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LETTER

Environmental risks and opportunities of orphaned oil and gas wells in the United States

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Supplementary material for this article is available online

Abstract

Hundreds of thousands of documented and undocumented orphaned oil and gas wells exist in the United States (U.S.). These wells have the potential to contaminate water supplies, degrade ecosystems, and emit methane and other air pollutants. Thus, orphaned wells present risks to climate stability and to environmental and human health, which can be reduced by plugging. To quantify environmental risks and opportunities of well plugging at the national level, we analyze data on 81 857 documented orphaned wells across the U.S. We find that >4.6 million people live within 1 km of a documented orphaned well. 35% of the documented orphaned wells are located within 1 km of a domestic groundwater well, yet only 8% of the wells have groundwater quality data within a 1 km radius. Methane emissions from the documented orphaned wells represent approximately 3%–6% of total U.S. methane emissions from abandoned oil and gas wells, but this estimate is based on measurements at <0.03% of U.S. abandoned wells. 91% of the documented orphaned wells overlie formations favorable for geologic storage of carbon dioxide and hydrogen, meaning that orphaned well plugging can reduce leakage risks from future storage projects. Finally, we estimate plugging costs for documented orphaned wells to exceed the $4.7 billion federal funding by 30%–80%, emphasizing the importance of prioritizing federal spending on wells with large remediation benefits. Overall, environmental monitoring data are not extensive enough to quantify risks, especially those related to air and water quality and human health. Plugging orphaned wells can provide opportunities for geologic storage of carbon dioxide and hydrogen and geothermal energy development, thereby facilitating efforts to transition to net-zero energy systems. Our analysis on environmental risks and opportunities of orphaned wells provides a framework that can be used to manage the millions of documented and undocumented orphaned wells in the U.S. and abroad.

1. Introduction

Abandoned (i.e. temporarily or permanently inactive or idle) oil and gas wells that are unplugged can contribute to air and water quality degradation, and greenhouse gas emissions (primarily in the form of methane), posing risks to ecosystem and human health (figure 1). One approach to reduce climate and environmental risks is to plug, or more broadly to seal, remediate, and reclaim, unplugged wells. Due to the 160 year history of oil and gas development [1, 2], the high costs of plugging [3, 4] and the underfunding of state programs responsible for ensuring remediation of this legacy infrastructure [5], many abandoned wells in the United States (U.S.) remain unplugged. A subset of abandoned wells, known as orphaned wells that include both known (‘documented’) and unknown (‘undocumented’) wells, lack a financially responsible party [6–8], placing the financial burden associated with plugging on the government, and thus, the tax-paying general public. Addressing environmental risks through well plugging creates jobs [6], allows for repurposing land for other developmental uses, and facilitates subsurface energy production and storage operations. In November 2021, the Infrastructure Investment and Jobs Act was signed into law creating the Bipartisan Infrastructure Law (BIL), and $4.7 billion USD was allocated to plug orphaned oil and gas wells across the U.S. This federal funding provides an unprecedented opportunity to address the climate and environmental risks posed by orphaned oil and gas wells, while stimulating the economy and creating jobs.

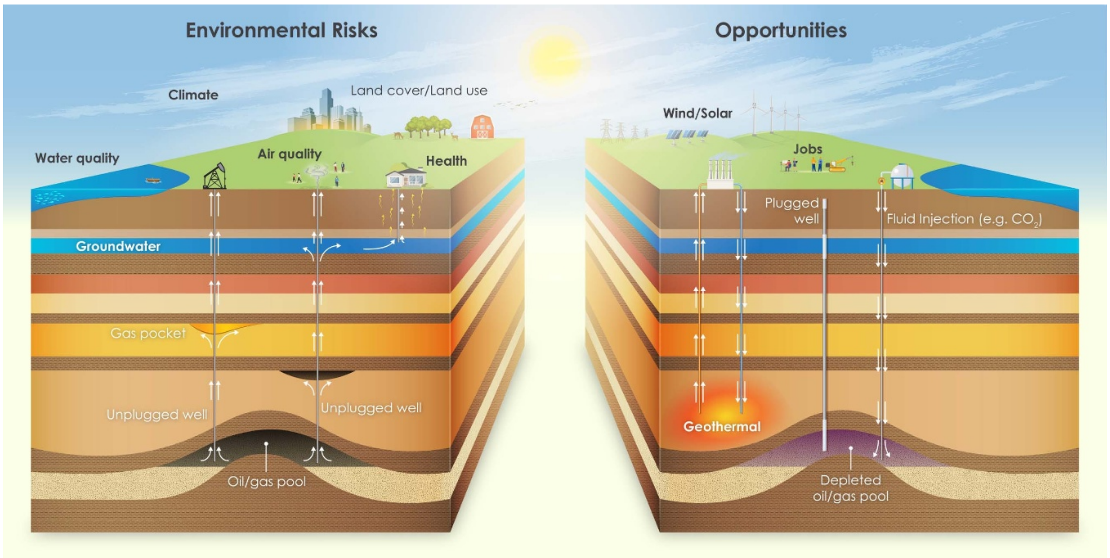
Addressing environmental risks and quantifying opportunities of orphaned oil and gas wells are hindered by the limited capacity of many government agencies to document where orphaned wells are located and their physical (e.g. depth, well construction and emission rates) and contextual (e.g. proximity to human populations and groundwater) attributes. Oil and gas wells not located on federal lands or Tribal Lands are regulated at the state level. Thus, the documentation of orphaned wells has been left primarily to the states and federal agencies (e.g. the United States Bureau of Land Management) [7, 8]. Although some Tribes may be documenting orphaned wells, data from Tribes remain unavailable. Recently, the locations and attributes of documented orphaned wells across the U.S. verified by states as eligible for federal funding were compiled [9, 10]. Given the water quality, air pollution, and climate risks posed by orphaned oil and gas wells and the potential opportunities that extend to economies (see figure 1), spatial analyses of these orphaned oil and gas well locations and their physical and contextual attributes, paired with environmental monitoring, natural resource, and other available datasets are needed.

