Three Essays on Governance of Pennsylvania's Oil and Gas Well Plugging

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This three-essay dissertation focused on the identification of knowledge commons and its utilities in the Pennsylvania's oil and gas well plugging with the Governing Knowledge Commons framework. I argue that public decisionmakers can utilize information retrieved from the knowledge commons and improve policy outcomes efficiently and equitably. Voluntary actions among private and non-private actors with sufficient incentives to accumulate and share information were identified. One of the knowledge commons is the Zillow transaction and assessment dataset, which can be used to estimate the population exposed to unplugged oil and gas wells. I found no evidence of environmental injustice in the Pennsylvania's well plugging program with the Zillow transaction and assessment dataset. Also, I revised the well plugging program that improve efficiency and equity simultaneously under the limited budget. This dissertation may have implications for public decisionmakers that governing knowledge as a commons can help to find and resolve public problems efficiently.

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1.0 Knowledge Commons as Solutions to Social Dilemmas in Public Decision-makings: Pennsylvania's Oil and Gas Well Plugging

1.1 Introduction

It has been reported that numerous oil and gas wells were not properly decommissioned and these wells put threats on public health and environments across the United States (IOGCC, 2020; Kang et al., 2014). Scholars and policymakers have estimated the number of unplugged wells (PA DEP, 2021a), drafted new environmental policies (Weber, 2021), and plugged some wells in emergency (PA DEP, 2021c). For example, the Pennsylvania Department of Environmental Protection (DEP) has selected 8,000 abandoned oil and gas wells and plugged 3,090 wells by 2021 (PA DEP, 2020b). Nevertheless, two issues remain at the amounts of knowledge necessary to regulate unplugged wells. It seemed that governmental regulators have limited information and data about the locations and environmental impacts of unplugged wells (Weber et al., 2018). Another can be that individuals are atomized and then fail to generate, share, and maintain information about unplugged wells and plugging together. Given the fact that knowledge itself is public goods, improperly established formal/informal institutions may result in the lack of knowledge (less than amounts enough to deal with unplugged wells).

Presumably, the gaps between rational choices at an individual level and products at a group level could be cured by voluntary activities among public and private actors. Knowledge commons can be an alternative to the social dilemma embedded in the oil and gas well plugging.

Knowledge commons may be referred to as an "institution for governing the production, use, and/or preservation of a particular knowledge or information, including resources linked to innovation and creative practice (Madison et al., 2019)." Knowledge commons is not mere the set of knowledge or open sources but "governance of a shared information or knowledge resource by some collective or community (Murtazashvili et al., 2022)." Technological innovation and digital media can be seen as knowledge commons. This is because information can be copied and shared with negligible costs but a facility where information is stored can be depletable and excludable by information owners (Nordman, 2021). A small talk in conference may be also an example of knowledge commons. Empirical studies have found that citizens, non-profit organizations, and professionals have collected information that had not been explored or would be highly costly to get and disseminated new data and knowledge publicly in various fields (Boggio, 2017; Kuchař & Dekker, 2020; Sanfilippo et al., 2018b; Sanfilippo & Strandburg, 2021).

This research explored how each individual has voluntarily governed the knowledge commons to reduce negative externalities from abandoned oil and gas wells. Governing Knowledge Commons framework may be useful for analyzing the incentives and choices of participants. The finding is that citizens, non-profit organizations, researchers have generated and exchanged information and tacit knowledge with one another. Individuals in each group featured the high levels of homogeneity in terms of locality, socio-economic status, and goals. For example, residents living next to polluted oil and gas wells collectively sought to clean up the sites to protect public health and maintain their property values. Each group has developed informal institutions such as common value, reputation, and accepted norms through repeated interactions. As a result, group members were able to deter opportunistic behaviors and boost collective actions so that the knowledge commons could be built sustainably. Specifically, residents explored well locations and measured the degree of pollution by themselves, and researchers suggested new regulations and plugging methods to public authorities. The knowledge commons constructed by the private actors may help the DEP administrators to find, evaluate, remediate more unplugged wells accurately and efficiently. It is expected that the public decisionmakers can improve budgetary efficiency and political responsiveness to residents near the polluted industrial sites.

1.2 Governing Knowledge Commons Framework

Ostrom suggested the Institutional Analysis and Development (IAD) framework for more efficient and equitable management of common-pool resources. The IAD analyzes how and why each user decides to do collective actions or not in the CPRs management. Each user is under pre-existing exogenous variables that include biophysical conditions (e.g., types of resources, resource reserves), the attributes of a community, and rules in use. Those who own resources collectively may be required to reach a mutual agreement and monitor opportunistic behaviors to avoid resource over-exploitation. It was expected that socially or demographically homogenous groups can easily make collective actions over CPRs and enjoy higher benefits from resource use in the long-run. Rules in use, which may be same as or different from formal rules, usually affect local resource users' decisions. Each would follow the widely accepted rules within a local community when long-term net benefits are greater than the ones of violating rules in use. Consequently, E. Ostrom advocated that "designing institutions to force (or nudge) entirely self-interested individuals to achieve *better* outcomes has been the major goal… (Ostrom, 2010)."

She also found that communities based on trust and repeated interactions may have sufficient incentives and capacities to cope with social dilemmas around common-pool resources (CPRs) standing on their own feet (1990). Local communities with informal institutions (e.g., trust, sanctions, norms) (Sugden, 1989) and mutual agreements were likely to be more resilient and receive long-term net benefits while avoiding resource depletion (e.g., species' extinction) (Gardner et al., 1990).

Hess and Ostrom (2005) showed the possibility of collectively governing knowledge for better outcomes with the IAD framework. But it was necessary to modify the IAD framework and explore the roles of knowledge in the resource governance (Frischmann et al., 2014). The IAD focuses on informal institutions embedded in specific situations as well as biophysical/material resources, not the roles of knowledge and informational resources. Knowledge itself is public goods because one does not reduce another's knowledge consumption and it may be hard to prevent one from using knowledge (non-rivalry and non-excludability). Thus, the Governing Knowledge Commons (GKC) framework has differences from the Ostrom's IAD (figure 1). Firstly, the GKC framework assumes that there are interactions among the three external variables, including resource characteristics, attributes of communities, and rules-in-use. For example, those who have specialty in IT apparatus are more likely to increase the utilities of information consumption. It means that knowledge can be an endogenous factor in the decision-making of members because shared knowledge would be influenced by the capacities of groups and rules applied to knowledge governance. In contrast, the IAD framework focuses on natural resource commons, which may be an exogenous factor in local communities. That is, the attributes of communities and rules-in-use cannot change the characteristics of natural resources. Secondly, an action arena can affect the resource characteristics back and forth because knowledge and information are easy to be edited, stored, delivered in contrast to natural common-pool resources (e.g., fisheries).

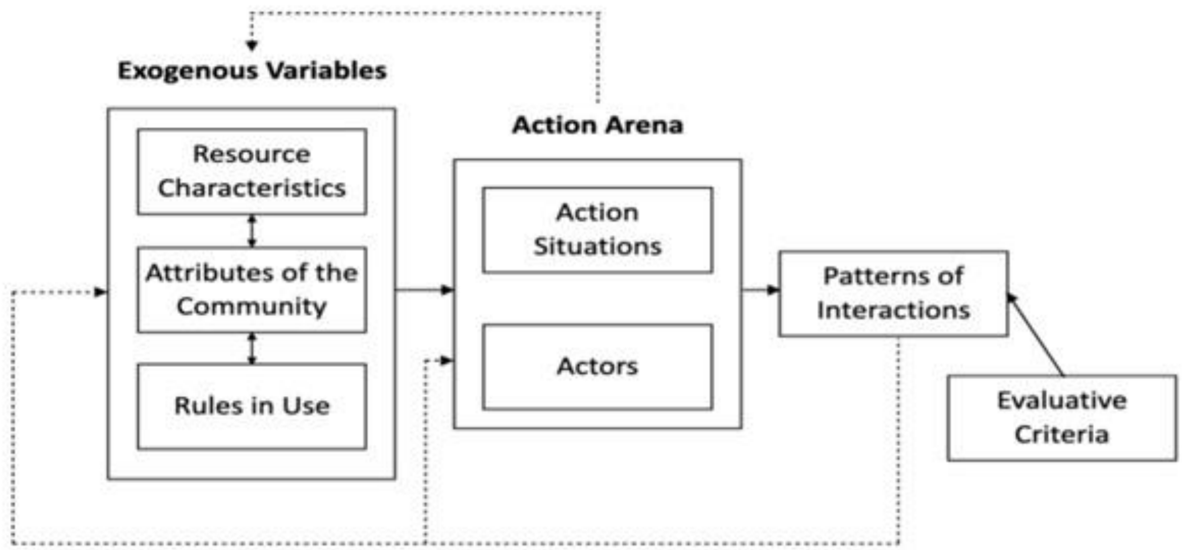

Figure 1.1: Governing Knowledge Commons Framework[1]

The GKC framework can refer to "a method of researching constructed cultural commons" including knowledge and information in scientific domains, domains related to arts and culture, and resource domains defined by human-generated character and their intangibility (Murtazashvili et al., 2022). With the GKC framework, researchers are able to analyze how social and cultural variables affect the governance of human mind in a systematic way of case studies (Madison et al., 2009). The research interests can be categorized within the GKC framework: 1) characteristics of tangible/intangible resources, 2) boundaries and membership, 3) social dilemmas users are facing, 4) rules and practices facilitating coordination and distribution,

[1] Source: Frischmann, Madison, Strandburg, 2014. *Governing Knowledge Commons*.

5) institutional settings, 6) interactions between participants and institutions, and 7) mechanism of dispute resolution (e.g., monitoring, rules, norms) (Murtazashvili et al., 2022).

Community members who experienced strong collaboration and fair distribution of resources are more likely to maintain patterns of interactions, adjust rules-in-use tailored to changed environments. Also, they are able to develop knowledge commons from bottom-up (not via planning), and improve community attributes and capacities. As a result, groups based on knowledge commons could collect big data that had not been obtained due to high costs and utilize public and private decision-making for efficient and equitable outcomes. Literature on the GKC framework (Geary et al., 2019; Hensher et al., 2020; Joranson, 2008; Lister, 2018) and government-driven projects show that mining and processing big data used for resource governance efficiently could be possible by citizens' participation and sharing. Those who successfully governed knowledge commons in a long-run may prevent the omission or losses of information but increase the level of openness so that research participation and user rights are guaranteed (Tempini & Del Savio, 2019). Literature on citizen science revealed that diversely motivated individuals voluntarily joined projects searching for new data, summarizing extensive information, and producing knowledge in multiple regions (Li & Phelps, 2018) or in digitalized environments (Nov et al., 2011). Privacy can be also one component of knowledge commons that are connected and organized within homogenous communities based on IT technologies and cultural norms (Sanfilippo et al., 2018a). Blockchain (Allen et al., 2021), Wikipedia (Safner, 2016), and innovation (Allen & Potts, 2016) were also analyzed as a commons.

1.3 Issues in the Regulations of Pennsylvania's Oil and Gas Well Plugging

There have been concerns that oil and gas industries contaminated water, soil, and air (Rozell & Reaven, 2012) but did not fully take responsibility for remediating unproduced well sites (Harleman, 2018). Consequently, not only landowners who made leasing contracts with well operators and but also neighbors could be exposed to hazardous materials (Adgate et al., 2014; EPA, 2016) or a decrease in the values of properties (Gopalakrishnan & Klaiber, 2014; Muehlenbachs et al., 2015). The negative externalities can be seen as the deterioration in the common-pool resources among residents and landowners. Polluted underground (or surface) water and soil could prevent other individuals from clean environment, which is called as subtractibility. Also, it would be hard and costly to exclude one person from being damaged by leaked pollutants, which is called as non-excludability.

The Pennsylvania Oil and Gas Act[2] mandates the state governments to hold various policy instruments to internalize the negative externalities from abandoned and orphan wells; financial burdens, well plugging, zoning, monitoring, information collection. First, well operators are required to pay impact fees before well production so that the state departments can prepare for well operators' insolvency (§3216). Impact fees are calculated depending on the prices of oil and gas and the production volumes (§2302). Energy firms need to submit application fees for well permits and surcharges (§3271) before oil and gas well drilling. The assurance bonding (§3225) can be used to require oil and gas companies to prove that they can bear plugging costs and protect the state from cleanup costs (Legere, 2021). Second, the DEP has directly removed abandoned and orphan wells with administrative authorities and plugging

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[2] URL: http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/2012/act13.pdf. Accessed December 20, 2022.

funds. The DEP has plugged 3,090 wells by 2021 July under the well plugging program but needs to remove 6,171 orphan wells and 2,588 abandoned wells on the DEP list (PA DEP, 2020b). Third, the PA state government may use a setback policy, which designates lands as residential or industrial zones to restrict oil and gas mining sprawls. For example, some industrial facilities should be away from wells over 300 feet (§3304) to reduce exposure exceedances. Fourth, the DEP has administrative authorities to oversee the density of pollutants and chemicals, the presence of unplugged wells, and determine well permits depending on prerequisites and conditions (§3258). The DEP caught the 5,000 violations conducted by well owners from more than 21,000 inspections for conventional and unconventional wells (PA DEP, 2021a). In addition, the DEP issued administrative orders to enforce existing well operators to spend corporates' budgets in plugging abandoned wells. Lastly, well operators should regularly report information about well development, surface activities, and well plugging to the DEP to oversee regulatory compliance and manage data (§3222.1). Information exchange between firms and the state government may help regulators to oversee regulatory compliance, identify hidden wells efficiently, and select which wells should be plugged with priority. A well operator must file with the department a well record within 30 days of drilling a well, including vertical depths at which methane was encountered and the country of origin and manufacture of the tubular steel products in well construction (PA DEP, 2022).

However, it seems that state regulations may not be efficient in plugging wells because of limited fiscal and informational capacities under the regulations. Weber, McClure, and Simonides (2018) recognized the two limitations of the current well-plugging regulations: 1) financial obligations of well operators may not be enough to cover all restoration costs, and 2) imperfect information may not guarantee efficient well plugging and compliance, Firstly, the current shale regulatory framework may be weak to have polluters pay for costs associated with remediating all the polluted wells in Pennsylvania (Chalfant & Corrigan, 2019). The bonding amounts are $2,500 for each conventional well drilled on or after April 18, 1985 and $10,000 bond for each unconventional well. However, the DEP estimated that a well-plugging cost per one well ranges from $17,000 to $100,000, depending on geographical characteristics (e.g., access roads, slope, coal mines) and well conditions (e.g., well depth) (Adams, 2021). The DEP estimates that thousands of wells are under a single blanket bond or have no bonds at all (PA DEP, 2020b). More wells could be abandoned by well operators who cannot afford to pay plugging costs. But, the current well plugging funds are not sufficient to plug all the unplugged oil and gas wells; "received less than $755,000 to plug abandoned wells from the surcharges (§3271) …this is only sufficient to address wells that pose an imminent risk to public safety and DEP was only able to plug four such wells" in the 2020 DEP's fee and cost analysis report (PA DEP, 2020a).

