using a suitable technology. From this common source, put infrastructure in place to convey and distribute the treated waters. Another way is to install technology that is flexible which can handle smaller amounts of produced water as well as fluctuation of produced water quality. This could be done by selling the new technology to individual facilities. The new technology under development promises low maintenance costs which seem to be a favorable value proposition to few water professional

interviewees. But, again the distribution from this point onwards needs to be figured out. Irrespective of the business model adopted, both the treatment especially desalination (effluent management) and distribution costs are exorbitantly high. Without public funding, it may not be feasible for oil companies to bear the costs and scale.

These limitations are associated with technology and infrastructure that involves questions pertaining to scalability of such a massive public-private venture, and safe disposal of the waste (mostly brine) generated.

6.1.3 Public Perception and Psychological barriers

Figure 3 highlighted four psychological barriers including, fear, disgust, safety concerns, trust about the use of produced water that is directly or indirectly consumed. The interviews revealed that there are surprisingly few psychological barriers to using produced water among the famers and regulators. Their main concern is the availability of suitably treated produced water that they could buy from the oil and gas companies at a reasonable cost. In contrast, the same is not true for the general public and other stakeholders who harbor an overall mistrust of the oil and gas companies. People increasingly see these oil and gas businesses as pursuing profits at the cost of social and environmental well-being (see Fig. 3). Few respondents opined that there needs to be greater trust and transparency amongst the various stakeholders such that the well-being of consumers, agricultural field workers, communities living in close proximity to oil production facilities, and the environment are all taken into consideration.

A respondent who is into certification of organic farming and one from an environmental group felt that the health risk is not limited to the end consumer who eats the produce grown with produced water. The risks are greater for the field/farm workers and communities living in close proximity to wherever the produced water is handled, stored, treated or transported. For instance, the agricultural field workers might potentially be exposed through dermal contact and/or inhalation of volatile compounds present in the OPW that can pose both short- and long-term health risk depending on the exposure to known and unknown contaminants present in produced water. One of the experts also commented:

the pre-treatment of the produced water has to be adequate. Merely mixing one part of produced water to three parts of freshwater (as is currently being done in some water districts of California) is not sufficient.

This expert said that during the drought years from 2011 to 2016, there were rumors that this ratio was not maintained owing to lack of fresh water supply. In addition, the participant felt that the pre-treatment, especially of hydrocarbons by running the wastewater over crushed walnut shells to skim it off, is probably not sufficient.

Both the respondents also reminded the potential risk to the environment centered around produced water. On one hand, augmentation of fresh water sources by alternative sources such as produced water looks desirable while on the other, they felt that the flow of produced waters should be seen as declining as oil drilling in the state slows down and the state eventually get out of oil and gas production. They opined that given the extreme climate changes and the risks posed by fossil fuel production to the safety of the environment, the future of long-term benefits of using produced water seems bleak and may not deserve much attention.

With regards to the end consumer, the interviews revealed that the general public's psychological barrier might be the biggest hurdle to widespread adoption of PW for farming. Few interviewees commented on the attention span of people today: one of the water district managers who use produced water mentions that the attention span of the general public has reduced to a three- or five-second sound bites. While referring to oilfield produced water, if they hear the environmental groups lobbying against "toxic frack water," they stop listening further and form an opinion or judgement. Another water district manager, who uses produced water and is a big believer of the PW as an alternate water resource, mentioned the news made by one of the prominent oil companies in LA Times (2015) when the said oil company started treating their produced waters and selling the treated produced water to farmers. There was a huge backlash and generated questions about food safety and risk for the produce that was irrigated and grown using produced water.

Several participants felt that consumers are generally unaware about how the foods that they consume were grown, especially those imported from other countries. Their attention is caught only when there is news on the media or when environmentalist groups voice out safety and risk concerns about using reclaimed waters for food production. The respondents opined that as long as water requirements meet the standards for crop irrigation, there is not a need to announce the source of water. However, transparency needs to be maintained among the various stakeholder groups in the produced water about monitoring plans, test results, blending procedures during drought and wet years and so forth and readiness to make these public if required.

Another trait that was revealed is trust (or lack of) of the general consumer that seem to be broken by the oil companies: two interviewees commented that people normally do not trust the oil companies and they feel that they are a lot of secrecy, say, about the chemicals the oil companies use to handle and treat the produced water despite extensive testing for contaminants.