The objective of this paper is to conjunctively analyze documented orphaned oil and gas well data (figure 2) and available socioeconomic, environmental, and natural resource data to inform U.S.-wide assessments of environmental risks and opportunities associated with all orphaned wells (figure 1). In terms of environmental risks, we consider demographics, domestic groundwater production well locations, groundwater and surface water quality data, methane emissions, non-methane air pollutant emissions (benzene), and health and environmental studies to the extent that data is available. We then compare locations of the documented orphaned wells with maps categorizing renewable energy potential (enhanced geothermal, wind, and solar) and formations valuable for geologic storage. Finally, we combine the well attribute data with a model to estimate plugging costs [3] and approximate the number of jobs that could be created directly by the orphaned well plugging work made possible by the BIL. Our results can be useful for prioritizing the $4.7 billion federal spending, for developing studies to quantify benefits of the BIL, and for managing the millions of documented and undocumented orphaned wells that exist across the U.S. and internationally.

2. Data

2.1. Documented orphaned oil and gas wells

We used location, type, depth, and last production date of the 81 857 documented orphaned wells compiled from both state and proprietary databases and quality controlled in [9]. Of the 81 857 documented wells, location information is available for 78 685 wells (96%) (figure 2), which we used for the proximity analyses. For wells with locations available from both public and proprietary sources, we compared their locations and found discrepancies to be less than 1 km for 90% of the wells (table S2). However, we note that in one study focused on eastern Oklahoma, field-verified well locations differed from the state databases by ~1.0 km on average [11]. We used the full dataset (81 857 wells) for methane emission estimates and plugging costs and job creation estimates. Well type, well depth, and last production date information is available for 83%, 49%, and 16% of the documented orphaned wells in our database (table S1).



Climate	Methane emissions (Fig. 3d)
Groundwater	Groundwater production well locations (Fig. 3b)
Water quality	Surface water and groundwater quality data availability (Fig. 3c)
Air quality	Methane emissions and benzene data (Fig. 3d and 3e)
Health	Potential exposures and health outcomes

Geothermal	Enhanced geothermal system favorability (Fig. 4a)
Geologic storage	CO_2, hydrogen, natural gas, etc. (Fig. 4b)
Wind/Solar	Wind/solar capacities (Fig. 4c and 4d)
Jobs	Directly related to plugging

Figure 1. Schematic of potential environmental risks (left) and opportunities (right) associated with plugging orphaned wells. The lists at the bottom show the environmental risks (climate, surface water quality, groundwater, air quality, and health) and opportunities (wind/solar, geothermal, geologic storage, and jobs) analyzed in this paper. The bolded words in the schematic correspond to the bolded words in the two lists at the bottom, which are followed by more detailed description of what is analyzed in this paper with references to the corresponding figures. Schematic courtesy of the U.S. National Energy Technology Laboratory.