Second, information held by regulators may be insufficient for remediating polluted wells. It seems that the DEP administrators do not fully have information about well locations and conditions, characteristics of affected communities, damages to populations, environments, and properties, and plugging technologies and costs. Also, the regulators have not properly collaborated with DCNR, DCED, and even PennDOT in the procedures of well plugging (Mallinson et al., 2022). Energy firms are legally required to report information about well drilling. The Pennsylvania Oil and Gas Act articulates that "Each well operator shall file with the department (DEP)…an annual report specifying the amount of production, on the most well-specific basic available, along with the status of each well…The Commonwealth may utilize reported information…in making designations or determinations." Specifically, well owners are required to report chemical additives (§ 3222. 1.), volumes of fluids, water sources and use, and pump rates and pressures (§ 3222). But well owners do not have to disclose business-sensitive information to the DEP. Administrators do not have entire datasets used to regulate timely because companies do not need to submit business confidential (§3222) and governments do not have enough resources to gather information by themselves (Wiseman, 2014). Furthermore, state agencies are less likely to inspect the violations of regulations in poorer regions (DiSalvo et al., 2020).

1.4 Applying the GKC framework to the Knowledge Commons on the Well Plugging

Per the GKC framework, the knowledge commons of the well plugging can take a form of community governance that possesses the set of informal institutions facilitating collective actions among members. The multiplicity of private entrepreneurs as well as public decision-makers in the state government also have been engaged in the knowledge commons. For the private actors, landowners (who contracted with well operators for well drilling), residents living nearby unplugged wells, non-profit organizations, researchers, and well operators can be included. They show the diversity in roles, backgrounds, specialty, values, locations, and perception to oil and gas industry. The work scope and size of self-organizing groups vary but the ultimate objectives may be the protection of public health and environments damaged by leaking pollutants from unplugged wells. For the public actors, the Department of Environmental Protection, the Department of Conservation and Natural Resources, and The Department of Transportation can be actors who engaged in inspection, approval, policy formulation, regulations, enforcement for the general management of oil and gas industry (please refer to the above-mentioned legal grounds). The Pennsylvania Oil and Gas Act mandates the PA DEP to organize oil and gas technical advisory board to discuss with professors, energy businessperson, research institutes on resource development and environmental preservation (§3226). The Oil and Gas Technical Advisory Board dealt with evaluation of environmental impacts, unconventional well spill reporting, technical guidance documents, and orphan and abandoned well funding and contracting (PA DEP, 2022).

Informational resources from the knowledge commons of the well plugging can be the geographical information of abandoned and orphan wells, the levels of contamination or damage on public health, the changes in environmental policy for a larger number of well plugging. The apparatus to pool and keep the information and data are governmental website, personal blogs, social media, school websites, academic journals, conferences, webinars, workshops and on media. Not only the participants to the knowledge commons but also others (e.g., citizens, firms, federal governments) can have access rights. No legal system forces individuals to engage in knowledge commons in an authoritative way but research ethics may be the primary informal institutions to regulate the behaviors of researchers and enhance the values and virtues of those conducting research. For example, Environmental Science & Technology where research articles on unplugged oil and gas wells were published sets journal scope, authorships, and research data policy per its author guidelines. The existence of freely shared information that could be used for better outcomes from plugging can indicate the collective activities by grass-root movement, not command and control approach. Landowners (who have property rights on lands) facing leaking fluids and methane at their backyards are likely to report accidents to local and state governments to avoid lower home prices. Researchers also found unknown but not trivial observation and announced new policies that put more responsibilities on energy developers and strengthen governments with larger amounts of plugging funds. These voluntary actions could be beneficial to their reputation, careers, and funding for future research.

1.4.1 Public Decision-makers in the Knowledge Commons

Given the informational limitation and gaps between governments and local communities (referring to the social dilemmas), the Pennsylvania DEP administrators have produced the DEP well mapping database, reports, blogs, and attended online/offline conferences. Basically, well operators are legally required to submit the well characteristics (well depth, pressure, locations, nearby environments) to get the approvals of well digging at the beginning. With the participation of the private entrepreneurs in generating well information, the DEP well mapping database was established and has been updated. When it comes to the use of well database, the DEP has released the well database publicly. People, researchers, and non-profit organizations could download the data from the DEP website and know the locations of active and abandoned wells, production status (e.g., active, plugged), the number of permits, and types of wells (e.g., oil, gas). Also, people can locate wells with address, latitude/longitude, well pad names, and zip codes. One notable point is that there are interdependencies and feedback loops among the DEP and well applicants through the well registration procedures.

The DEP has issued oil and gas reports accessible to public online so that users can select specific criteria for the desired information. The reports deal with oil and gas production information, permits issued (required for drilling and spudding), drilling commence date, country data, operator specific data, inspections, violations, and enforcement actions (Department of Environmental Protection, 2022). Oil and Gas Compliance Reports deliver the results of site restoration inspections (plugging and surface restoration) when an operator notifies DEP the requests to end an Erosion and Sediment Control General Permit. The DEP also has posted blogs that cover the history of abandoned and orphan wells, the procedures of plugging, DEP's plugging program, and contact points[3]. Webinars for environmental protection performance standards at oil and gas well sites were held to distribute information on administrative procedures, techniques, and regulations[4].

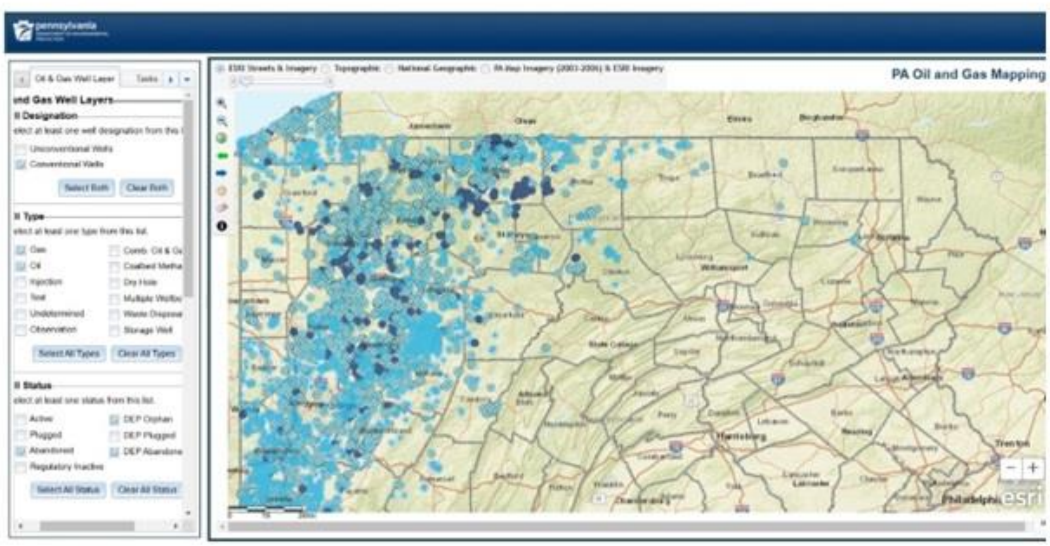

Figure 1.2: PA DEP's Well Database[5]

[3] The DEP blogs release not only oil and gas wells but also energy saving, water contamination, illegal dumping to inform people and encourage participation. URL: https://www.dep.pa.gov/OurCommonWealth/pages/Article.aspx?post=91. Accessed December 20, 2022.

[4] Webinars can be downloaded from the DEP website in the form of MP4 files. URL: https://www.dep.pa.gov/DataandTools/Webinars/Pages/Oil-and-Gas.aspx. Accessed December 20, 2022.

[5] The PA DEP's website is linked to https://gis.dep.pa.gov/PaOilAndGasMapping/OilGasWellsStrayGasMap.html?

1.4.2 Private Decision-makers in the Knowledge Commons

The knowledge commons governed by private actors may cover the detection of undiscovered (or officially undocumented) oil and gas wells, the risk measurement of unplugged wells, and the new regulation formation. The residents living near unplugged wells, non-profit organizations, researchers can be the significant private actors in the knowledge commons. The residents are usually based in the same or small boundaries adjacent to an unplugged well because the negative environmental effects can be limited to a certain distance. The actors seem to have common incentives and similar social and cultural circumstances to locate wells to be plugged and clean up the sites (Environmental Defense Fund, 2021). They are likely to be physically affected by unplugged oil and gas wells (Denham et al., 2019; Rabinowitz et al., 2015). Leaked pollutants can cause landowners to bear the additional clean-up costs of abandoned wells and restore the surfaces of orphaned and abandoned wells. Also, neighbors may not receive compensation for diseases or discomfort, and non-profit organizations could not achieve goals such as environmental protection. Information searching costs are relatively small and the benefits of participation would be satisfactory in small groups. Also, the individuals are likely to have long-term relationships because most wells are less-populated regions and residents have similar socioeconomic attributes. Since local residents and organizational members know each other and have local knowledge within shared social contexts, monitoring the violations of rules-in-use and sanctioning can be effective and less costly. The high degrees of autonomy and independence among individuals are attributable to the exchange of knowledge and the prevention of rent-seeking behaviors that influential groups hold powers exclusively and decrease social welfare. With informal gatherings or cheap talks, residents and NGOs can efficiently learn about plugging failure, collective responses to pollution, and others' strategies iteratively. For example, the Sierra Club submitted the petitions that encourage the PA's Environmental Quality Board (EQB) to raise bond amounts for unconventional wells in 2021 (Sierra Club, 2021). This civil mobilization asked the EQB to raise bond amounts from $2,500 to $38,000 per well. Reinforcing the well operators' financial responsibilities for plugging unconventional wells and not further increasing the number of unplugged wells in Pennsylvania could help DEP to clean up abandoned wells.

The residents in Pennsylvania have voluntarily discovered wells through field examination and detected leaking pollutants near residential areas under strong informal institutions. For example, some abandoned wells were recorded by citizens and uploaded into Internet. Local people reported wells that leak gas, fluids, even make flares to the DEP in their properties (PA DEP, 2021b). People in Washington and Westmoreland counties publicized the relatively higher incidence rates of Ewing's sarcoma, rarely occurred bone cancer to childhood, than other non-drilling counties (Frazier, 2019). The PA Department of Health issued the report saying that "Although the rate of Ewing's tumors was slightly higher in fracking counties than non-fracking counties, the difference also was not statistically significant (Department of Health, 2019)." The local people criticized the results because some families were excluded from the used cases through a grass-root movement, so the PA governor set additional funds to examine potential health impacts (Chaffin, 2020). Southwest Pennsylvania Environmental Health Project (EHP) aims to provide residents who have been or could be impacted by oil and gas wells with information about health effects, health systems, and self-protection measures. The EHP This group consists of data analysts, medical practitioners, policy analysts and has partnerships with academic institutions, other non-profit organizations, and universities to share datasets and research resources. The EHP drafted research papers about air and water pollution (Brown et al., 2019), health impacts (Weinberger et al., 2017), and public planning (Lewis et al., 2018), and issued brochures to make residents report concerns easily and quickly to state and federal agencies. The individuals often co-work with environmental groups to mobilize human and technical resources and acquire more information through field investigation. These voluntary and spontaneous activities can help administrators to 1) fill the data gap by gathering scattered and localized information, 2) save administrative costs by leveraging local communities' resources and capacities, and 3) have "cheap talks" with citizens frequently and accumulate social capital further.

Universities and entrepreneurs also can be the "source of the knowledge commons that understand the shale revolution (Murtazashvili & Piano, 2018)." The incentives of participating in knowledge commons may include more fundings, reputation and promotion, and increased influence on public decision-making. Also, scholars could seek plural values, including altruistic motivations, intrinsic values, relational values (Arias-Arévalo et al., 2017), though they do not receive pollution directly. Each one has a high level of autonomy and independence, leading to reviewing others' findings (e.g., peer-review) and raising different opinions. The research findings of well plugging have been distributed through on-line/off-line such as published articles, blogs, conferences. From some perspectives, a journal can be a "self-constituted group" striving to set norms and regulation by itself and create new knowledge (Potts et al., 2017). Shale gas knowledge hub, administered by Washington and Jefferson College, has posted blogs about oil and gas resource governance as well as hosted webinars educational programs (Shale Gas Knowledge Hub, 2019). The American Association for the Advancement of Science (AAAS) has issued blogs about not only the management of abandoned and orphaned oil and gas wells but methane emission and hydraulic fracturing (American Association for the Advancement of Science, 2022). The working group for well abandonment in the AAAS is made up of 42 specialists and shows diversity in jobs, regions, and interests. Researchers have estimated the number of unplugged wells (Boutot et al., 2022), their locations and conditions (Dilmore et al., 2015), and adverse impacts by conducting field examinations (Pekney et al., 2018). The Environmental Defense Fund made a map of more than 120,000 documented orphaned wells across thirty states with researchers at McGill University (Environmental Defense Fund, 2022). The wellMapper, which is a mobile application developed by Indiana University of Pennsylvania, provided the locations and details of abandoned wells to the public. The department of geoscience of the school received 9,500 dollars as funds to make abandoned and orphaned wells software (IUP Research Institute, 2018). The application users were able to upload and know the information about wells' locations and conditions in Pennsylvania. Scholars also have identified the pathways (e.g., water, soil, air) and targets, and then measured the extent to which people could be negatively affected by hazardous materials from abandoned wells (Kang et al., 2014; Townsend-Small & Hoschouer, 2021). Geologists have used unmanned aircraft systems and remote sensing technologies to map natural resources and locate legacy oil and gas wells (Society of Exploration Geophysicists, 2017). With the techniques, it was found that more both abandoned and active wells, totaling from 395,000 to 466,000, were detected than the one in databases with aeromagnetic surveys in Pennsylvania (Saint-Vincent et al., 2020). The National Energy Technology Laboratory used light detection and ranging (3-D laser scanning) and confirmed the sites of undocumented abandoned wells in Oil Creek State Park, Pennsylvania (National Energy Technology Laboratory, 2022). Researchers also have drafted and modified environmental policies, including direct regulations, financial incentives, and self-regulation by energy firms to develop oil and gas governance (Ho et al., 2016). Particularly, they have worked on plugging funds from the U.S. federal government to abandoned wells (Kang, 2021) and plugging techniques (Akbari & Taghavi, 2021). Adjusting bond amounts may be necessary to incentivize well operators to be responsible for well plugging. The probabilities of being plugged can be influenced by the levels of impact fees and bonding requirements (Mitchell & Casman, 2011). Some advocate the plan to increase the current bonding amounts to put more financial burden on well operators and collect more revenues for well plugging by governments (Harleman, 2018; Weber, 2021).