6.2 How could these barriers be overcome?

The following sections discuss this study's findings regarding ways to overcome potential barriers to the successful implementation of water reuse and the possibilities for extending these techniques towards a circular economy.

6.2.1 Psychological barriers

The main question that arises is how much do the public need to know about the water sources used to grow their foods? Is it required? If yes, is it through public awareness and

education rather than through media and/or environmental groups? (Fig. 4) The main users of oilfield produced water, namely, food producers are adequately informed about the subject and can dictate the exact water requirements and specifications to their respective water districts. However, as already discussed, the same is not true for the common people or consumers. One of the Water District Manager said:

The same is not true for the general public who tend to go by short sound bites. Further, the consumers (who consume the produce or products grown using produced water) need not know the source of water once the water has met the standard requirements of the Central Valley Water Quality Board. However, when there is a media report or an environmentalist group takes up the issue, the general public gets easily swayed by the negative publicity about consuming products grown using oilfield water.

Research and scientific studies conducted by the water districts, oil companies, and independent assessors in the last several years show no red flags when it comes to the safety risk of consuming food products grown using suitably treated produced water. For instance, the Cawelo water district has been providing blended water to ~ 150 farmers since 1995. The monitoring and testing standards are stringent to ensure that water meets the quality requirements for irrigating the specific crops. Despite all of these, the media, environmentalists, and the general public are not convinced about the safe use of oilfield produced water. The need is to prevent sensationalism by the media by creating a unified voice about produced water usage. Given the long-standing nature of Kern’s existing produced water programs, there needs to be tighter integration and collaboration among the water districts and other players: oil and gas producers, farmers, local community representatives, environmental group representatives, public health experts, and academics. This is already initiated by bringing together all stakeholders under the auspices of a food and safety risk panel, like the one organized by the Central Valley Regional Water Quality Control Board. The findings revealed that the various stakeholders are both recipients and co-creators of value in a joint value creation process that supports a business model for sustainability.

Further awareness could be created through, say, town hall meetings in farming communities in the Central Valley. On the consumer side, launch a transparency initiative and publish the testing results after the produced water has gone through the suitable treatment processes. An interviewee associated with organic farming certification commented that although there seems to be a collective agreement by the oil and gas producers, the ag industry, and the water board on the best practices on producing clean produced water, there still seems to be a shroud of mystery when it comes to getting straight forward and a unified message from these stakeholders about produced water and its suitability for farming and other beneficial uses. This has resulted in general distrust amongst individuals when it comes to the question of putting more amounts of treated produced water to beneficial uses. This closely ties in with the concern that after decades of research and monitoring on oilfield produced water, we still lack solid and standardized remedial protocols.

6.2.2 Shared Value in a Circular Economy

Companies in both the two major industries involved, namely, the oil and gas industry, and the agriculture industry must revisit their 'shared value' mission which is about solving societal problems in order to create economic value (Porter & Kramer, 2019. The diminished trust in business might lead to policies that are unfavorable to the business's profitability and competitiveness, thereby, resulting in a vicious circle (Porter & Kramer, 2019). Few glaring examples are depletion of natural resources, water shortages, customers well-being, and so forth (Long, Blok & Coninx, 2019). The business has to act in a way that can take societal issues to a strategic level to create economic value, which underlies the concept of shared value popularized by Michael Porter, a world-renowned business strategist (Porter & Kramer, 2006, 2011). Many oil companies are already doing it and might require leaders and managers to acquire new skills and knowledge to engage in these activities in collaboration with profit/non-profit boundaries and a unified message to the general public, media, and environmentalists.

The concept of a circular economy business model needs to be accepted where the focus is on two important issues. One is the collection and treatment of the oilfield produced water for distribution to food producers; the other being recovering valuable resources such as critical materials and rare earths from the produced water. This would provide a new way of looking at the different stakeholders while minimizing the amount of virgin resources (freshwater) that are extracted or imported at high prices from abroad (rare earths and critical materials).

6.2.3 Economic Barriers-Costs Versus Benefits

As already discussed, the amount of produced water generated versus the farm irrigation requirement is minimal, about 5%. However, an entrepreneur in the energy sector emphasized that after crunching all the numbers, there remains a big difference between the costs of treating the water and what a farmer could afford to pay for the water.