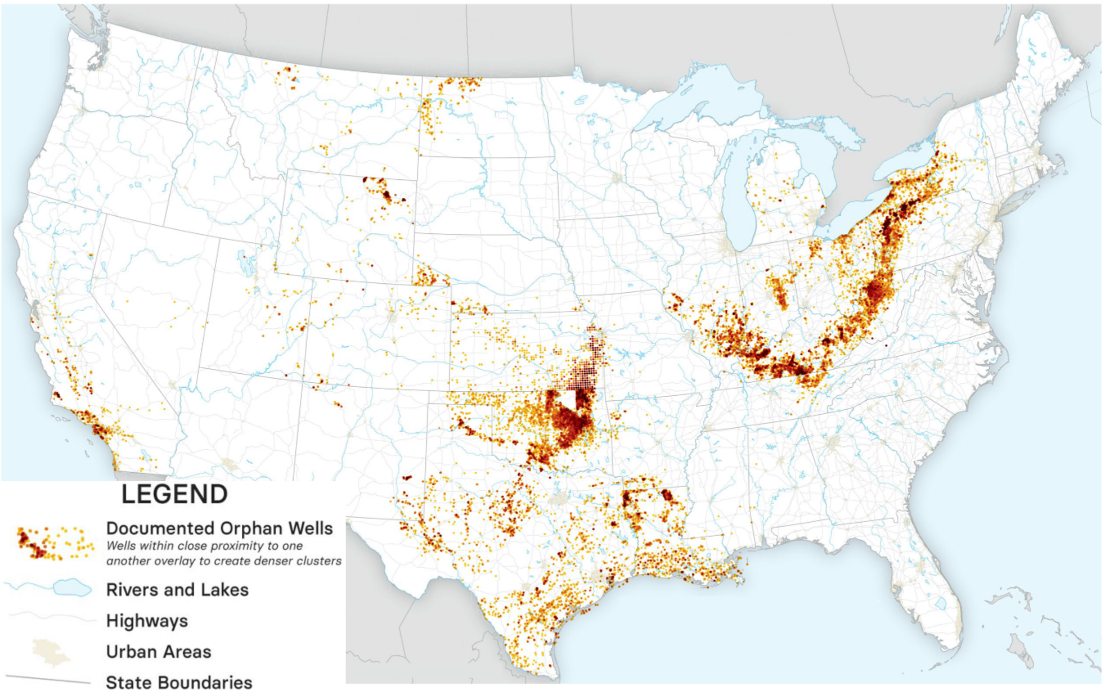


Figure 2. Map of 78 685 documented orphaned oil and gas wells with location information across the U.S. as of September 2021 [9] (left) (table S1). Data: Environmental Defense Fund and McGill University; Cartography by Nick Trotter and Alan Bucknam/Notchcode Creative.

We used these well attribute data in the plugging cost estimates. Additional details are provided in the SM.

2.2. Environmental risks: demographics, groundwater production wells, methane emissions, water quality data, and health studies

We used the demographics data compiled in [12] and the groundwater production well data compiled in [13]. Specific conductance measurements of both surface water and groundwater samples collected in the contiguous U.S. from 1920 to 2022 were downloaded from the Water Quality Portal [14]. For estimates of methane emissions from documented orphaned wells, we used emission factors and the five scenarios from [15], which are based on well type (gas wells or oil/combined oil and gas wells), plugging status, and geographical location. For demographics, groundwater production well data, and water quality data availability assessments, we used a 1 km radius as a proximity metric [16–19]. We note that this 1 km distance may not be a sufficient surrogate for all environmental risks, however the epidemiological literature suggests that adverse perinatal and respiratory outcomes are observed out to 1 km and sometimes further [19]. Additional details are provided in the SM.

2.3. Opportunities: subsurface formations and plugging costs

For enhanced geothermal system favorability, we used the U.S.-wide shapefile created by the National Renewable Energy Laboratory (NREL) [20]. For saline aquifers, oil and gas fields, coal, unmineable coals, and basalt formations, we acquired shapefiles from the U.S. Department of Energy Carbon Storage Atlas [21]. Locations of U.S. shale plays were gathered from the U.S. Energy Information Administration [22] and locations of U.S. salt deposits and hard rock outcroppings were from [23]. For solar and wind capacities, we used shapefiles created by NREL [24, 25]. These shapefiles were spatially joined with the orphaned well data and the numbers of wells overlying each formation/capacity area were summed to determine the overlap between orphaned wells and valuable geologic formations/renewable energy capacity in the U.S. To estimate plugging costs, we used a model developed in [3]. We used the plugging costs to estimate the number of direct jobs created using two approaches [6, 26]. Additional details are provided in the SM.

3. Results

3.1. Environmental risks

3.1.1. Demographics

People living near some orphaned wells may be exposed to their methane and other gas emissions and subsurface fluids leaking to groundwater and/or soils. To estimate the number of people and demographics of those living in close proximity to orphaned wells, we conducted a geospatial analysis within 1 km of documented orphaned wells in the U.S. (figures 3(a) and S1–S2 and tables S3–S6). At least 4.6 million people live within 1 km of at least one documented orphaned well (figures 3(a) and S2). Of these, 3.2 million are Caucasian, 1.2 million are Hispanic/Latino, 450 000 are African American, 470 000 are Asian Americans and Pacific Islanders, and 120 000 are Native American/Alaskan Natives. Hispanic/Latino populations are present in higher proportions than on average nationally (figure S1), as 28% live within 1 km of at least one documented orphaned well compared to the national average of 20%. This difference in proportions at the national level is largely driven by California and Texas (table S3), the two most populous states. Native Americans are also present in higher proportions than on average nationally (figure S1), with 2.6% living within 1 km of at least one documented orphaned well compared to the national average of 1.8%. This difference in proportions is particularly high in Oklahoma and New Mexico (table S5). There are also 270 000 children under five years old and 700 000 adults 65 years old and older living within 1 km of at least one documented orphaned well (figure S2).