The open data sources generated by private corporates can be one of the knowledge commons when the datasets can be freely leveraged to obtain insights and new findings by residents and researchers. The cost of well abandonment would be increased with deeper well, older well, the necessary of surface restoration, lower number of wells per contract, and wells in hilly areas (Raimi et al., 2021). In addition to the variables affecting well plugging costs, socio-economic characteristics could be one of the evaluative criteria on well abandonment. For example, the Zillow freely distributed the Zillow's Assessor and Real Estate Database (Ztrax) to public decision-makers, researchers, and non-profit organizations. The Ztrax involves deed transfers, mortgages, foreclosures, auctions, property tax delinquencies, and more for both residential and commercial properties (Zillow, 2021). The Ztrax has been updated over transacted properties in real-estate markets quarterly. All the residential and commercial buildings are categorized by "ImportParcelID," which were created from Five-digit Federal Information Processing Standards (FIPS) numeric code and the AssessorParcelNumber (APN). The FIPS identifies every county and the APN indicates parcels of real property by the County tax assessor for purposes of identification and record-keeping (Zillow, 2022). Local governments also contributed to improving the Ztrax by providing data as a level of county. Ztrax's data coverage has been changed over time and over space by collecting local data from county assessor and recorder's offices (called County Direct). Buyers and sellers in real-estate markets can be actors who reflect the characteristics of properties into prices, resulting in the real-estate market data generation.

When it comes to the use of the Ztrax, non-profit organizations, researchers, and public administrators can access the Ztrax and use for research findings (Zoraghein & Leyk, 2019). Researchers can use home price data with higher qualities such as timeliness, referring to how up to date information is collected (Gindelsky et al., 2020). The estimation of demographic attributes can be more accurate even in rural regions that has lower population density and may lead to high sampling variation and biased estimates. Previous studies leveraged the Ztrax and measured local effects more accurately from contaminated sites to people with spatial analyses. For example, Norwood (2020) used the locations of oil and gas wells and Ztrax, and found that houses closer (e.g., within 0.5 miles) to wells are likely to be higher in prices than others (e.g., more than 2 miles away). Constructing the pipelines of unconventional oil and gas may lead to the decrease in housing prices nearby the industrial facilities up to 9% (Boslett & Hill, 2019).

1.5 Limitations of the Knowledge Commons in the Oil and Gas Well Plugging

Despite the existence of the knowledge commons, the amounts of shared and accumulated information may not reach at a socially desirable level. This is because that residents and researchers may not have perfect information and enough budgets and face the free-riding of residents living in no-well areas. The participants in the well plugging knowledge commons do not hold the responsibilities of removing the well sites. Also, their roles in the knowledge commons were limited to the well identification, violation report, and research findings mostly. Instead, economic circumstances and governmental funding might be the more important driver in well plugging (Alex Wolf, 2021). Thus, governing knowledge commons may not necessarily result in public consensus and improved outcomes. Howell (2018) pointed that “more knowledgeable participants held more polarized views and were significantly more likely to agree with negative statements.” McLaughlin and Cutts (2018) also argued that future fears, community concerns, and distrust would influence the fracking ban in Pennsylvania more than knowledge deficit or NIMBY. Moreover, public opposition to oil and gas drilling has been mobilized by liberal politicians (Dokshin, 2016) and can be framed by wording (Clarke et al., 2015), not scientific knowledge. In addition, knowledge commons may not necessarily guarantee that those who have innovative technologies and private databases would exchange their knowledge with users wholly and freely. Although compensation of information sharing might be an option to encourage knowledge holders to disseminate local experience (Brush & Stabinsky, 1996), questions about how users can collect payments and valuate shared knowledge can remain unfigured. Furthermore, energy firms with intellectual property rights may have high incentives to fence off stakeholders’ access or temporarily disclose parts of all information.

2.0 Estimating Population with Ztrax and Examining Environmental (In)justice: The Case of Pennsylvania's Abandoned and Orphan Well Plugging Program

2.1 Introduction

Environmental Justice (EJ) has been one of administrative goals in environmental policies that seeks "the same degree of protection from environmental and health hazards and equal access to the decision-making process (U.S. EPA, 2021a)." But empirical studies have found that benefits or costs from pollution-producing facilities were disproportionately distributed across communities. The rich and those who got educational attainments over high schools received higher salaries (O'Neil, 2007). Longer time was taken for environmental restoration in poor or minority-populated neighborhoods (Burda & Harding, 2014; Eckerd & Keeler, 2012). Lower-income people were more likely to be exposed to pollutants and increase incidence rates located near the only place they can afford to live (Gamper-Rabindran & Timmins, 2011).

Most EJ studies used various methods to detect evidence of environmental (in)justice in each case. One shows the spatial associations between locations of pollution sources and demographic attributes. Environmental injustice can be found when most pollution sources are clustered in lower-income and minority communities (Montgomery & Chakraborty, 2015). Another is to analyze a regression so that each variable is statistically significant in affecting the siting of polluting facilities. For example, a logistic regression was often used to predict the siting (which can be seen as a binary dependent variable) (J. Pastor, Manuel, Sadd, & Morello-

Frosch, 2002). The third is to use ratios to see whether lower-income people disproportionately received remediation activities or not. One example can be the Palma ratio showing income inequalities (Liu, Kwan, & Kan, 2021). The Palma measures the share of all income received by the 10% people with highest disposable income divided by the share of all income received by the 40% people with the lowest disposable income (OECD, 2022). A higher Palma ratio indicates an unequal income distribution, which can result in evidence of environmental injustice. However, the above-mentioned three methods may not deliver the population affected by hazardous materials and their socio-economic attributes within a certain distance. Presumably, the local information can be leveraged for public decision-makers and researchers to diagnose public issues exactly and redesign policies. One example is the estimated findings about the demographic information (e.g., population, incomes, race) living near oil and gas wells in the United States (Proville et al., 2022).

The purpose of this article is to estimate the population (potentially) suffered from pollution and their incomes and examine the existence of environmental (in)justice in a case. I selected Pennsylvania's oil and gas well plugging program (WPP) and counted the estimated number of people influenced by leaking pollutants and their incomes. Then, I checked whether the PA state government mostly cleaned up abandoned oil and gas wells from 2010 to 2019 in poor regions or not. It is known that unplugged oil and gas wells can emit pollutants, contaminate environments, and harm residents through water, soil and air (Kang et al., 2016; PA DEP, 2021a). The Pennsylvania Department of Environmental Protection (DEP) has remediated about 3,300 abandoned oil and gas wells by September 2021 (PA DEP, 2021c). The DEP uses a scoring system and ranks the unplugged wells under the limited plugging funds. The wells that pollute environments seriously but harm few residents could have a higher priority in well plugging. On the contrary, the wells that leak fewer pollutants but affect many people would remain unplugged. As a result of limited number of plugged wells, environmental injustice could occur across PA communities when rich and/or white-dominated communities were more likely to receive the benefits of the WPP.

For the methodology, the plugged and unplugged wells of the 2010-2019 DEP plugging lists are the units of analysis. The DEP-plugged and the DEP-unplugged wells were matched by the WPP scores to control each well's environmental risk for each year. I leveraged the Zillow Transaction and Assessment Database (Ztrax) to calculate the number of residents who can get damaged physically or have lowered property values caused by unplugged oil and gas wells. The Ztrax offers the characteristics and locations of properties transacted in real-estate markets to academic, non-profit and policy researchers freely (Zillow, 2021). The American Community Survey (ACS) datasets were also used to get socio-economic datasets but needed to be adjusted because some oil and gas wells can make negative spill-over effects across multiple census units. Quarter-mile buffers were applied to estimate the number of residents living nearby the DEP's plugged and unplugged wells. Then, the populations were categorized by income deciles to compare the distributions of populations between the DEP-plugged and DEP-unplugged wells. As a result, it is estimated that 57,406 residents were favored by the DEP well plugging from 2010 to 2019. Among the beneficiaries, 51,964 residents were from 2010 to 2014 and 5,442 residents were from 2015 to 2019. On the other hand, it seems that 42,268 residents living near unplugged wells did not receive environmental protection by the DEP from 2010 to 2019. Among them, 36,302 residents were from 2010 to 2014 and 5,966 residents were from 2015 to 2019. The population below the bottom 10% income for the DEP-plugged wells was 18,732 and the one for the DEP-unplugged wells was 3,752 from 2010 to 2014. The population below the bottom 10% income for the DEP-plugged wells was 1,882 and the one for the DEP-unplugged wells was 788 from 2015 to 2019. The number of poor people who cannot afford to leave polluted regions but received the environmental services is greater than the one who were not protected by the DEP. Given the estimated populations, evidence of environmental injustice was not found in the PA DEP well-plugging.

2.2 Identification of Environmental (In)justice in the U.S. Oil and Gas Sectors

Environmental Justice (EJ) can be defined as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (U.S. EPA, 2021a)." The Executive Order 12898 in 1994 was released to address environmental justice in minority populations and low-income populations. Federal agencies should 1) identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations, 2) develop a strategy, and 3) promote non-discrimination in federal programs (U.S. EPA, 2021b).

Despite of the legal frameworks, demographic features seemed to be significantly correlated with the siting of environmental hazards or residential utilities at state and local levels (Bullock, Ard, & Saalman, 2018). Some EJ studies focused on the extent to which local communities can influence public decision-making and administrative procedures significantly. The socially excluded may not have political resources enough to influence public decisions to avoid pollution (NIMBY) and bring public funds for better welfare (PIMBY). One explanation about why "minorities attract facilities" can be a lack of political resources (Hamilton, 1995) or complexity in negotiation for compensation (Hurley, 1997) that could leave environmental justice communities unprotected. Legislators that politically represent constituents could marginally but significantly influence the priorities of environmental policies by adjusting time or budgets to clean up polluted facilities. Also, minorities, low-income, and those who had education below colleges can be statistically significant variables for environmental injustice due to language barriers (Gibson-Wood & Wakefield, 2013) and lack of experience and solidarity (de Souza Briggs, 1998) as well.

Other EJ studies selected regions that are polluted and not polluted, and compared socio-economic attributes to know who gained benefits or received costs. Some found evidence of environmental injustice; industrial wastes were clustered nearby a vulnerable population (Gamper-Rabindran & Timmins, 2011; Mohai & Saha, 2007). On the other hand, some types of residents could receive more economic gains from industries such as incomes than others. This approach, so-called benefit-sharing EJ, has examined whether the socially disadvantaged benefited or got losses from facilities (Feyrer, Mansur, & Sacerdote, 2017; Fry, Briggle, & Kincaid, 2015). However, the correlations between demographic variables and the presence of pollution may not be sufficient in explaining whether differences in socio-economic factors have the independent effects on the siting of polluting facilities. It is because that minorities or the poor voluntarily had moved in the regions at which environmental hazards arrived afterwards ("move-in effects"). One empirical finding (M. Pastor, Sadd, & Hipp, 2001) indicates that minorities are likely to live near storage and disposal facilities, rejecting the hypothesis that minorities would move to regions where unwanted facilities are located because of relatively lower housing prices. Environmental injustice may exist when people move in before installing facilities because they have paid for housing without recognizing future environmental harms. Economically, some moved to environmentally dangerous regions to find cheaper residential buildings. The economic perspective regards no environmental injustice when people in danger of pollution had recognized the presence of polluting facilities before moving and then paid for accommodations. In contrast, environmental injustice occurs when people had not known pollution sources and faced environmental risks after moving. Thus, researchers used statistical regressions to estimate the causal effects between socio-economic variables and know the possibilities of being damaged in regions.

Most EJ literature on the U.S. oil and gas industry also analyzed the distributions of economic benefits and environmental risks in the stage of resource development. Revenues may be transferred mostly to landowners (J. Brown, Fitzgerald, & Weber, 2017; Kelsey, Metcalf, & Salcedo, 2012) or resource experts (Hardy & Kelsey, 2015), not flowing to local communities. In contrast, the facts that property values can be lowered by oil and gas exploration activities (Balthrop & Hawley, 2017; Gopalakrishnan & Klaiber, 2014) supported environmental injustice. Racial minorities are less likely to have contractual leasing terms about bonus and royalties to landowners or well restoration because of lower English proficiency and fewer channels to information (Timmins & Vissing, 2022). Some communities bore environmental risks from well drilling (Johnston, Chau, Franklin, & Cushing, 2020; Meng, 2015; Ogneva-Himmelberger & Huang, 2015; Rozell & Reaven, 2012) to locally unwanted land use for pipelines (Strube, Thiede, & Auch, 2021). The clusters of leaking pollutants were detected around O&G wells (D. R. Brown, Lewis, & Weinberger, 2015) and residential areas and were likely to cause physical (Casey et al., 2016) and mental (Hirsch et al., 2018) diseases through the noise (Hays, McCawley, & Shonkoff, 2017), particulate matter (McCawley, 2015), contaminated water (Brantley et al., 2014). It was expected that racial minorities are more likely to be exposed to flaring from oil and gas production sites (Johnston et al., 2020). Furthermore, fewer regulatory inspections have occurred near poor communities, resulting in higher complaints of citizens about the violations of rules (DiSalvo, Hill, & Zhang, 2020). Laurens, York, and Arnold (2019) concluded that communities exposed to harm were less likely to acquire fund use with priority and achieve consensus and the inclusion of profit and non-profit organizations in Pennsylvania. As to distributive impacts after well plugging, Shappo (2020) compared the temporal trends of housing values close between unplugged and plugged wells and found that residential buildings' prices around plugged wells increased because of cleaner environment.