In addition, the Westside would require massive capital investments and public-private partnerships if regular treatment and distribution of produced water is to see the light of the day. A topwater professional voiced the opinion in our seaway. He believes currently, water is affordable, and the percentage of available produced water compared to the water needs of the farmers is relatively small. Very few customers' (e.g., farmers) willing to buy produced water for irrigating their crops unless the economics of water change or until we get to the point where water is consistent $1300/acre-foot. He further added, "*There is still a lot of applicability for process plants and process facilities, and a lot of applications for high recovery technology in those types of operations, but we just didn't get to the point where we can* *have enough meaningful solutions to provide customers with the decision that gave the customers the willingness to buy it."*

Another participant in the ag fresh produce industry voiced the same opinions and questioned the value proposition for farmers in using treated produced water if it could not be provided at a reasonable cost. Within the Central Valley, there are still areas where fresh water is available for $27/ acre foot of water, while in other regions the cost varies between $60–200 / acre foot of water. However, with the existing treatment technology for produced water, the costs are anywhere between $900–1200/acre foot of water in addition the other hassles of dealing with reclaimed waters. The participant opined that unless the cost and dynamics of water availability changes drastically, food producers would be unwilling to use treated produced water for irrigating their crops.

The opinions of both the above participants reveal that produced water treatment to make the water suitable for irrigation purposes is very expensive, and there needs to be supplementary

beneficial uses (such as extraction of critical materials and rare earths form the OPW so as to make the final recycled product mor cost-effective to the farmers.

As Fig. 5 shows, capital costs primarily include the cost of infrastructure needed that currently does not exist, such as pipelines and treatment plants, that would need to exist for commoditization of produced water for irrigation and /or municipal purposes across Kern County. A manager working in a prominent oil and gas company commented on the infrastructure as:

Using produced water for irrigation is not always a simple thing of, hey, I have this extra water. You want to put it in your pistachio trees. The infrastructure piece behind it is massive. I mean, the water flows through an eight-mile 42-inch diameter pipeline, reaches to fairly large retention basins that is then sent into an extensive canal system to get to the end crop users.

An expert in oil and water separation echoed the above by saying that for treating, say, 5000 barrels/day of OPW, the cost could range between $1 Million to $5 Million.

Benefits of using produced water for irrigation does have a positive impact on the environment as a supplement to freshwater sources, and to charge the ground water through irrigation of the agricultural fields. As one participant puts this together as:

Kern County is a significant breadbasket of agricultural productivity and the other alternatives of bringing water into the region are substantially more expensive and provide no significant benefit. I would focus on the low hanging fruit and technology that is readily available to do every form of contaminant removal.

A reasonably priced technology could certainly be a *business opportunity* to water professionals who could collaborate with the oil & gas (O&G) companies and the Water Districts to treat and distribute produced water to farmers. One caveat is that the treatment costs depend on the location and subsequent quality of the produced water. For example, East Kern produces high quality produced water and 300,000-800,000 barrels of such high quality OPW could be easily treated very cheaply, say, for 5 cents a barrel. This would not be true, however, for West Kern where the quality of OPW is bad and larger R.O water treatment facilities would be required to make the economics work.

Another model suggested by an energy entrepreneur is to install pipelines to transport the poor quality OPW of West Kern to East Kern and use this in the oilfields for water flood and stea flood. Similarly, transport high quality produced water from the Eastern side and use it for beneficial reuse such as crop irrigation after minimal treatment. This model might be more cost-effective than trying to make potable water out of the high-saline OPW on the West side of the Valley. This would also mitigate another significant concern of treating and disposing off the wastes (mainly brine and/or oil and grease) generated. An O&G business owner who has treated produced water at site and is in favor of more extensive produced water programs said that already small– and medium-size enterprises in the oil sector are already incurring high utility costs to handle the produced water. However, as this respondent and several others pointed out, the major cost to any new technology would be the brine management.

7. Discussion And Future Research Directions

The current study that involved twenty-six qualitative interviews with the major stakeholders in the oilfield produced water (that involves two separate industries of Kern – O&G and ag) revealed findings that demand further actions. Additional data could be collected through detailed survey instruments, One, a needs assessment survey to gather the needs of oilfield produced water in farming, and second, a consumer survey to capture the public perceptions of reclaimed water (including OPW) and consumer preferences for its usages. The findings of both the surveys are expected to reveal the future utilization potential of OPW and subsequent commercialization potential of technology through a cost-benefit analysis.