3.1.2. Domestic groundwater wells

Orphaned wells may increase the risk of nearby groundwater contamination [27], and people relying on domestic groundwater wells are at increased risk of exposure to contaminants leaked via orphaned wells. Through investigation of groundwater contamination incidents in Ohio and Texas, a report by the Groundwater Protection Council identified 22% of 185 recorded incidents in Ohio and 14.2% of 211 incidents in Texas to be caused by orphaned oil and gas wells [27]. We find 35% (27 241 wells) of documented orphaned wells are located within 1 km of at least one domestic groundwater well (figure 3(b)). These documented orphaned wells with domestic groundwater wells nearby are predominantly found in Pennsylvania, Oklahoma, Kentucky, and New York (figure 2 and S3).

3.1.3. Water quality

Nationally, only 8% of documented orphaned wells have at least one groundwater quality monitoring site [14] within a 1 km radius (figure 3(c)). However, there is variability among states from over 30% in Oklahoma to less than 5% in Ohio, Colorado, and other states (figures 3(c) and S5). Moreover, at most groundwater monitoring sites, 70% of the available groundwater quality data (775 014 out of 1110 065) were collected before the year 2000 (figure S6).

Similar to groundwater, surface water quality data [14] is available within 1 km of only 7% of documented orphaned wells across the U.S. At the

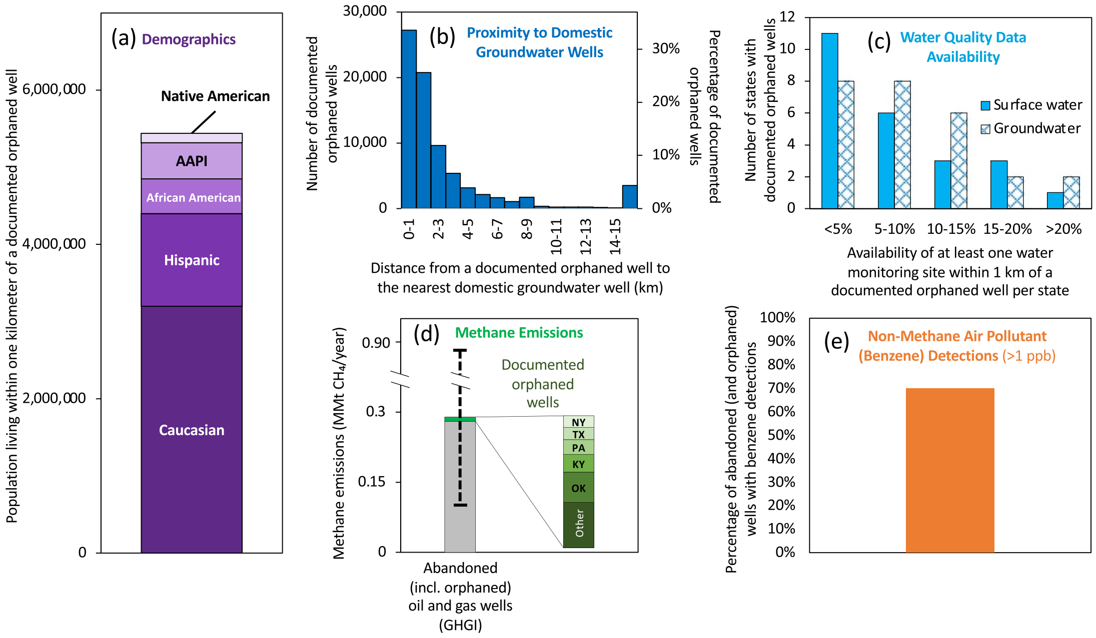


Figure 3. Analysis of environmental risks of documented orphaned wells, showing (a) the number and demographics of people living within 1 km of a documented orphaned well in the U.S., (b) the proximity of documented orphaned wells to domestic groundwater production wells, (c) surface water and groundwater quality data availability based on monitoring sites located within 1 km of documented orphaned wells at the state level, (d) methane emissions of all abandoned oil and gas wells and documented orphaned oil and gas wells, and (e) detections of benzene, an important air pollutant, made at abandoned (and orphaned) oil and gas wells. In panel (a), 'AAPI' stands for Asian Americans and Pacific Islanders.

state level, 11 of the 24 states have <5% of documented wells with surface water quality data within a 1 km radius (figures 3(c) and S5). Only two states (Kentucky and Oklahoma) have over 20% of documented wells with surface water quality data within a 1 km radius. 65% of the surface water quality data (7336 832 measurements out of 11 300 472) were collected since 2000 (figure S6).