2.3 Pennsylvania's Well Plugging Program

Well operators are legally required to plug oil and gas wells after finishing resource extraction to prevent pollutant leaks and protect people and environments[6]. Per the Pennsylvania Act 13, well operators can be defined the person who did well registration with a well permit application or those who locate, drill, operate, alter and plug a well for natural resource production from a well. Well operators "shall plug (unproduced wells) to stop vertical flow of fluids or gas within the well bore, unless the department has granted inactive status for the well or it has been approved by the department as an orphan well (§3220)." Despite the regulations, approximately 145,000 documented oil and gas wells remain unplugged in Pennsylvania (IOGCC, 2020). Pennsylvania could be the state that have the largest number of unplugged wells among oil and gas producing states based on the fact that the number of undocumented wells could be from 100,000 to 560,000 (IOGCC, 2020). Figure 1 shows that abandoned wells, pipelines, and oil storage tanks are still located in Pennsylvania, not treated by responsible parties. Unplugged wells are likely to

[6] URL: https://www.legis.state.pa.us/WU01/LI/LI/CT/HTM/58/58.HTM. Accessed December 20, 2022.

pollute groundwater, soil, and air through industrial waste leaks (Kang et al., 2014; US EPA, 2016), and induce disease (Department of Health, 2019; Frazier, 2019). Also, the presence of unplugged wells may lower property values in real-estate markets because of considerable cleanup costs borne by landowners and residents (Shappo, 2020). However, more stringent regulations and the decreases in oil and gas prices may make more well operators insolvent and leave wellheads, oil and gas storages, and pipelines abandoned as follows. “The incident, while extreme, reflects a growing global problem: more than a century of oil and gas drilling has left behind millions of abandoned wells, many of which are leaching pollutants into the air and water. And drilling companies are likely to abandon many more wells due to bankruptcies, as oil prices struggle to recover from historic lows after the coronavirus pandemic crushed global fuel demand, according to bankruptcy lawyers, industry analysts, and state regulators.” – Nichola Groom, Reuters, 2020

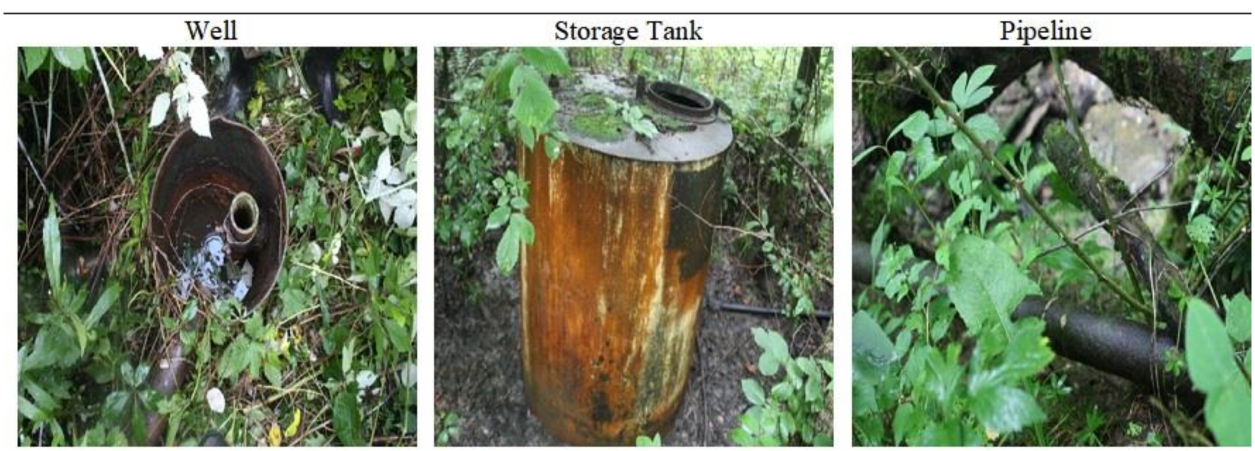

Figure 2.1: Industrial Debris in the Abandoned Well Sites (Image by the Author)

The Pennsylvania 2012 Oil and Gas Act 13 mandates the PA Department of Environmental Protection (DEP) to collect and make available data on fines, penalties, compliance, and wells drilled (Murtazashvili & Piano, 2018). The DEP has executed the well plugging program (WPP) since 1989 and plugged abandoned wells by spending $15,100 per well on average and a minimum of $3,400 per well (Weber, 2021). The DEP has plugged 3,330 wells, and 8,663 wells were on the DEP lists (PA DEP, 2021a) as of September 2021. The primary funding sources are the surcharges[7] from well operators who applied for drilling permits, legislative appropriations, growing greener, DCNR funded, and others. But the policy instruments for well plugging, including impact fees, surcharges, and assurance bonding, seem insufficient to guarantee well restoration by energy companies even when well operators become insolvent (Weber, McClure, & Simonides, 2018). Also, there have been the limited administrative capacities of removing all the remaining abandoned wells "at current surcharge rates and per-well plugging costs (PA DEP, 2021a)." The expenditure of well-plugging funds has continuously decreased since 2008 and so has the number of plugged wells[8]. Thus, the DEP scored all the targeted wells on the list and

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[7] Well plugging contractors are funded with permit surcharges which are the permit application fee. The orphan surcharge is $200 for a gas well or $100 for an oil well. The abandoned well surcharge is $50. URL: https://files.dep.state.pa.us/oilgas/bogm/bogmportalfiles/AbandonedOrphanWells/WellPluggingProgram.pdf. Accessed December 22, 2022.

[8] After 2012, the DEP has expended the well plugging funds mostly less than 50% of the expenditure in 2008. URL: https://www.dep.pa.gov/Business/Energy/OilandGasPrograms/OilandGasMgmt/LegacyWells/Pages/Well-Plugging-Program.aspx. Accessed December 22, 2022.

selected an 0.5% of the total wells approximately as priority-wells by the degrees of environmental risks (PA DEP, 2021b)[9].

There are several factors affecting the presence of being plugged except the degree of environmental risk. Firstly, demographic attributes may facilitate or deter the well plugging in communities determined by the PA DEP. Low population or minorities may have smaller bargaining power with well operators in the dispute of well plugging similar to the leasing contractual process (Timmins & Vissing, 2022). Also, it was found that lower-income households moved nearby hazardous sites because of their lower propensity to invest environmental quality (Banzhaf & Walsh, 2008). In the context of oil and gas well restoration, Ogneva-Hilmmelberger and Huang (2015) found that poverty levels were higher in potentially exposed areas than non-exposed ones, implying evidence of traditional environmental injustice. In contrast, Clough and Bell (2016) concluded that poverty levels and minorities percentages closer to wells are smaller than those further from wells, which can be seen as no evidence of traditional environmental injustice. Instead, it was found that highly salaried and educated people were more prominent within the areas closer to oil and gas wells. Secondly, unplugged wells are more likely to be plugged than others when economic incentives are larger from well plugging. For example, landowners and real estate developers would be reluctant to invest in well plugging because of lower expected rate of return (e.g., recovery costs). Harleman et al. (2022) found the decreased property values and tax annual revenues near unplugged wells compared to plugged

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[9] Some wells that showed leak gas and even explored were plugged by the DEP urgently, not based on evaluative scores. URL: https://padep-1.maps.arcgis.com/apps/MapTour/index.html?appid=8344ed34ab57446cbdaad3c9e4b2a8d5. Accessed December 22, 2022.

ones in Washington, Pennsylvania. The failure of plugging wells may put more financial burdens on residents and landowners, resulting that the volumes of housing investments and local governments' revenues decreased. Lastly, the well plugging priorities and time to be taken for completing well plugging can be marginally influenced by the attributes of legislators who politically represent local preferences and interact with administrators in a state government (Bang & Hollibaugh Jr, 2021). The oil and gas wells' plugging were determined by well firms and landowners. This study raised the question that how public decisionmakers have provided the WPP services to various types of residents from 2010 to 2020.

2.4 Data, Analyses, and Findings

The wells that were plugged by the PA DEP (hereafter "DEP-plugged wells") and were unplugged (hereafter "DEP-unplugged wells") from 2010 to 2020 were leveraged as a unit of analysis. The information about the DEP-plugged wells can be available from the PA DEP website[10], including the well identification numbers, the presence of plugging, plugging years, and locations. Most DEP-plugged wells were in the Southwest, Northwest, and Northcentral regions above the Marcellus formation. Thus, the lists of DEP-plugged and unplugged wells that were not actually happened but could have occurred from 2010 to 2020 were generated with the PA oil and gas compliance reports and production reports. Matching DEP-plugged wells with

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[10] URL:
http://cedatareporting.pa.gov/Reportserver/Pages/ReportViewer.aspx?/Public/DEP/OG/SSRS/Abandoned_Orphan_Web. Accessed December 22, 2022.

DEP-unplugged wells by evaluative scores is necessary for controlling unknown factors possibly affecting well plugging. Previously, Bang and Hollibaugh (2021) generated "synthetic" priority scores on the wells plugged by the PA DEP by using geographical and well-specific characteristics[11]. Since the evaluative scores by the DEP include technical and geographical attributes on each well, DEP-plugged wells may have the similar degrees of pollution and road accessibility as DEP-unplugged wells at the similar or same scores. I regressed the 2018 DEP scores on the characteristics of wells, distances to roads, and sizes of areas to generate synthetic scores on DEP's plugged and unplugged wells. DEP-unplugged wells were paired up with DEP-plugged wells for each based on scores for controlling technical factors in the comparison of demographic variables.

The spatial analyses between demographic variables and the locations of the DEP's plugged and unplugged wells in 2020 were conducted with the geographic information system (GIS). Quarter-mile buffers were applied to all the plugged and unplugged wells to capture the local information. The results for DEP-plugged wells and DEP-unplugged wells are compared to see whether low-income residents received the WPP more or not. The EJ variables used were incomes, race, educational attainments, and children at the U.S. census tract levels; (1) median household incomes, (2) the percentage of minorities (or only white), (3) the percentage of those

[11] However, the score estimation might be inappropriate for evaluating the impacts of pollutants on people and environments because targets (e.g., population potentially influenced by pollution sources) were not considered. Rather, the U.S. EPA considers residents and sensitive environments in the prioritization of abandoned facilities in the Superfund and Brownfields programs. Specifically, the hazard ranking system of the Superfund uses the scoring system that multiplies the concentration of pollutants, the presence of pathways (e.g., air, water) and targets. Then, wasted sites with high scores would be listed on the National Priorities List.

who finished high schools or below, and (4) the percentage of children (5 to 14 years)[12]. Incomes and race are differently colored by the figures; the darker in each census tract, the higher values in incomes or the share of whites. There were variations in the two demographic variables for DEP's plugged and unplugged wells respectively; for example, some DEP-plugged wells were in higher income areas but others were in lower income areas. Also, it seems that there might be small differences in the demographics between DEP-plugged and unplugged wells. Most DEP-plugged and unplugged wells were located in the Southwest, Northwest, and Northcentral regions above the Marcellus formation. Figure 2 tells us that it might be hard to find the significant differences of incomes or racial compositions with only the visualized results. Instead, per the table 1, the t-test concludes that the incomes, race, and children are not statistically significant in explaining the differences in the locations of DEP's plugged and unplugged wells. On the other hand, the educational attainments are statistically significant at the 0.10 significance level.

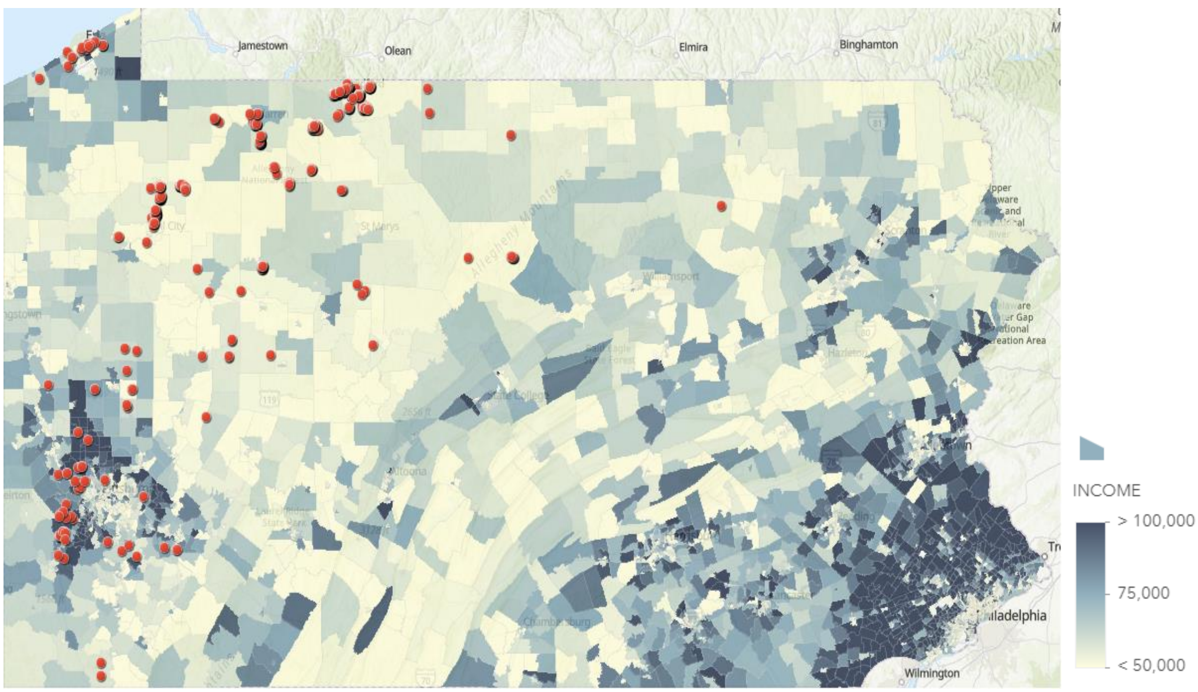
[12] Similarly, the PA DEP environmental justice office designated some regions as EJ communities, which can be defined to "any census tract where 20 percent or more individuals live at or below the federal poverty line, and /or 20 percent or more of the populations identifies as non-white minorities, based on data from the U.S. census bureau and the federal guidelines for poverty." URL: https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx. Accessed December 22, 2022.