8. Conclusions

Respondents agreed that the extreme climate conditions, droughts and severe water shortages could result which might necessitate commoditizing any alternative water source. In order for that to happen oil companies must take the lead to bring business and society together again. The company's "corporate social responsibility" mindset may still be at the periphery, and not at the core. The solution might lie at revisiting and refining their shared value by addressing these societal and environmental issues at a strategic level. In addition, all stakeholders in the produced water including regulatory and government, entrepreneurs, oil and gas producers, food producers, media and environmentalists need to come together to partner and collaborate on such a project.

Declarations

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Figures

Figure 1

Barriers in Implementation of Wastewater Reuse

(Dev, Shankar, & Swami, 2019), and psychological factors (Mukherjee & Jensen, 2020) (Figure-1).

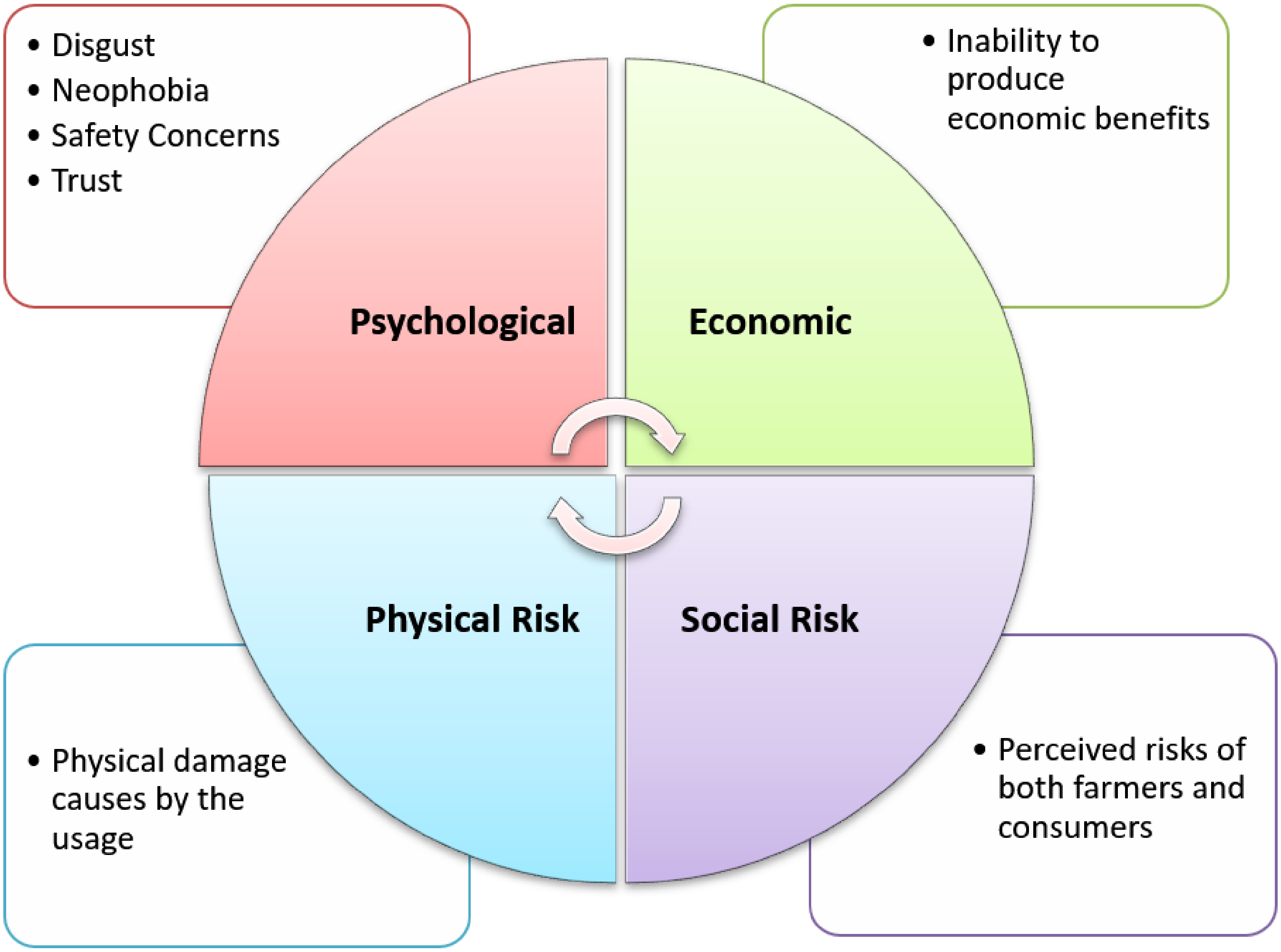

Figure 2

Barriers to Oilfield Wastewater Reuse

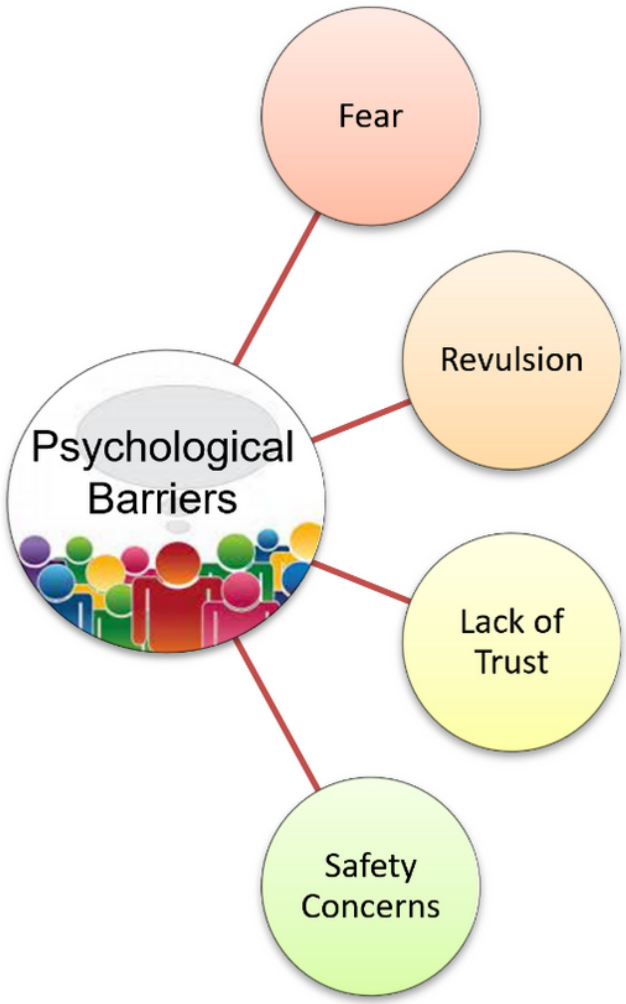

Figure 3

Psychological Barriers Revealed by Interviewees

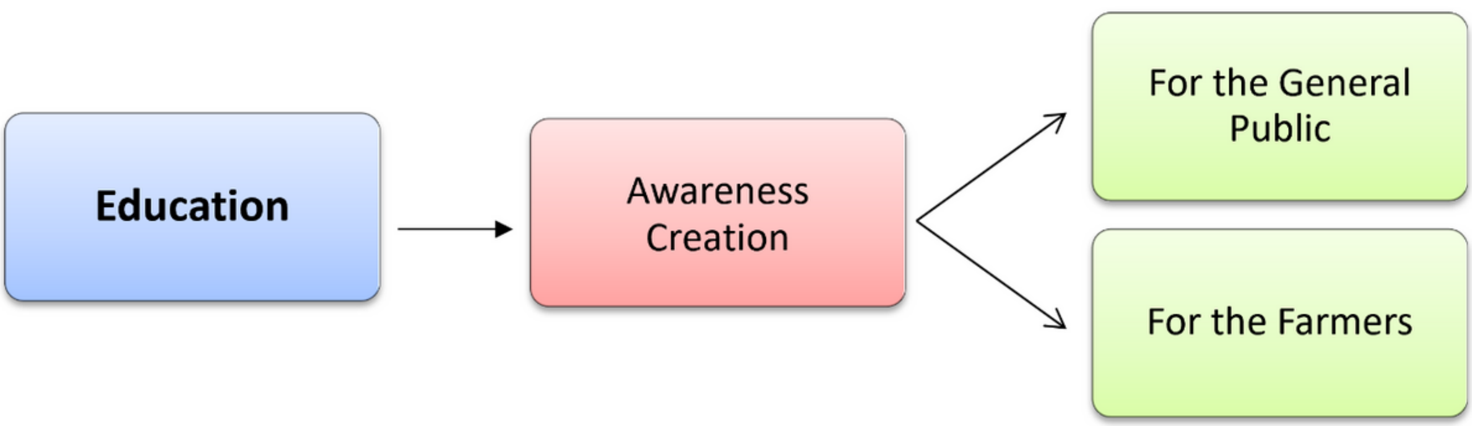

Figure 4

Education to Overcome Psychological Barriers

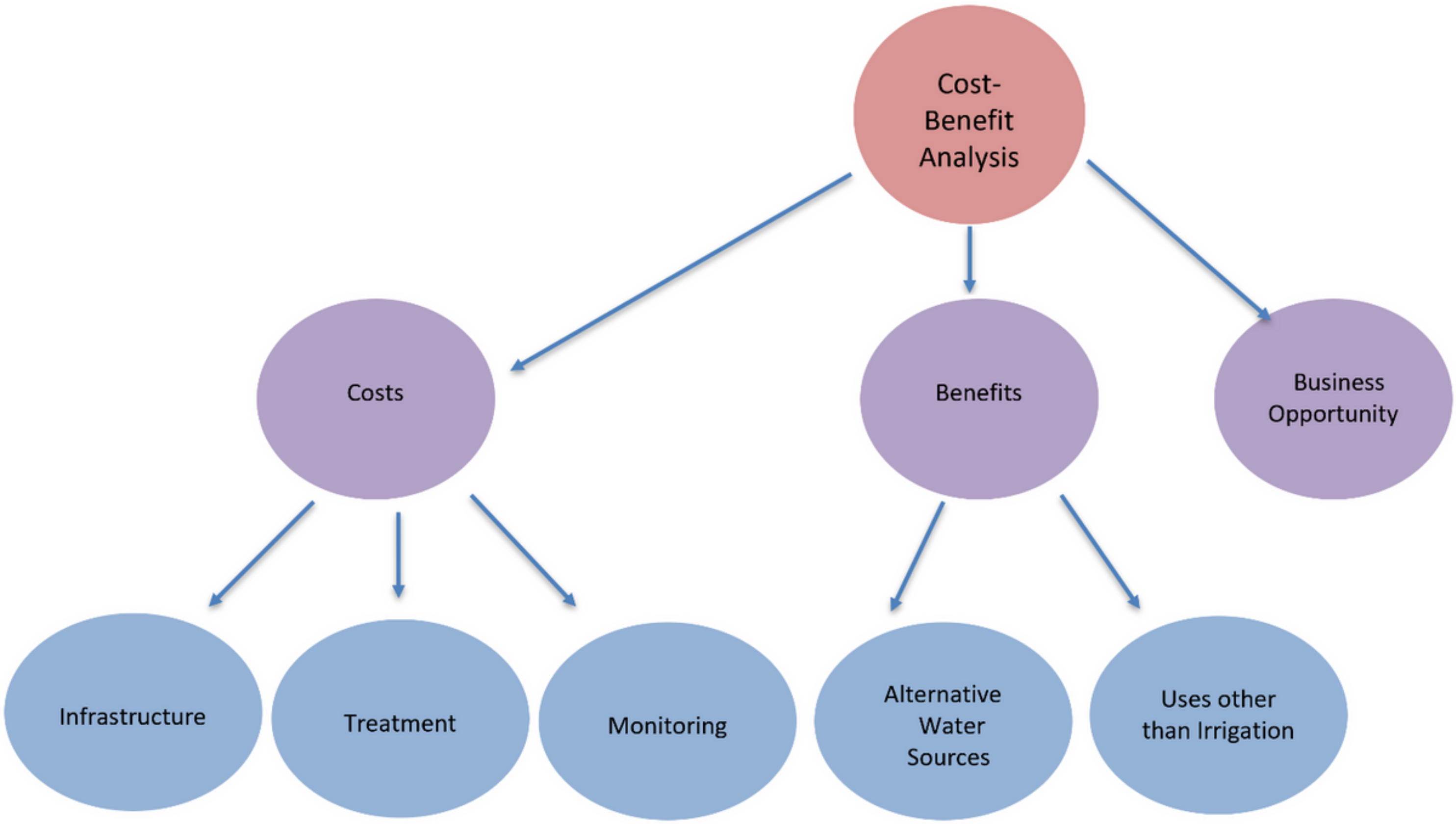

Figure 5

Cost-Benefits Diagram