3.1.4. Methane emissions

The 81 857 documented orphaned wells emit 0.0093 to 0.010 MMt methane per year (table S6), which represents 3% of total methane emissions from all abandoned oil and gas wells in the U.S. Greenhouse Gas Inventory (GHGI) [28] (figure 3(d)). The spatial distribution of annual methane emissions follows the spatial distribution of documented orphaned wells (figure 2), with Oklahoma, Kentucky, Pennsylvania, Texas, and New York representing the top five U.S. states (figure 3(d) and table S6). A recent study based on 123 318 documented orphaned wells found their methane emissions to be 5%–6% of total methane emissions from all abandoned wells in the U.S. GHGI [9].

The uncertainty in methane emissions from abandoned (including orphaned) oil and gas wells in the GHGI is estimated to be large, ranging from −83% to +197% [28]. Large uncertainties arise because the number of undocumented wells is likely high [2, 29] and because emissions have been measured at only a small number of abandoned wells. Direct measurements of methane emission rates per well [30] are available for 1136 wells (table S7), which translates to 0.03% of the 3.7 million abandoned wells estimated in the GHGI [28].

3.1.5. Non-methane air pollutant emissions

Methane is not the only component of natural gas, and we can expect other non-methane air pollutants, including benzene, a known carcinogen, to be co-emitted [31, 32]. Other non-methane air pollutants that can be co-emitted include hydrogen sulfide, toluene, ethylbenzene, and xylenes [33, 34]. A recent study of measurements of air pollutants from abandoned oil and gas wells in Pennsylvania detected benzene at ∼70% of abandoned wells with maximum, mean, and median concentrations of 250, 36 and 2.8 ppmv, respectively [34] (figure 3(e)). Differences in concentrations of benzene and other volatile organic compounds in active and abandoned wells in Pennsylvania were not statistically significant [34]. Although air pollutant emissions from actively producing wells may not necessarily be representative of all orphaned wells, benzene concentrations in production and bradenhead gas have widely been detected at actively producing wells surveyed in seven southern and western states (figure S7). Overall, additional measurements are needed to quantify the extent to which non-methane air pollutants are emitted from abandoned (and orphaned) wells.

3.1.6. Potential human exposures and health studies

Orphaned wells can be associated with short-term (acute) and longer-term (chronic) exposures with the potential to adversely affect health. The most concerning acute health risk arises from leakage along abandoned (incl. orphaned) wells that leads to methane accumulation in buildings [33, 35]. Such events can result in acute exposure to volatile organic compounds and other contaminants. Methane accumulations in confined spaces such as buildings that lead to exceedance of the lower-flammability limit for methane (∼5% of air by volume) can lead to catastrophic explosions. A national-scale quantification of these acute exposures is not available.

Over the past decade, there have been several hundred health and environmental studies focused on active oil and gas development [36, 37], with many studies in Pennsylvania, Texas, and Colorado (figure S8), where many documented orphaned wells are located. While this literature is helpful for understanding potential chronic and acute exposures and health effects related to active oil and gas development, it does not specifically focus on orphaned (or abandoned) oil and gas wells. An understanding of the health risk posed by orphaned (or abandoned) oil and gas wells specifically would be helpful for prioritizing them for plugging. Wells beneath residential buildings and other structures are of particular concern given the potential for vapor intrusion.

3.2. Opportunities

3.2.1. Enhanced geothermal systems

Thirty-eight percent of documented orphaned wells (29 911 wells) are located in regions that are mapped as least favorable for enhanced geothermal systems (approximately 3 to 10 km below ground surface) by NREL [20] (figure 4(a)). This is partially because many documented orphaned wells are located in the Appalachian region (∼30 000 wells), which is generally least favorable for enhanced geothermal development (figure S9). Sedimentary basins with oil and gas generally have lower subsurface temperatures than needed for geothermal, which can explain the lack of overlap between documented orphaned wells and high enhanced geothermal favorability. Nevertheless, 25 943 wells (33%) are in regions of moderate enhanced geothermal favorability, such as North Dakota [38]. The 63 documented orphaned wells (1%) located in regions most favorable to enhanced geothermal development are found in Utah, Colorado, and California.