Table 2.1. Comparison between DEP-unplugged and DEP-plugged Wells (2020)

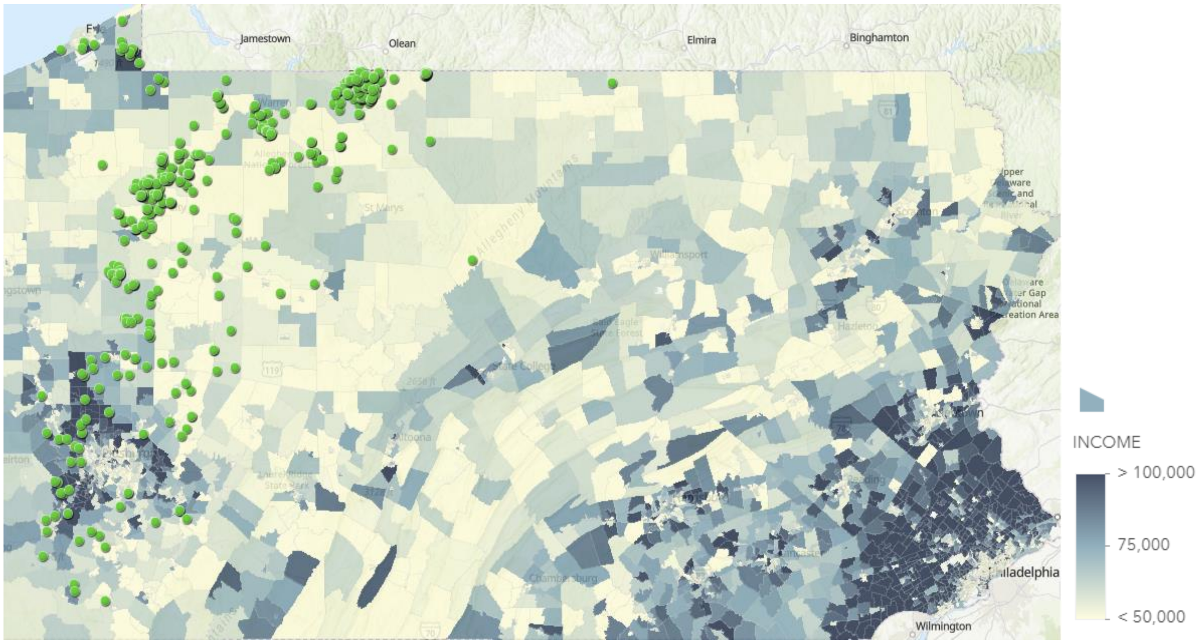
Variables	Average	Differences between DEP-plugged Wells and DEP-unplugged Wells
Household Income	$55,908.8	$371.2
% of Minority	3.20	-0.24
% of High Schools or Below	8.83	-0.26*
% of Children (5-14 years)	10.53	0.18
Number of Observations	1,234	

* $p < .10$. * * $p < .05$. * * * $p < .01$.

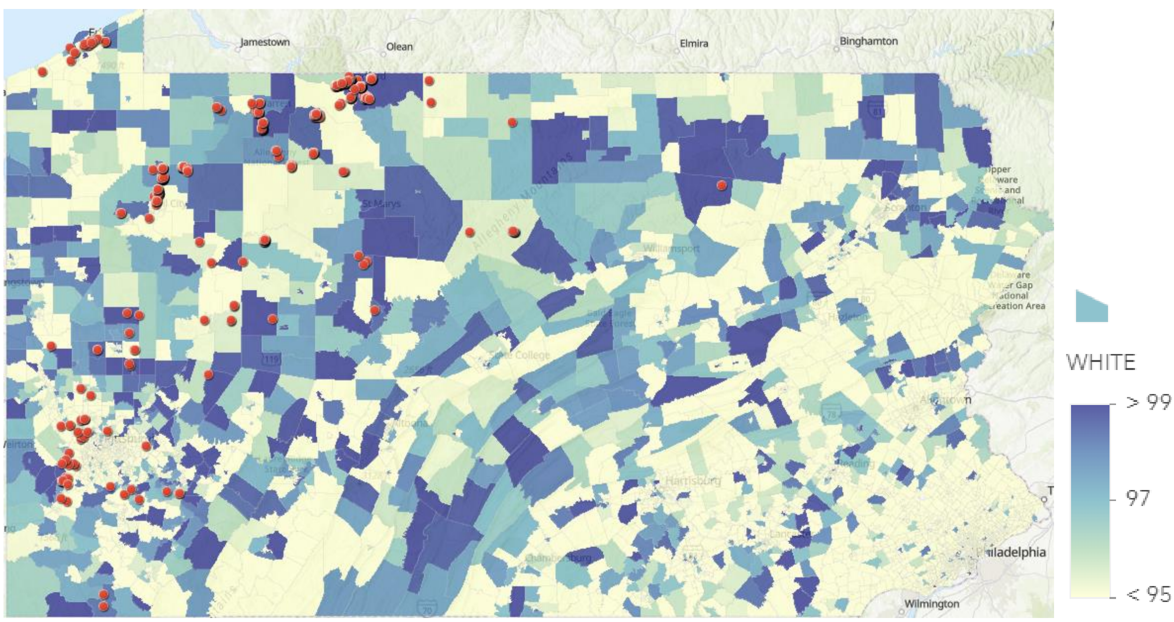
- DEP-plugged Wells and Median Household Incomes (2020)



- DEP-unplugged Wells and Median Household Incomes (2020)



- DEP-plugged Wells and % of White (2020)



- DEP-unplugged Wells and % of White (2020)

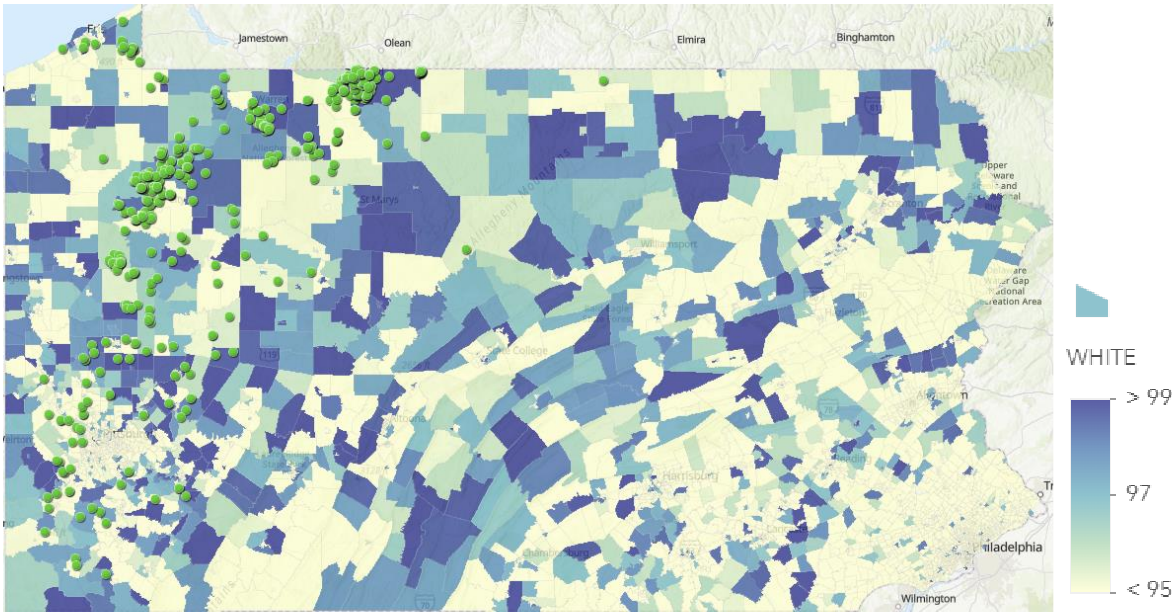


Figure 2.2. Spatial Analyses over Demographic Attributes in Pennsylvania

To estimate and compare the distributions of the demographic variables differently, I leveraged the Ztrax and counted the population nearby DEP’s plugged and unplugged wells. The Ztrax has freely but conditionally provided the large-scale information about properties, its locations, assessed values, and transaction records to those working on non-profit research (Zillow, 2021). Scholars and practitioners could adjust the scope of environmental impacts and estimate the number of affected residents more accurately with the Ztrax. The assumption that two people live in each residential building is needed. The estimated populations were used to give a weight to the demographic attributes for each DEP’s plugged and unplugged well; if no population is estimated for the region, the EJ variables will not be considered. It might be appropriate to rule out sparsely-populated areas in the analyses because abandoned and orphan oil and gas wells may not damage anyone.

The unit of analysis is a specific buffer around each well (hereafter referring to "location"). I applied the buffer containment approach with a geographic information system to estimate highly localized effects of unplugged wells on residents. Previous studies assumed the scope of influence, set fixed distance (Kearney & Kiros, 2009; Mohai & Saha, 2007) or varying distance (Chakraborty & Zandbergen, 2007) buffers, and generated more accurate and localized information (Czolowski, Santoro, Srebotnjak, & Shonkoff, 2017; Greenberg, 2017; Zwickl, 2019). It is assumed that leaking pollutants could harm health, environments, and property values locally, not widespread. Also, using a large radius of buffer may make some buffers overlapped, which can raise the issue of estimating the marginal effects of well plugging correctly. When most residents live in the intersection of buffer zones, plugging one contaminated well may be less significant to them than those living closer to the plugged well. Smaller sizes of buffers may be necessary to prevent excessive cases of buffer overlaps. I applied the three different-sized buffers that have radius less than one mile (0.25, 0.5, 0.75 miles) to estimate the number of people living next to the oil and gas wells. One location mainly falls within one U.S. census tract, but some locations are overlapped with multiple U.S. census tracts. To make one location reflect the characteristics of communities over multiple census tracts, I made weights that are proportional to the sizes of overlapped locations and averaged demographic information with the calculated weights. So, the original ACS data for each well can be subject to be adjusted when a location could contain neighboring census tracts' attributes, leading to the increases or decreases in the weighted figures. In the figure 3, the red circle is the DEP-plugged wells (API: 049-00183) in Erie County. The three red circles are the buffers ranging from 0.25 mile to 0.75 mile. The black dots are buildings imported from the Ztrax. No census tracts are overlapped for the smallest size buffers (0.25 mile) but other two buffers cover two census tracts.

Figure 2.3. The Estimation of Population with Buffers Containments of Ztrax

For each year, it was estimated that some DEP-plugged and unplugged wells affected NO population within the three size buffers. For example, there might be no one living next to 290 DEP-plugged wells (or 306 DEP-unplugged wells) within a quarter buffer in 2020. This is almost half to the number of 2020 DEP-plugged wells, which may influence the comparisons between the two types of wells after excluding the wells without affected population. I found the number of residents falling into income ranges by a ten-percentile for DEP-plugged and unplugged wells from 2010 to 2020. The income deciles were imported from the household income dispersion of the U.S. census.[13] The EJ measure, which determines the existence of environmental (in)justice, is the difference between the estimated population for DEP-plugged wells and the one for DEP-unplugged wells at the bottom 10% income. A larger number of people for DEP-plugged wells indicates evidence of environmental justice because more people with the bottom 10% income received the public services and fewer people were excluded.

The table 2 shows that the number of residents in the bottom 10% income are the largest one among the WPP's beneficiaries during each period. Also, more residents below the bottom 40% income (who cannot afford to leave polluted regions) received the WPP. It is estimated that 57,406 residents were favored by the WPP from 2010 to 2019. 51,964 residents were from 2010 to 2014 and 5,442 residents were from 2015 to 2019. On the other hand, 42,268 residents living near unplugged wells did not receive environmental protection by the DEP from 2010 to 2019. 36,302 residents were from 2010 to 2014 and 5,966 residents were from 2015 to 2019. The population below the bottom 10% income for the DEP-plugged wells was 18,732 and the one for the DEP-unplugged wells was 3,752 from 2010 to 2014. The population below the bottom 10% income for the DEP-plugged wells was 1,882 and the one for the DEP-unplugged wells was 788 from 2015 to 2019. That is, the number of poor people who received the public services is greater than the one who were not protected. Given the estimated populations, evidence of environmental injustice cannot be found in the WPP execution.

[13] The data can be available from the PA DEP website as follows:

https://www.census.gov/data/tables/time-series/demo/income-poverty/historical-income-inequality.html

Table 2.2. Incomes and Population for DEP-unplugged and DEP-plugged Wells

Year	2010 - 2014		Year	2015 - 2019	
Type	Unplugged Wells	Plugged Wells	Type	Unplugged Wells	Plugged Wells
Decile 1 ($17,653-$33,636)	**3,752**	**18,732**	Decile 1 ($0-$42,250)	**788**	**1,882**
Decile 2 ($33,636-$41,321)	2,478	1,504	Decile 2 ($42,250-$45,895)	1,874	872
Decile 3 ($41,321-$42,870)	2,440	1,482	Decile 3 ($45,895-$46,203)	0	48
Decile 4 ($42,870-$45,724)	11,010	4,294	Decile 4 ($46,203-$46,203)	24	40
Decile 5 ($45,724-$46,250)	2,848	2,808	Decile 5 ($46,203-$49,583)	206	32
Decile 6 ($46,250-$48,300)	768	1,784	Decile 6 ($49,583-$53,160)	1,620	588
Decile 7 ($48,300-$49,398)	1,786	3,444	Decile 7 ($53,160-$53,160)	0	880
Decile 8 ($49,398-$50,568)	5,346	6,534	Decile 8 ($53,160-$59,518)	854	640
Decile 9 ($50,568-$57,208)	1,598	1,070	Decile 9 ($59,518-$63,393)	102	6
Decile 10 ($57,208-$145,504)	4,006	10,312	Decile 10 ($63,393-$94,356)	498	454
Total	**36,032**	**51,964**	Total	**5,966**	**5,442**

2.5 Discussion and Conclusions

This study examined evidence of disproportionately distributed well plugging services by estimating the number of residents living nearby unplugged wells and counting how many poor people were benefited or isolated. Evidence of environmental injustice was not found with the comparison of demographic attributes (e.g., incomes, the ratio of whites, educational attainments, and the ratio of children) between DEP-plugged wells and DEP-unplugged wells. The spatial analyses conducted with the GIS also concluded that there are not clear differences in the EJ factors for the two types of oil and gas wells in Pennsylvania. Setting the scope of negative influence, leveraging the Ztrax, and counting the population living within quarter-mile buffers from wells were conducted to describe the distribution of public services in more details. I compared the local characteristics of the DEP-unplugged and the DEP-plugged wells from 2010 to 2019. Consequently, the number of residents who benefited from the PA government was larger than the one of those who were not protected from hazardous materials from 2010 to 2014. On the contrary, the number of residents were not protected from unplugged wells was larger than the one of those who received well plugging services. But commonly more well plugging services were distributed toward the poor not eligible for well plugging by themselves (at the below 10% percentile); evidence of environmental injustice was not found.

