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Methane Emissions from Suspended Wells: Can Internalizing the Cost of Methane Leaks Incentivize Plugging and Reclamation of Petroleum Wells in Alberta?

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ABSTRACT

There are currently over 81,000 suspended status petroleum wells in the province of Alberta, Canada. These wells are prone to gas leakage, including methane emissions, and present a liability estimated to be as high as $8 billion to have each of them plugged and abandoned. The provincial government faces the dual challenge of protecting the public from this liability and achieving a methane emissions reduction goal of 45% by 2025. A cost-benefit analysis shows that private firms are economically incentivized to the leave a well in the suspended state, indefinitely shifting the cost of clean-up into the future. This paper investigates if applying a social cost of methane to the expected emissions from a suspended petroleum well can change the business decision and encourage plugging and abandonment by private firms. Results indicate that the costs of methane emissions will be insufficient to cause a change in behavior as, on average, it will remain less costly for a firm to leave a well suspended than to undergo plugging and abandonment. Tighter controls and regulations will be necessary to reduce methane emissions from these wells; alternatively, finding **A** new purpose for these older wells, such as the production of geothermal energy, can reduce the number of suspended wells and shift the potential public clean up burden from public to private.

1. INTRODUCTION

Since 1883, when natural gas was first discovered in Alberta while CP Rail drilled a water well near what is now Medicine Hat (Petroleum History Society, 2001), petroleum exploration and production have become big business in the province and many thousands of more wells have subsequently been drilled. While the drilling and operation of these wells have created many jobs and been a tremendous source of revenue to both industry and the province, there is rising concern over the liabilities the wells represent. Of the roughly 450,000 petroleum wells registered in Alberta, 155,000 of them are no longer producing and waiting to either be reactivated for production or permanently plugged and the land reclaimed (Dachis et al., 2017). A current search of the Petrinex Alberta Public Data database, an online data repository jointly operated by government and industry, reveals that there are over 81,000 petroleum wells in the province currently classified as “suspended.” Although suspended is considered a temporary state of inactivity while the well’s owner decides to either reactivate or permanently plug/abandon the well and reclaim the land, there is no stipulated limit to the length of time a well is permitted to be suspended (AER, Directive 013). Under the auspice of maximizing utilization of resource the Alberta Energy Regulator (AER), which is the provincial body responsible for oversight of the oil and gas industry, allows indefinite suspension in the hope that improving economic conditions or extraction technologies will once again make it profitable to produce from the well. However, economic modelling by Muehlenbach (2015, 2017) indicates that even a doubling of petroleum prices results in reactivation of only 7-12% of wells, suggesting that corporate decision-making is governed more by avoidance of costs than gaining of benefit. Since the drop of petroleum prices towards the of 2014, Alberta has experienced a rapidly growing number of suspended status wells. From 2011-2014, there was an average of 446 new suspensions per month and 363 abandonments performed; after that time through 2018 there has been an average of 622 new suspensions per month and 380 abandonments (AER ST37 – Mar 2019). There is a definite trend of higher numbers of wells being suspended and being left in that state.

Each of these suspended wells poses a direct economic hazard as eventually, someone must pay the cost of plugging and reclamation; the longer a well stays in a suspended status, the more likely its owner will go out of business and leave the well “orphaned” with no financially responsible party. In the current era of low petroleum prices, Alberta is experiencing a rising number of orphans left by insolvent owners; it then falls upon remaining industry players and the province to pay for monitoring and cleanup. To combat this issue, the AER established the Orphan Well Association (OWA); primarily funded through industry fees and levies, the OWA takes on responsibility for an orphan and ensures that it is properly plugged and reclaimed (OWA, 2017). The number of orphan wells in the province has increased from fewer than 100 wells in 2012 to over 3200 in 2017, and the potential burden of abandoning and reclaiming Alberta’s wells has been estimated to be as high as $8 billion (Dachis et al., 2017). While this number is already large, it has not factored in the indirect costs associated with suspended wells. While all petroleum wells have the potential to leak methane gas. The AER’s Upstream Petroleum Industry Flaring and Venting Report for 2017, shows inactive wells to be more than twice as likely to have a reported Surface Casing Vent Flow (SCVF) or Gas Migration (GM) event and studies generally indicate that permanently plugged wells are less likely to leak than temporarily plugged wells (Ho et al., 2016). These gas leaks pose human health hazards and environmental risk, including contribution to greenhouse gas emissions (Ho et al., 2016) and the cost of these risks is not addressed by current policy and decision making. In this paper, after a review of current policy and practice by government and industry, this article will expand upon and update previous studies to demonstrate how the current environment costs related suspended wells create a cost benefit analysis (CBA) which encourages the decision to leave wells in a suspended state. Second, using a dataset obtained on request from the AER, will examine the volume of methane emissions from suspended wells and investigate the social cost of methane and whether incorporating those costs may change the