3.2.2. Geologic storage of carbon dioxide, natural gas, and hydrogen

Most documented orphaned wells (71 299 or 91%) are co-located with at least one of the following geologic formations: saline aquifer, unmineable coal, shale, salt deposits, hardrock outcrops, and basalt formations (figures 4(b) and S10, S11), all of which are formations that offer subsurface storage potential for carbon dioxide, hydrogen, and natural gas. If we include active and depleted oil and gas fields among formations for subsurface storage potential, the number of documented orphaned wells overlying potentially valuable underground storage formations increases to 74 094 (94%). Some depleted oil and gas fields have been repurposed for natural gas storage. However, only 117 documented orphaned wells are located within 1 km of a currently operating underground natural gas storage facility with the number precipitously declining closer to the facility (figures S11–S13). 76% (59 967) of the documented orphaned wells overlie saline aquifers (figure S10), which are currently used to store natural gas in the Midwest and are a primary target for carbon dioxide storage [39]. Many documented orphaned wells are also co-located with unmineable coal (31 532 wells) and shale (40 601 wells) formations, which are also being considered for carbon dioxide storage [40]. 28 940 documented orphaned wells (37%) are found over salt deposits, which are currently the only formation type used to store hydrogen in the U.S. [41].

3.2.3. Wind and Solar

Instead of restoring the surface to pre-development conditions, the land may be repurposed for wind and solar energy production (figures 4(c), (d) and S14). Looking at wind/solar capacities alone (and not including land owner considerations and access to infrastructure), the potential to redevelop documented orphaned well sites for wind energy appears to be high with 57 860 wells (74%) located in the top bracket for wind capacity of 300 to 4000 MW by NREL [25] (figure 4(c)). In terms of solar capacity [24], most documented orphaned wells (45 587 wells, 60%) are located in regions with a capacity of 3000 to 4000 MW (figure 4(d)). A smaller percentage (16 947 wells, 22%) are in the 4000 to 5000 MW solar capacity areas, the top bracket for solar capacity potential [24]. However, many orphaned wells are in forested and developed areas (figure S15), which can present challenges to solar and wind development.

3.2.4. Plugging cost and job creation

Assuming no inflation, we find the total cost of plugging to be $4.1 billion USD (2019 dollars); this is less than the $4.7 billion USD that was allocated to plug orphaned wells under the BIL (figures 5 and S16). These costs include surface clean up and remediation/restoration costs. Our average (mean) per well cost is roughly $46 000 to $50 000 and is considerably lower than the roughly $76 000 per abandoned (incl. orphaned) well estimated in [3]. This difference is largely due to relatively shallow depths of the documented orphaned wells, compared to the abandoned wells analyzed in [3] (see SM). For example, the three states with the largest number of orphaned wells in our sample have average depths of 2419 feet