However, it seems that there are the limitations of the analyses. First, from the view of the rich (at the over 90% percentile), more people were benefited from the government from 2010 to 2014 compared to the one excluded from the WPP. Also, there was no significant difference in the population living nearby DEP-plugged and DEP-unplugged wells from 2015 to 2019. It could be regarded that evidence of environmental injustice was found because environmental benefits from the WPP were distributed to the rich more. Second, when it comes to the use of buffer containment approach and the American Community Survey, the estimated incomes used to compare could be overestimated. The buffer estimation may require the assumption that the variations of demographic characteristics within a census tract is equal to the one within a buffer. But the distribution of income can influence the estimator of each buffer; more poor people within a buffer, an estimator in the analysis would be *overestimated*. Since the U.S. census tracts are the smallest units available in every year, the findings should be interpreted with the limitation of data and estimation. Lastly, there may be other factors influencing the likelihood of being plugged by the DEP at given unplugged well or the rates at which each unplugged well is plugged (Hird, 1990). One possible factor can be the characteristics of legislators who could urge public administrators to proceed mediational activities quicker (Bang & Hollibaugh Jr, 2021). Bigger amounts of abandoned well plugging funds could increase the number of plugged wells and make poor people enjoy environmental protection service more. The experience of governing environments collectively without resort to public authorities are likely to reduce the number of unplugged wells. In a community where members share trust and interact with one another sustainably, it is probable that costs associated with information collection and negotiation would be lowered and opportunistic behaviors could be prevented.

This research may have implications to public managers and scholars that mining more accurate demographic attributes could result in the evaluation of environmental policy in a different way. Setting the geographic scope of influence and leveraging large-scale datasets can be one possible approach for measuring the extent to which policy goals are attained. It is expected that public managers can know how many people benefited or isolated from policy execution and their other socio-economic status. An existing public program could be redesigned to change the distribution of environmental hazards (or public services) and maximize the number of policy beneficiaries. If public administrators can assist larger number of people who are socially marginalized to overcome public issues, relevant policy goals would be improved compared to the status quo. For example, political responsiveness and budgetary efficiency could be achieved more by approximating the population and their attributes and restructuring public programs.

3.0 Redesigning Public Program and Balancing Policy Goals: Pennsylvania's Oil and Gas Well Plugging Program

3.1 Introduction

Goals may conflict or cooperate. Sometimes, one goal should be attained less to make another goal better off. In markets, efficiency can be lowered to enhance equity (Okun, 1975). A lack of resources can be attributed to the tradeoffs between goals. Public and private decisionmakers would be required to substitute one objective with another under limited budgets, information, and human resources. Ambiguity in goal definitions or goal prioritization may also cause conflicts in goals (Chun & Rainey, 2005). On the other hand, goals can be improved without harming any goal (Wenger, O'Toole Jr, & Meier, 2008). Technological advances (e.g., blockchain) could enable decisionmakers to attain multiple goals more without increasing budgets or trading one goal for another (Adams, Kewell, & Parry, 2018). High levels of administrative capacities also may lead to the simultaneous improvement of goals (Smith & Larimer, 2004).

Goal tradeoffs and goal synergy can co-exist within a public program. Some goals could be achieved more but others would be attained less. A large body of studies on the United Nations' Sustainable Development Goals found the existence of goal conflict and goal synergy among the seventeen goals and suggested the possibility of transforming goal conflict into goal synergy (Bastos Lima, Kissinger, Visseren-Hamakers, Brana-Varela, & Gupta, 2017; Nerini et al., 2018). Also, some Sustainable Development Goals were selected and prioritized (Forestier & Kim, 2020). For example, it seems that "no poverty" has a synergistic relationship with other goals but improvement in "responsible consumption and production" may sacrifice others (Pradhan, Costa, Rybski, Lucht, & Kropp, 2017). While the seventeen goals may be compatible with the mission of the United Nations (United Nations, 2022), it would not be possible to make all the goals better off relative to the status quo (Kroll, Warchold, & Pradhan, 2019). Then, how can public decisionmakers balance multiple goals and justify the changes in policy outcomes?

This article redesigned an environmental policy with large-scale information, and simulated the changes in policy outcomes in the context of the Pennsylvania's oil and gas well plugging program (WPP). There have been concerns about unplugged oil and gas wells in the United States because unplugged wells can emit hazardous materials and put a threat to residents and environments (Groom, 2020). The PA Department of Environmental Protection (DEP) has selected abandoned oil and gas wells under budgetary constraints and cleaned up the well sites (PA DEP, 2021a). However, it seems that the current WPP does not evaluate the negative influence of pollutants on communities, which may result that the DEP fails to provide the public service efficiently and/or equitably. For the methods, two goals were added to the current WPP, and abandoned oil and gas wells were re-prioritized under the new scoring system of the WPP. Then, I examined the extent to which each goal is attained more or less. The three goals were in the analysis; one is to reduce the severity of environmental pollution, and other two goals are to maximize the population benefited from the WPP and to increase the incomes of beneficiaries respectively. The DEP evaluative scores, the population living nearby wells within a quarter-mile, and the median household incomes were used as variables to measure the changes in the three goals. The Zillow Transaction and Assessment Database (Ztrax) and the U.S. census were leveraged to approximate the population and the incomes near wells to be plugged by a government. The Zillow has provided the Ztrax to scholars and public administrators so that the Ztrax can be used to analyze real-estate issues freely for research and policy formation (Zillow, 2021). The Ztrax includes the public records, deed transfers, mortgages, property characteristics, and even geographic information. An assumption that two people live in one residential building was set to count the population influenced by abandoned oil and gas wells in Pennsylvania. The 2010-19 median household incomes at U.S. Census tracts were used. The weighted sum approach was applied to consider multiple criteria simultaneously and make new scores for wells. As a result, the revised WPP could plug more wells in lower-income and densely populated areas but clean up highly-polluted wells fewer compared to outcomes under a current WPP. Substantively, the PA DEP would achieve more the goals of protecting citizens influenced by unplugged wells and assisting the socially disadvantaged under the new WPP. However, it is found that improving the budgetary efficiency and environmental justice sacrifices the goal of plugging technically unstable wells first, not showing the synergistic relations among the goals. Despite the inability of eradicating the goal conflict of the WPP, the new WPP can be justified because more people with lower incomes could be protected from hazardous materials under the revised WPP.

3.2 Goal Tradeoffs and Goal Synergy in Public Programs

Public administrators often encounter multiple goals to be achieved under limited administrative resources in planning (Walker, 2008) and resource governance (White, Halpern, & Kappel, 2012).

Objectives that are widely sought in public programs may be prudent use of public funds, equal distributions of public services across jurisdiction, open access to public decision-making for democratic governance and so on. However, the issue with managing goals may arise from the conflicts among goal attainments (Rainey, Backoff, & Levine, 1976), which means that public administrators would sacrifice one goal for achieving another more. For instance, public projects could be efficient when a government does not have to hold public hearings which may be one critical part of administrative procedures. It is because that administrators can save time and costs necessary for coordinating various interests. Goal conflicts are likely to be prevalent when policy goals are complicated or ambiguous, and public tasks are difficult to be accomplished (Meyers, Riccucci, & Lurie, 2001). The goal preferences of public decision-makers could affect which a goal should be prioritized and result in goal conflicts (Roberts, Velotti, & Wernstedt, 2021). Political control mechanisms such as monitoring, rewarding and punishing public managers may influence the decisions of goals during policy implementation (Rutherford & Meier, 2015). The characteristics of politicians and workforce in governments are likely to be related to preferrable goals within public programs (Bang & Hollibaugh Jr, 2021; Liang, Park, & Zhao, 2020). However, substituting one goal with another in public programs may provoke the political resistance of those who receive outcomes and could raise the questions about both goal hierarchy (e.g., does efficiency dominate equality?). Public planners would be asked to justify the changes in policy outcomes.

Much literature largely identified the presence of goal-tradeoffs and/or goal synergy in public programs, and explored the conditions and strategies of resolving the conflicts between/among goals. Okun (1975), in his book "*Equality and Efficiency*," acknowledged the presence of a tradeoff between efficiency and equality in our society. But, at the same time, he pointed the possibility of achieving "greater efficiency and greater equality (pg. 4)" because of technologies and increased productivity. The managerial capacities of public servants may be also one significant factor improving multiple performances without sacrificing one another. With the school performance measurements in Netherlands, Mikkelsen (2018) did not found evidence of trade-offs among goals, instead, found that a principal who performed better in procedures was more likely to generate better outcomes for production. Resh and Pitts (2013) showed that goal synergy is conditionally possible in the case of interactions between lower/instrumental goals in the public high schools. Public organizations and public mangers that adopt innovative management skills could improve seemingly conflicting goals at the same time (Meier & O'Toole Jr, 2001; Wenger et al., 2008). Given conflicts in goals, it is likely that people would accept all relevant goals and make balancing between goals to avoid extreme solutions (Shaddy, Fishbach, & Simonson, 2021).

However, it might not be necessarily that goal conflicts or goal synergy are found within a specific policy environment. Some goals are in trade-offs relationship but other goals are synergetic within the Sustainable Development Goals (Nerini et al., 2018). The balanced scorecard can be seen as a strategic tool to monitor progress for each business goal and balance multiple objectives with goal trade-offs and goal synergy (Sundin, Granlund, & Brown, 2010). One possible method of balancing goals could be the (re)prioritization of policy targets by maximizing all relevant policy outcomes. Prioritization can be useful for public decisionmakers to set justifiable evaluative criteria, allocate limited public funds, and adjust the extent to which multiple goals would be attained. For example, the United States Internal Revenue Service provided the economic impact payment to those in need of financial supports because of the covid pandemic by establishing the eligibility standards (The U.S. IRS, 2022). Government also utilized scoring systems to prioritize planned sites including conservation (Moilanen et al., 2005), construction (Cholodofsky, 2019), and transportation (Sharma, Jagannath, Kar, & Prentkovskis, 2018). The multiple-criteria decision analysis can be applied to balance multiple goals quantitatively and objectively. This approach can refer to the objective and quantitative approach of scoring each alternative and selecting the highest-scored one (Zionts, 1979). Among the analytical methods, the widely-used one is a goal programming that captures the deviations between goals and outcomes for multiple objectives and selects the best option minimizing the sum of the deviations (Jayaraman, Colapinto, La Torre, & Malik, 2015; San Cristóbal, 2012). In most case, the unit of a measurement may vary according to a goal. Thus, decisionmakers are required to normalize the variable for each goal to overcome the issues of incommensurability. For the weighted sum approach, weights over each goal are used to reflect relative importance, generate a single sum as the achievement indicator, and compare alternatives directly. Technically, decisionmakers would choose the combinations of weights that minimize weighted sums of the different objectives (Das & Dennis, 1997). One advantage of applying the weighted sum approach may be that decisionmakers can find the combination of conflicting goals more than two for optimization. In contrast, the weighted sum approach could generate an optimal solution that are not consistent with pareto improvement; one goal will be better off with harming other goals.

3.3 Pennsylvania's Well Plugging Program

Pennsylvania has developed oil and gas production because of private property rights, polycentric governance, and entrepreneurship (Harleman & Weber, 2017; Murtazashvili & Piano, 2018). The subsurface natural resources can be regarded as private goods under clearly defined and strongly enforced property rights (Demsetz, 1974). Landowners with property rights over natural resources spontaneously contracted with energy firms to "finance the acquisition of assets, minimize risks of owning assets, and enable the parties to specialize in different functions (Merrill, 2020)." Leasing contracts may include duration, bonus, and royalties, well plugging terms, and other rights and obligations. Thus, residents involved in oil and gas play have earned higher economic gains than others through royalties (J. P. Brown, Fitzgerald, & Weber, 2016). State and local governments also collected taxes and surcharges from energy companies (US CBO, 2014).

However, some oil and gas wells were not decommissioned by well operators, and became categorized as abandoned and orphan wells[14]. Unplugged wells have leaked industrial fluids and methane (Kang et al., 2014), contaminated sensitive environments (US EPA, 2016), and harmed public health (Reid Frazier, 2019). Per Pennsylvania's Oil and Gas Act, well operators should pay for the total costs of plugging all produced oil and gas wells (§3220, 2012

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[14] An abandoned well and an orphan well are commonly unplugged wells. But unplugged wells are differently designated by the Oil and Gas Act (58 P.S. §§ 601.101 – 601.605), which became effective April 18, 1985. An abandoned well can be defined as 1) a well that has not been used to produce, extract, or inject any gas, petroleum, or other liquid within the preceding 12 months, 2) for which equipment necessary for production, extraction, or injection has been removed, and 3) considered dry and not equipped for production within 60 days (about two months) after drilling, redrilling, or deepening (§3203, 2012 PA ACT 13). An orphan well refers to a well abandoned prior to April 18, 1985, that has not been affected or operated by the present owner or operator and from which the present owner, operator, or lessee has received no economic benefit other than as a landowner or recipient of a royalty interest from the well (§3203, 2012 PA ACT 13). https://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2012&sessInd=0&act=13

PA ACT 13). Well plugging can refer to the blockage of wellbores with cement or other materials to prevent the spills of pollutants and damage to environments and health. However, no parties responsible for plugging some wells exist for the bankruptcies of wells operators that held production permits (Kang et al., 2021). Besides, energy firms choose to exit oil and gas extraction sites without plugging when profitability is lower than expected (e.g., price drop, insufficient reserves) (Robert J. Burnett, 2021) or the chances of being punished for regulatory violation would be low because of imperfect institutions and monitoring (Bi, Guo, Zhao, Sun, & Wang, 2022). Energy companies, landowners, and residents cannot afford to clean up all the abandoned oil and gas wells because of plugging costs (PA DEP, 2018). Fiscal instruments such as bonding requirements are not sufficient to cover plugging costs (Mitchell & Casman, 2011). Thus, landowners and their neighbors might bear environmental risks without proper compensation.

The DEP has implemented the Well Plugging Program (WPP) since 1989 to clean up unplugged well sites that do not belong to any entity to prevent pollutant leaks and protect environments and citizens (PA DEP, 2021c). The PA DEP has plugged 3,332 wells and still needs to plug 8,912 wells more as of 2021. The oil and gas wells plugged by the PA DEP are mostly located in western Pennsylvania. Wells that need plugging are also scattered in western Pennsylvania. In figure 1, the red dots are the locations of the abandoned oil and gas wells to be plugged by the DEP, and the white dots are the locations of the orphan oil and gas wells to be plugged by the DEP.