CBA for private firms. Finally, review of the results that investigate and discuss policy options for how government may choose to insure the burden of these costs are placed primarily on those who will benefit from the well and not the public.

2. BACKGROUND

2.1 Well Definitions

To assist in reading and interpretation of this paper, definitions and background information will be provided on the well lifecycle and on methane emissions.

According to AER's Directive 013, a petroleum well is deemed "inactive" if there has been no fluid production or injection for a period of 12 months. Once deemed inactive, the licensee (or owner) has an additional 12 months in which to suspend the well. Suspension requires cleaning any spills or debris around the wellhead, ensuring flow valves are turned off and either locked and chained or removed so that they cannot be reopened, and placing plugs in all outlet pipes, along with additional downhole plugging for medium and high-risk wells (figure 1). Once suspended, a well must be inspected for spills or gas venting every 1, 3, or 5 years depending on risk category. Well abandonment (often referred to as plugging a well) is the next step and is governed by AER Directive 020. Abandonment involves placing cement and non-corrosive fluids (non-saline water is common) or mechanical plugs down the wellbore to seal off zones of oil or gas production from the surface, followed by digging a minimum of 1 metre below land surface, cutting and capping the wellbore and covering with a vented plate (figure 2). Eventually, as there is also no time limit for this process, the land overlying the well must undergo reclamation, where the land is restored to a condition equivalent to what it was prior to petroleum development (AER- Reclamation). The term remediation is used to refer to any decontamination of soil and groundwater that takes place during the reclamation process; remediation typically accounts for 2/3 to 3/4 of the total cost of reclamation (OWA, 2017), references in this paper to reclamation will include remediation. Until reclamation has been completed and a certificate issued by the AER, which often takes several years, the well owner must continue to make surface lease payments to landowners.