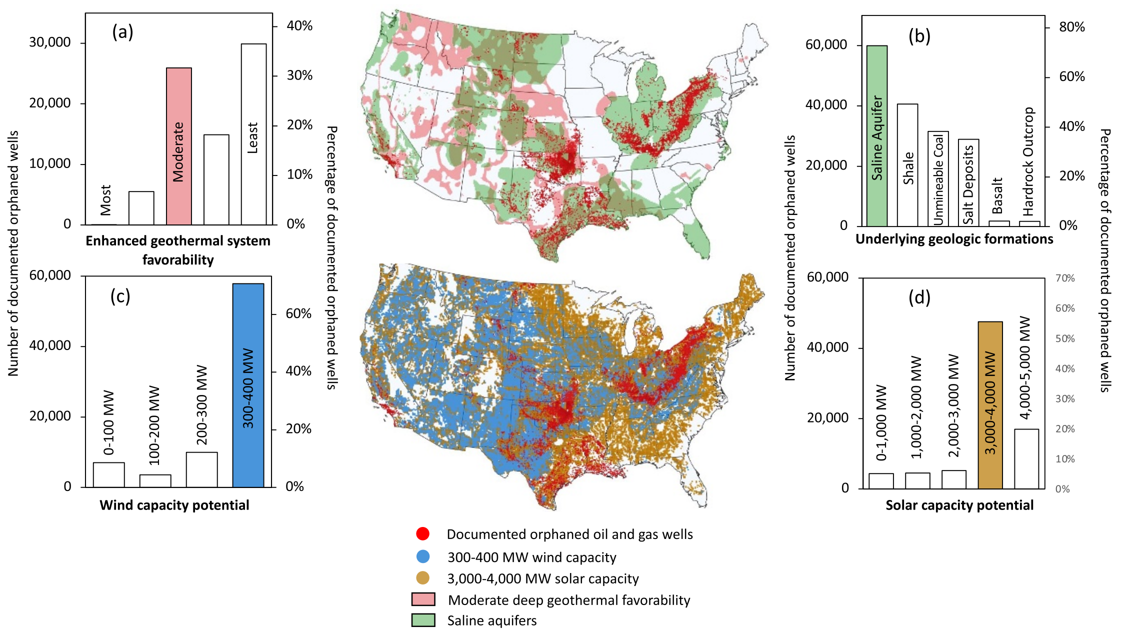


Figure 4. Numbers and percentages of documented orphaned wells according to (a) enhanced geothermal system favorability, (b) underlying geologic storage formations, (c) wind capacity, and (d) solar capacity potential. The geographic region associated with the colored bars in the four panels (a)–(d) are shown in the two maps of the contiguous U.S. in the center. The top map shows the documented orphaned oil and gas wells overlaid with regions with moderate enhanced geothermal system favorability and saline aquifers, and the bottom map shows the documented orphaned wells overlaid with 300–400 MW wind capacity and 3000–4000 MW solar capacity regions. The gray lines represent state boundaries. Additional maps for each panel are provided in figures S9–S11 and S14.

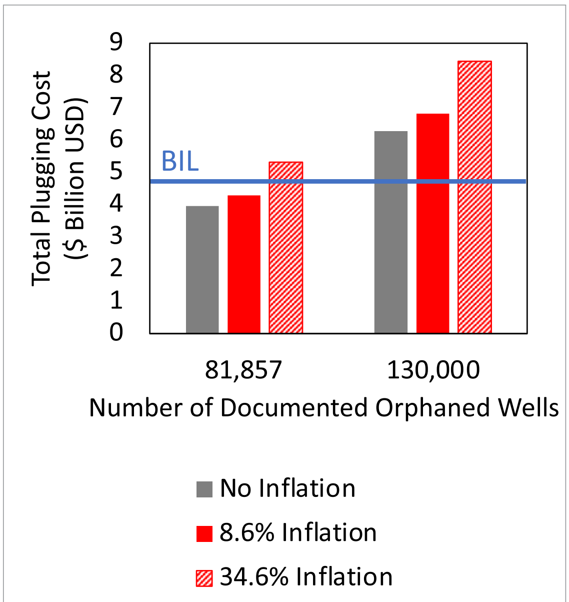


Figure 5. Cost to plug 81 857 and 130 000 documented orphaned wells in the U.S. assuming different inflation rates. The blue line shows the $4.7 billion allocated to documented orphaned well plugging in the BIL.

(Oklahoma, 15 965 wells) 1154 feet (Kentucky, 14 367 wells), and 1444 feet (Pennsylvania, 8840 wells), which are all lower than the average depth of 3550 feet in [3]. However, considering recent inflation rates are 8.6% (all items) to 34.6% (energy only) (U.S. Bureau of Labor Statistics for May 2022), the total costs can reach $4.3 billion and $5.3 billion USD.

Although not analyzed here, ∼130 000 documented orphaned wells [8, 9] have been reported as eligible for federal funding through the BIL (figure 2). If we assume 130 000 documented orphaned wells and scale up our estimate for the 81 857 wells, we get a total plugging costs of $6.3 billion to $8.4 billion USD (figure 5) depending on inflation rates. Because this larger number of documented orphaned wells is more likely to be applicable, the total cost of plugging documented orphaned wells is likely to exceed the current federal funding by $1.6 billion to $3.7 billion (+33% to +80%).

Using the total plugging costs for 81 857 and 130 000 documented orphaned wells and assuming no inflation, we estimate roughly 20 000 to 46 000 direct job-years for well plugging and surface remediation/restoration work (see SM). We do not include indirect and induced employment associated with plugging wells. For example, spending to plug wells not only supports employment on-site, it also provides economic benefits for supply chains and communities that are connected with the companies and workers. We also do not consider market and non-market benefits of plugging wells [42, 43].

4. Discussion

4.1. Current environmental monitoring data are not extensive enough to understand risks

Quantifying risks (the probability that the hazards will result in an impact) of orphaned wells will likely require more environmental monitoring and assessment. There is a need to understand how orphaned wells have or may affect the quality of air, surface water, and groundwater. A visual inspection of the spatial distribution of documented orphaned wells for which we have location data (78 685 out of 81 857 wells) suggests that many orphaned wells may be located close to water supplies used for domestic consumption [44] (figure 2). The recent reports of five orphaned wells in Texas releasing large volumes of water with brine, oil residues, and other hazardous substances [45] highlight the potential environmental and human health concerns. However, a national or regional scale study on surface and subsurface water impacts specifically due to orphaned wells has not been conducted [46, 47]. Moreover, available groundwater data is mainly for aquifers that are being used now, undermining our ability to monitor and protect groundwater aquifers that may be used in the future [44, 48–50]. In terms of air pollution, there is only one study based on wells in Pennsylvania [34]. For health studies, there are none specifically for abandoned (incl. orphaned) wells, despite the >4.6 million people living near documented orphaned wells, including disadvantaged groups. Finally, there are other environmental risks that we have not accounted for such as ecosystem impacts [42, 51, 52].