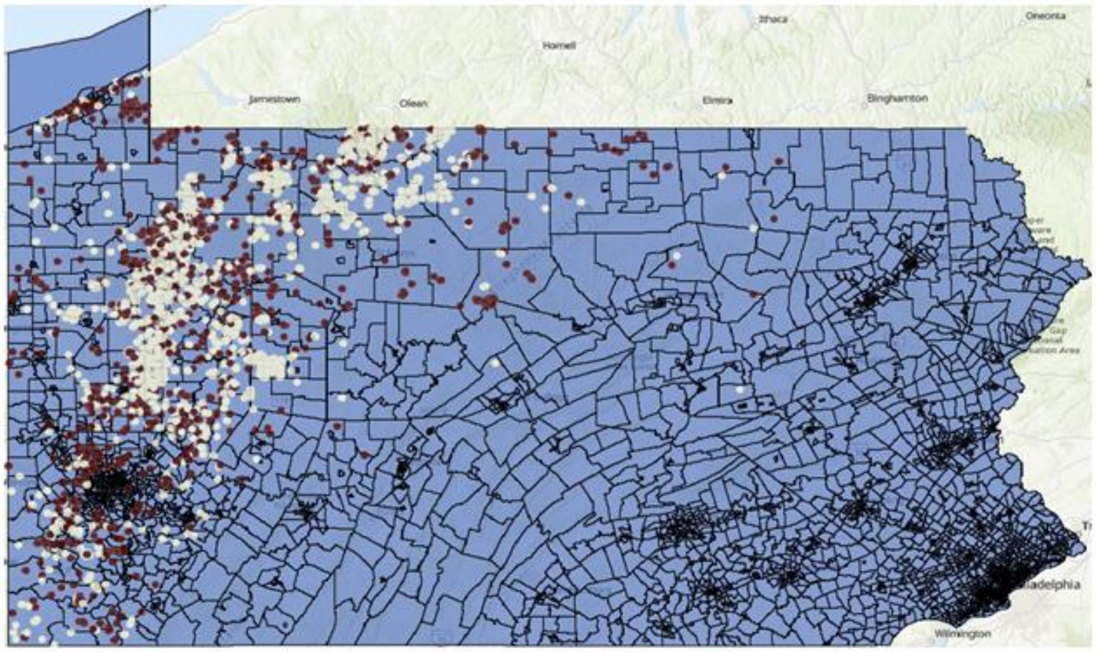


Figure 3.1. Locations of Abandoned and Orphan Oil and Gas Wells[15]

The DEP uses the official oil and gas well records and conducts field inspection to select and prioritize well plugging among all the unplugged wells in Pennsylvania. Specifically, the DEP administrators identify who can be liable parties, group oil and gas wells to be plugged immediately, and contract with firms for plugging operation. However, the DEP does not receive the well plugging funds sufficient to remediate all the unplugged wells in Pennsylvania. Historically, a 0.5% of the wells to be plugged by the PA DEP has been plugged annually under the budgetary constraints (Jackson, 2014). The WPP's expenditure dropped to less than $1 million in 2018 from $3.5 million in 2007 (Bang & Hollibaugh Jr, 2021). The well plugging

[15] "Oil and Gas Mapping Application." URL: http://www.depgis.state.pa.us/PaOilAndGasMapping. Accessed December 22, 2022.

costs can be from $20,000 (for only plugging) to $76,000 (for both plugging and surface restoration) (Raimi, Krupnick, Shah, & Thompson, 2021). Thus, it is expected that the PA DEP can remediate abandoned and orphan oil and gas wells from 13 to 50 wells for each fiscal year. While the 424 wells were plugged by the PA DEP from 2010 to 2012, 14 wells were plugged by the PA DEP from 2017 to 2019 because of the limited and decreasing sizes of the plugging fund.

Given the limited budgets, the DEP uses a WPP's scoring system to evaluate each unplugged wells quantitatively and rank all the wells by scores (Figure 2). The scoring system measures six objective and evaluative criteria, including the presence of leaked contaminants, environmental hazards, adjacent occupied buildings and mining sites, and other technical factors. Then, the DEP clusters unplugged wells that potentially harm people and environments significantly ("a priority well"), and cleans up it with priority. Non-priority wells are likely to be plugged later, but occasionally the DEP plugged non-priority wells when residents report emergencies by wells because of gas leaks and flares (PA DEP, 2021a). The current WPP's scoring system has the human receptors as one of the evaluative criteria but the demographic information about residents potentially influenced by unplugged wells[16] has not been involved to the human receptors. Instead, the closeness of occupied structures to leaking materials and the existence of oil and gas in water supply has been considered. One possible issue might be that the current WPP could make "expenditure used with little reference to consumer (mostly constituents) utility" (Ostrom & Ostrom, 1971) after the implementation of the WPP.

[16] The DEP clearly mentioned that "to protect Pennsylvania's air, land and water from pollution and to provide for the health and safety of its citizens through a cleaner environment" in the mission statement. URL: https://www.dep.pa.gov/Business/Land/Mining/BureauofMineSafety/Organization/Pages/Mission.aspx. Accessed December 22, 2022.

DEP OFFICE OF OIL AND GAS MANAGEMENT
WELL SCORING SHEET

API No.:		**GPS Latitude:**		**Scoring Date**	
Farm Name:		**GPS Longitude:**		**Quad Section:**	-
Well #:		**DEP Inspector:**		**Quad Name:**	-
County:	-	**District Office:**	-	**Well Classification:**	-
Municipality:		**Well Type:**	-		

Human Receptors *Choose Up To 5*		
Gas in occupied structure with similar isotopic signature or believed to be associated with well*	50	-
Oil/brine in occupied structure believed to be associated with well*	50	-
Soil gas within 200 feet of structure believed to be associated with well	25	-
Gas in water supply	25	-
Oil/brine in water supply	15	-
		0
Ecological Receptors *Choose Up to 2*		
Liquids (oil/brine) to stream or wetland	25	-
Oil/brine seep (discharge not from wellbore)	10	-
		0
Well Site Hazards *Choose Up to 4*		
Any ambient H_2S detection	25	-
Any ambient LEL readings $\geq$ 10%	25	-
Sustained ambient LEL <10%	10	-
Unstable equipment, open pits, E&S issues/washouts	10	-
Evidence of historical liquid spills not associated with well integrity breach	5	-
		0
Well Integrity *Choose Up to 4*		
Gas present outside surface casing/present in stream or liquid flow to surface	25	-
Measurable annular flow of gas	15	-
Wellhead pressure observed	10	-
Severe corrosion (pitting) on well component that possibly contains pressure or fluids	10	-
		0
Coal/Mining Status *Choose Up To 1*		
Well within active underground mine (sealed or undergoing mining ,i.e., longwall district)[1]	25	-
Within abandoned mined area	25	-
Permitted but not yet mined (intact coal/rock)[1]	10	-
Workable coal present but not permitted	5	-
		0
Setback/Surrounding Area *Choose Up to 4*		
Well within 200 feet of occupied building or water supply well	10	-
Well located in known gas migration area but not believed to be source	5	-
Well within 100 feet of stream	5	-
Well within 300 feet of any wetland >1 acre in size	5	-
		0
Final Score		0

Add remarks to Investigation Form

**Determine if situation justifies an emergency remediation or plugging contract*

[1] Notify the Coal Operator upon confirmation of well location.

Revised: April 2019

Figure 3.2. The Well Scoring Sheet of the Well Plugging Program

Redesigning the WPP's scoring system with demographic characteristics may be a solution for the efficient use of administrative resources. But, restructuring the current WPP could require time and administrative costs to collect more information and make those benefited from the current WPP unsatisfied with well plugging services. The DEP administrators need to know which residents have received hazards from unplugged wells and their socio-economic status. Localized information needs to be utilized or field studies should be conducted for the measurement. In addition, some residents that could not have DEP's plugging service under a current WPP would get benefits under a new WPP and support the WPP reprioritization. In contrast, others that could have DEP's plugging service under a current WPP would not enjoy benefits under a new WPP. For example, the DEP would move a well included in the priority well to the non-priority well if the well has lesser impacts on environments and people than other wells. One option for the WPP revision might be that the DEP administrators might choose one goal with its own preferences (Christensen, Dahlmann, Mathiasen, Moynihan, & Petersen, 2018). Public decisionmakers could lean toward general health protection or the prevention of leaking conditionally. But the goal selection with discretionary power can be criticized because of sub-optimal outcomes, a lack of procedural justice in public decision-making, and inconsistency in public decisions over time. Another can be that multiple criteria should be objectively optimized under the revised WPP, resulting in the current WPP's goal can be less attained relative to the status quo but new goals would be achieved. Based on the studies on reprioritization (Fleishman, Murphy, & Brussard, 2000; Noss, Carroll, Vance-Borland, & Wuerthner, 2002; Redding & Mooers, 2006), I propose a new WPP that includes new goals relevant to the WPP and show how expected outcomes and its goals have changed.

3.4 Redesigning the WPP and Examining Goal Relationships

3.4.1 Adding Two New Goals to the WPP and Making New WPP

Unplugged wells in Pennsylvania can be reprioritized based on technical factors and polluter factors for the DEP's well plugging. Technical factors may include the size of operating facilities, hazardousness of processed materials, and potential risks to surrounding neighborhoods. Polluter factors can measure polluter's ability to pay, polluter's violation history, and polluter's bargaining power. This paper assumes that the DEP administrators consider the three WPP's goals in the selection of wells to be plugged without goal preferences. That is, the weights over technical factors and polluter factors can be changed so that policy outcomes would be better off relative to the current status.

The first additional goal is to protect residents in the vicinity of unplugged wells from the leaked pollutants as many as the DEP can. Counting the population influenced by industrial wastes has been one of factors in the prioritization of remedial activities. For example, the Hazard Ranking System, which is the scoring system of the EPA Superfund, measured the probabilities of evaluative factors[17] to order the relative risk of polluted facilities on the national priority list (Haness & Warwick, 1991). One study estimated that at least 378,000 people lived within one mile from producing oil and gas wells in Colorado (McKenzie, Allshouse, Burke,

[17] The factors are "likelihood that a site has released or has the potential to release hazardous substances into the environment, characteristics of the waste, and people or sensitive environments affected by the release." URL: https://www.epa.gov/superfund/hazard-ranking-system-hrs. Accessed December 22, 2022.

Blair, & Adgate, 2016). Also, scholars found that causal pathways such as water, soil, air may increase public health risks through noise, methane, industrial fluids, and even could harm pregnancy and psychology (Amin Kiaghadi, Hanadi S. Rifai, & Dawson, 2021; Hirsch et al., 2018). One study estimated that at least 378,000 people lived within one mile from producing oil and gas wells in Colorado (McKenzie et al., 2016).

Environmental justice can be also the WPP's new goal that distributes the well plugging services fairly and equitably across communities near unplugged wells[18]. Legislative and administrative institutions (e.g., Executive order 14008) have been established to deliver environmental services from a government to those in lower socio-economic positions. Scholars found evidence of unevenly distributed environmental hazards on minorities or the poor and suggested environmental policy reform (Petersen, Minkler, Vásquez, & Baden, 2006) or communal activities (Bullard, 1993). In the context of oil and gas development in Pennsylvania, studies also concluded that the poor and the elderly are more likely to be exposed to leaking materials from unconventional wells (Ogneva-Himmelberger & Huang, 2015) or those living in the vicinity of well sites are less likely to get economic benefits from the oil and gas industries (Clough & Bell, 2016). Landowners in rural counties are likely to have low negotiation power

[18] The PA DEP built the office of environmental justice and the environmental justice advisory board so that the ideas of residents can be reflected to the decisions of locating well plugging through administrative procedures and the DEP's inclusive and participatory policies are managed. However, the board did not discuss the distribution of well plugging service among participants per agendas. URL: https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/pages/default.aspx. Accessed December 22, 2022.

during leasing contracts with energy companies, which may result to higher environmental risks (Malin & DeMaster, 2016).

The current WPP targets the reduction of environmental risk and uses six evaluative criteria to rank the unplugged wells. The new WPP includes the new two goals and its evaluative criteria including both the population living near unplugged wells and their incomes (Table 1). The new WPP's scoring equation changes the orders of unplugged wells and generates the different list of the priority wells. The weighted sum approach was used to structure the new WPP's scoring equation (Triantaphyllou, 2000), which sums the multiplicative results between the scores of evaluative criteria and its weights. The weighted sum approach is one of the multi-criteria decision-making ones, which helps decision-makers to evaluate alternatives with multiple criteria and maximize net benefits under trade-off situations. Tofallis (2012) pointed out the features of a weighted sum approach as follows; 1) the value of a weight must be significant relative to other weights and relative to its corresponding objective function, 2) all objective functions should be transformed such as that they have similar range, 3) the weighted sum provides only a basic approximation of one's preference function, which may result that a final decision may not accurately reflect initial preferences of stakeholders. In the scoring equation of table 1, the weight for the X_3 scores has a minus sign because a decrease in the X_3 scores implies that the DEP can advance the environmental justice in the WPP. Each goal has a different unit of scores including the number of people and incomes ($). Thus, the scores for each goal needs to be normalized so that the scores ($S_i^{X1}, S_i^{X2}, S_i^{X3}$) are from zero to one without units. S_i^{X1} is the normalized mean of the DEP scores among plugged wells, and S_i^{X2} is the normalized population in one-hundred units affected by abandoned and orphan wells within a quarter-mile buffer. $S_i^{X3}$is the normalized mean of the ACS median incomes in the tens of thousands where wells were plugged within a quarter-mile buffer. The three weights (α, β, γ) refer to the relative importance of decision-makers on environmental risks, public health, and distributive justice of public services. The number of wells used in the new WPP equation is 8,241. Each weight has a value from -1 to 1 by 0.01 but the sum of the weights should be equal to one as a constraint on the WPP prioritization. The new WPP could lead to the trade-off or synergic relations among the three goals depending on the weight combination of the scoring equation. Presumably, environmental protection could be attained less but other two goals could be better off, or vice versa, under the new WPP. In contrast, the three goals could be better off at the same time relative than outcomes under the current WPP.

Table 1: The Comparison between the Current and New WPP Scoring Systems

	Current WPP	New WPP		
Goals	Environmental Protection (X_1)	Environmental Protection (X_1)	Public Health (X_2)	Environmental Justice (X_3)
Evaluative Criteria	-Human Receptors -Ecological Receptors -Well Site Hazards -Well Integrity -Coal/Mining Status -Setback/ Surrounding Area	-Human Receptors -Ecological Receptors -Well Site Hazards -Well Integrity -Coal/Mining Status -Setback/ Surrounding Area	-Populations living near Unplugged Wells	-Incomes near Unplugged Wells

Scoring Equation	$Score_i = S_i^{X1}$	$Score_i = \alpha \times S_i^{X1} + \beta \times S_i^{X2} - \gamma \times S_i^{X3}$ $(i = 1, 2, \cdots 8241)$ $(-1 \leq \alpha,\ \beta,\ \gamma \leq 1)$ (s.t., $\alpha + \beta - \gamma = 1$)

3.4.2 Estimating Demographic Characteristics and Reprioritizing Abandoned Oil and Gas Wells

Measuring the demographic characteristics of regions in the vicinity of the unplugged wells is needed to know the changes in policy outcomes under the new WPP scoring systems. The Zillow Transaction and Assessment Database (Ztrax) and the U.S. census datasets were used to know the extent to which the health protection and environmental justice are improved. The Zillow is one of the U.S. real-estate companies but it can be seen as one actor in the knowledge commons. The Zillow has distributed the Ztrax to scholars, non-profit organizations, and administrators freely for specific purposes. The Ztrax has "real estate database…including public records, deed transfers, mortgages, foreclosures, property tax delinquencies…property characteristics, geographic information, and prior valuations for approximately 150 million parcels in 3,100 counties nationwide (Zillow, 2021)." The number of residential buildings near abandoned wells can be used to estimate the population exposed to leaked pollutant from unplugged wells.

This article applied the buffer-containment approach. It sets the scope of influence by distances (e.g., one mile) and generates local characteristics within the buffer such as the population close oil and gas wells (Czolowski et al., 2017). The three assumptions may be necessary for conducting geographic analyses in the GIS. Firstly, it was assumed that leaked materials from unplugged wells may directly damage residents within a quarter mile, not significantly affecting those beyond a quarter mile. Thus, a quarter-mile buffer was put to each well to be plugged by the PA DEP (Figure 3). The yellow circle is a quarter-mile buffer, the red dots are the residential buildings in the Ztrax, and black dots are the abandoned and orphan oil and gas wells to be plugged by the DEP. Secondly, it was assumed that two people live in one residential building to estimate the numbers of residents around each oil and gas well (the left side of figure 3). Thirdly, the variations in incomes for each buffer should be equal to the one within a census tract. However, since the number of residents near the oil and gas wells may vary, leading to the biased estimators of incomes. The median household incomes at the U.S. census tracts, which are the smallest administrative boundaries available for each year, were leveraged. Some buffers may fall into one tract, others were overlapped with multiple tracts (the right side of figure 3). The incomes for the unplugged wells were calculated by multiplying weights (referring as to the sizes of overlapped buffers) with median household incomes.

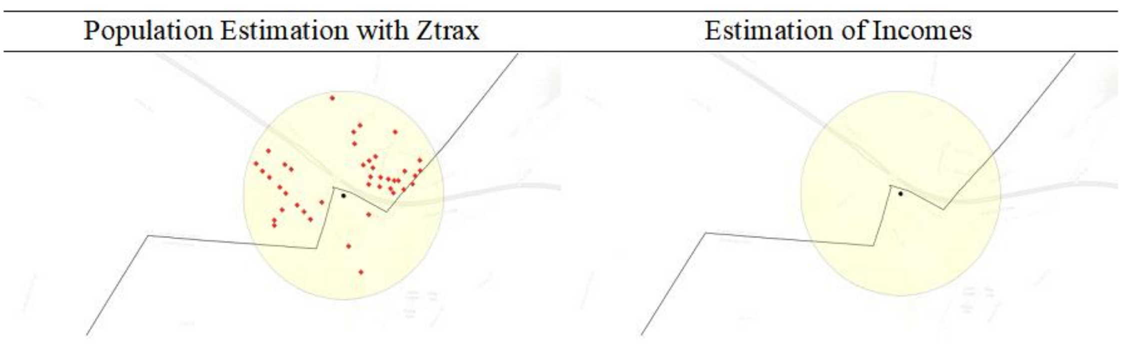


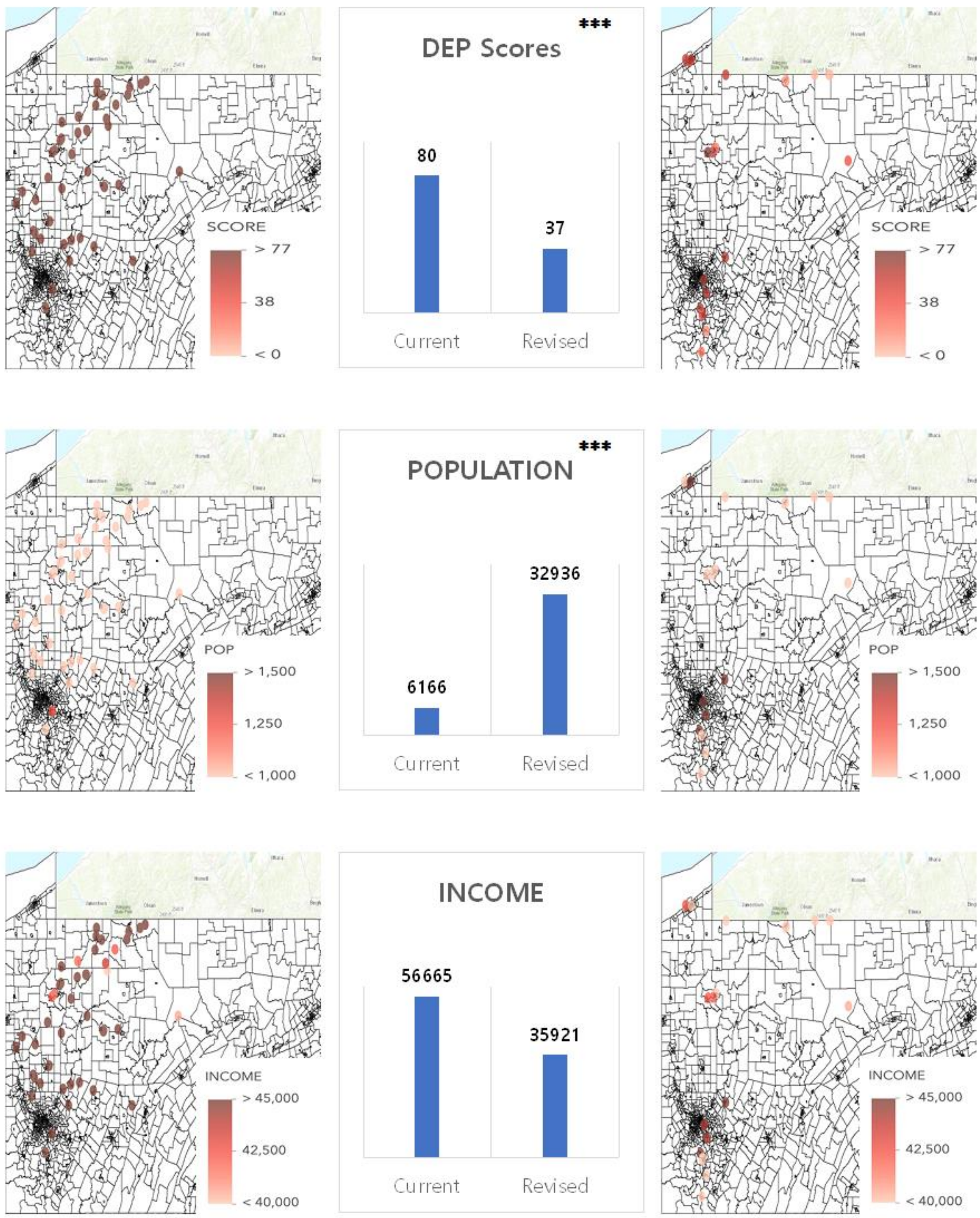
Figure 3.3. Estimating Population and Incomes with Quarter-mile Buffers

A heuristic approach was applied to find a set of optimal weights among the possible new WPP and avoid the subjective, ambiguous, and imprecise nature of assigning criteria weights (Hyde, Maier, & Colby, 2005). It was assumed that the revised WPP will select 49 abandoned and orphan wells because the average number of wells plugged by the PA DEP is equal to 49 from 2010 to 2019. It is estimated that 6,166 residents whose incomes were $56,666 on average benefited from the old WPP with the weight combination ($\alpha = 1, \beta = 0, \gamma = 0$) in 2018. The new WPP scoring equation generates the 14,126 combinations of three outcomes (Table 1). There are four possible cases showing the differences between the old WPP's outcomes and the new WPP's ones. First, the 4,671 weight combinations increased the population and the income under the new WPP; public health protection is expected to be better off by trading off EJ. Second, the 3,297 weight combinations decreased the population and the income under the new WPP; EJ is expected to be better off while sacrificing public health protection. Third, the 6,157 weight sets increased the population and decrease the income under the new WPP; EJ and public health protection are expected to be better off simultaneously. Fourth, the one weight sets decreased the population and increased the income under the new WPP; the two goals will be worse off at the same time. However, it should be noted that all the weight combinations cannot improve the goal X_1, referring to environmental protection, because the current WPP maximizes the mean DEP score. Substantively, the DEP decision-makers should balance the WPP's multiple goals, which means that improving health protection and EJ leads to lower the mean DEP scores of DEP-plugged wells.

3.4.3 Examining Expected Outcomes under the New WPP

Under the new WPP, some environmentally riskier wells that should have been chosen as priority wells under the old WPP would not be plugged. It is because these wells do not significantly affect residents nearby the DEP-unplugged wells. In contrast, some environmentally safer wells that should have been plugged under the old WPP would be plugged under the new WPP because the wells can influence more residents. For example, one weight combination in the diagram ($\alpha = 0.12, \beta = 0.16, \gamma$ =0.72) would lower the mean DEP scores and the mean income but increase the population compared to the outcomes under the current WPP. Substantively, the DEP could achieve budgetary efficiency and EJ better but should sacrifice environmental risk reduction in DEP-plugged regions. Graphically, the Geographic Information System illustrates the differences in the three outcomes between the current WPP and the revised one; the darker colored dots mean the higher values. The scattered dots of the DEP scores and the income under the current WPP were closer to dark red than the ones under the revised WPP. The dots of the population under the current WPP were lighter than the ones under the revised WPP. Quantitatively, the number of residents benefited from the WPP would be increased from 6,166 to 32,936 by 26,770. In contrast, the mean income (=$56,665) was expected to be lower under the revised WPP than the current one (=$35,921) by $20,744. But the mean of DEP scores would be decreased from 80 to 37 by 43, implying that the DEP administrators are expected to plug less dangerous wells more. The changes in the three variables were statistically significant at a 0.01 significance level in a t-test.

Current WPP (N=49)	Variables	Revised WPP (N=49)



***p<0.01; **p<0.05; *p<0.10

Figure 3.4. Changes in Outcomes from Current WPP to Revised WPP ($\alpha = 0.12, \beta = 0.16, \gamma = 0.72$)

The DEP administrators would have distributive issues about well plugging services under the new WPP because not all residents can be satisfied with the new WPP execution. Figure 5 has the numbers in parentheses under each scenario, including the number of wells, the mean of DEP scores, the population, the mean of incomes in order. Those who should have received the WPP under the current scoring system but would not enjoy the WPP under the revised scoring system are likely to be against the WPP reprioritization (Group 1). 47 wells would be excluded, and the mean of DEP scores for the unselected wells under the revised WPP is 80. The population excluded from the revised WPP is 5,256 and the mean income is $57,123. In contrast, those who should have been excluded from the current WPP but would benefit from the new WPP are likely to support the WPP reprioritization (Group 2). 47 wells would be selected for well restoration, and the mean of DEP scores for the selected wells under the revised WPP is 35. The population included to the revised WPP is 32,026 and the mean income is $35,495. Enhancing the three goals simultaneously is still limited. But the redistributive impacts caused by the WPP reprioritization might justify the goal balancing because greater number of residents nearby abandoned oil and gas wells whose incomes are lower would be the WPP's beneficiaries. However, it seems that there are limitations in the policy evaluation and policy reformation. Other relevant goals can be added to the WPP, resulting in the set of different policy outcomes. The revised WPP might not produce socially desirable outcomes when socio-economic status could be changed (e.g., moving, new infrastructures). Public decisionmakers would not execute the revised WPP and instead seek their own preferences regardless of expected improved outcomes. Legislative influence also could affect whether the revised WPP would be implemented or not.

		Revised WPP (a=0.12, b=0.16, g=0.72)	
		Plugged	Unplugged
Current WPP (a=1, b=0, g=0)	Plugged	(2, 78, 910, 45917)	Group 1 (47, 80, **5256**, **57123**)
	Unplugged	Group 2 (47, 35, **32026**, **35495**)	(8145, 12, 91136, 53902)

Figure 3.5: Expected Distributional Impacts by the Revised Well Plugging Program

3.5 Conclusions

This study revised the scoring system of the well plugging program and examined whether the relations of three relevant goals could be conflicting or synergistic. As a result, goal balancing among the three goals is found in the revised environmental policy; one goal (environmental protection) would be less attained but other two goals (health protection and environmental justice) would be improved. That is, goal tradeoffs may persist between environmental protection and the two goals but at the same time goal synergy also was found between health protection and environmental justice. The changes in the goal attainments would generate redistributive impacts because people who could have receive the well plugging service under the current WPP would not enjoy the environmental policy under the new WPP. The reprioritized WPP can be accepted to citizens, legislators, and public managers justifiably because a larger number of poorer residents could be favored under the new WPP. In contrast, a smaller number of richer residents would be excluded from the revised WPP. This research may have implications to public administrators and scholars interested in policy evaluation and the use of large-scale localized datasets. The first takeaway can be that public decisionmakers should consider all possible and relevant policy goals. Inserting omitted goals to a public program may allow public managers to satisfy various types of constituents. Also, leveraging large-scale datasets on demographic attributes may play an important role in analyzing the extent to which each goal is attained. Lastly, public decisionmakers are required to examine redistributive effects by policy reformation. It might be necessary to answer the question of who will gain and who will lose under a new public program because making synergistic relationships among multiple goals could be hard to achieve.

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