Water and air quality data can be useful to determine the extent to which orphaned wells have contributed to the contamination of water and air resources. However, measurements at a single time or geographic location may not sufficiently characterize the contamination (if any) caused by orphaned wells. This is because, for example, surface water contamination can be quickly diluted, while subsurface contaminant plumes can take a long time to reach groundwater users. With limited measurements of water and air quality available, it may be challenging to attribute water and air contamination to documented orphaned wells and, conversely, it also may be challenging to determine potential water and air quality improvements achieved through plugging.

4.2. Methane emissions may be a proxy for some environmental risks, but not all

The documented orphaned wells that are covered by the BIL emit approximately 3% to 6% of total U.S. methane emissions from abandoned oil and gas wells, which in turn represents 3% of U.S. natural gas and petroleum systems' methane emissions [28]. In addition to greenhouse gas emission reductions, there are many benefits to orphaned well plugging and remediation, for which methane emissions may serve as a proxy. Quantifying methane emissions may be a good proxy to understand the risk of explosions [33], which are among the top considerations by states when prioritizing wells to be plugged. For non-methane air pollution, methane emissions may also be a proxy; however, due to physical, chemical, and operational differences and a lack of measurements, it is challenging to relate non-methane air pollutant emissions to methane emissions [33, 53]. Moreover, a focus on methane emissions may lead to an emphasis on high methane emitters, which may lead to limited evaluation of the full suite of environmental risks. For surface water and groundwater contamination potential, methane emission rates measured at the surface are not likely to be a good proxy [54, 55]. In addition, there is potential for plugging to reduce methane emissions but enhance groundwater contamination [56].

4.3. Plugging orphaned wells reduce leakage risk for geologic storage projects, including carbon dioxide and hydrogen storage, and aid in energy transition

Geologic storage of carbon dioxide and hydrogen are two strategies being considered to reduce greenhouse gas emissions and transition away from fossil fuels [39, 57]. There are many documented orphaned wells that overlie saline formations, shale, unmineable coal, depleted oil and gas reservoirs, and salt deposits, which are all formations with significant geologic storage potential. However, we did not analyze the depths of the documented orphaned wells with respect to these formations. Analyses of orphaned wells leakage risk and the potential for repurposing orphaned wells as observation or injection/production wells are also needed. Overall, for future geologic storage projects [58], it may be beneficial to prioritize plugging wells close to potential geologic storage formations.

4.4. Total plugging costs for orphaned wells exceed federal funding

The total cost for plugging 130 000 documented orphaned wells exceeds the $4.7 billion BIL funds for orphaned well plugging by 33% to 80% (>$1.6 billion USD). Although state funding may cover some of this shortfall, the combined effect of finding undocumented orphaned wells and inflation may lead to many documented orphaned wells remaining unplugged even after the BIL funds are spent. Therefore, it is critical to develop effective strategies to prioritize wells to be plugged, which include national level analysis as presented in this paper.

4.5. Both documented and undocumented orphaned wells need further study

The Interstate Oil and Gas Compact Commission reports the number of undocumented orphaned wells in the U.S. to range from 310 000 to 800 000 [8], which is up to an order of magnitude larger than the number of documented orphaned wells (figure 2). A new (2022–2027) U.S. Department of Energy-funded project on undocumented orphan wells (Consortium Advancing Technology for Assessment of Lost Oil and Gas Wells or CATALOG) aims to develop methods to locate and characterize leakage from undocumented orphan wells [59]. In this paper, we only evaluated select risks and opportunities posed by the 81 857 documented orphaned wells, largely due to data limitations. Even for risks that we consider here, there are data gaps, such as in groundwater and surface water quality, air pollution, and health studies. There is also a need to better understand factors contributing to orphaned well leakage [60–62]. It is hoped that the BIL, in addition to plugging wells, will also result in data on environmental impacts, which can facilitate analysis of the environmental risks of both documented and undocumented orphaned wells.

5. Conclusion

We provide a national-scale analysis of the documented orphaned well dataset with 15 different datasets, covering methane emissions, demographics, water quality, air quality, health effects, and renewable energy and energy transition infrastructure projects. We find that there are at least 4.6 million people living within 1 km of a documented orphaned oil and gas well and that they face a wide range of environmental risks. However, we find that current environmental monitoring data are not extensive enough to understand risks. Nevertheless, we identify the large potential value of plugging in geological storage and renewable energy development projects, critical to energy transition projects.

We find that the recent $4.7 billion federal funding from the BIL is not sufficient to cover the plugging of documented orphaned oil and gas wells across the United States. This finding highlights the importance of rapidly developing a framework and environmental monitoring datasets to prioritize wells for plugging, as tens-of-thousands of wells will be plugged in a matter of years.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.5683/SP3/PLAOIX.

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