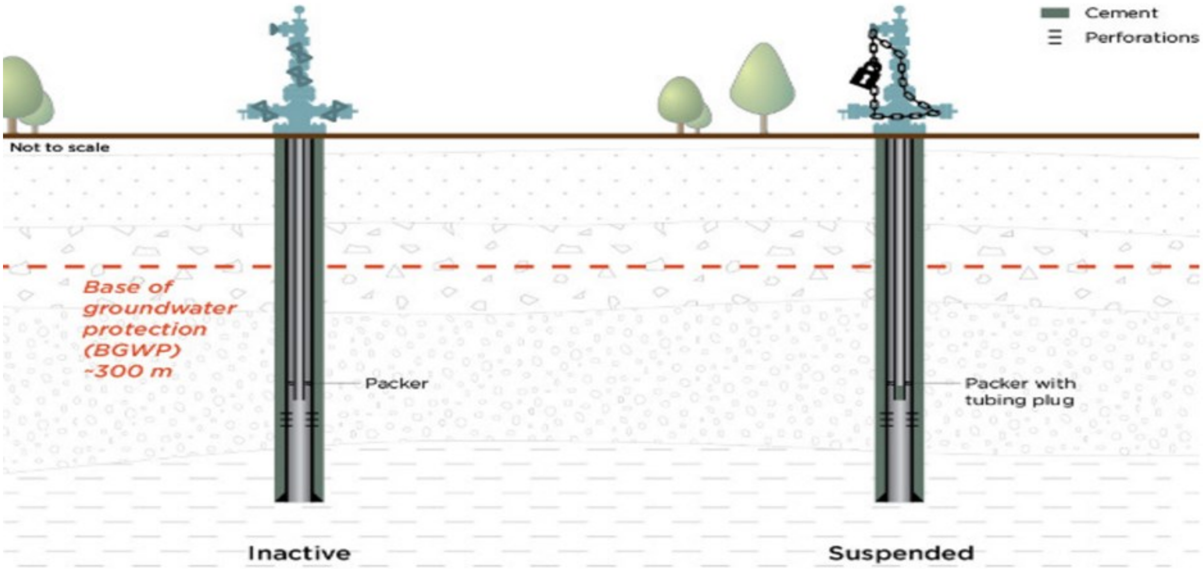

Figure 1: Active vs Suspended Wellheads. Source: AER: How are Wells Suspended. Available at https://www.aer.ca/regulating-development/project-closure/suspension-and-abandonment/how-are-wells-suspended

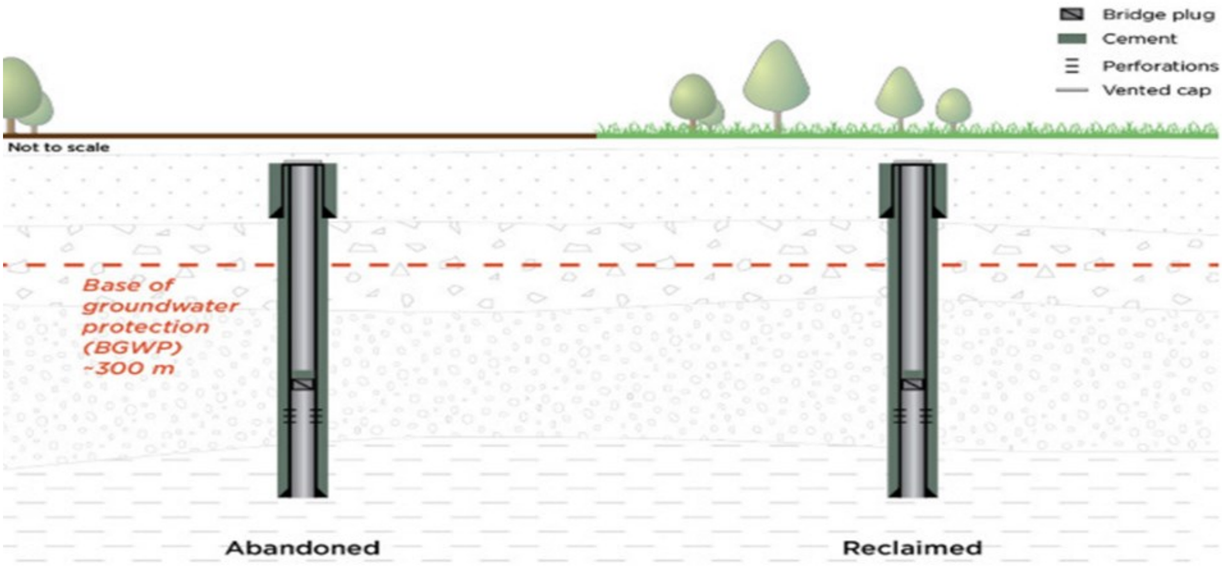

Figure 2: Abandoned vs Reclaimed Well. Source: AER: How are Wells Abandoned. Available at https://www.aer.ca/regulating-development/project-closure/suspension-and-abandonment/how-are-wells-abandoned

2.2 Surface Casing Vent Flow (SCVF) and Gas Migration (GM)

Surface Casing Vent Flow (SCVF), occurs when any plugging in the wellbore has failed, and there is sufficient downhole pressure to cause fluid flow up through the surface casing or annulus and escape through open venting at the surface as seen in figure 3 (Bachu, 2017 & AER Directive 020). There are several methods for testing SCVF, the most common being the "bubble test" where one end of a hose is connected to the surface vent and the other end is placed in a pail of water to check for the presence of bubbles resulting from gas flow. If flow is detected, a meter must be used to measure the flow rate. A serious leak is one that is greater than $300m^3$ of flow per day, is suspected to in contact with usable water, or presents an immediate hazard, and must be repaired within 90 days of discovery. A non-serious leak requires only annual monitoring for 5 years to test for change in flow rate; these subsequent reports do not need to be submitted to the AER (AER ID 2003-01).

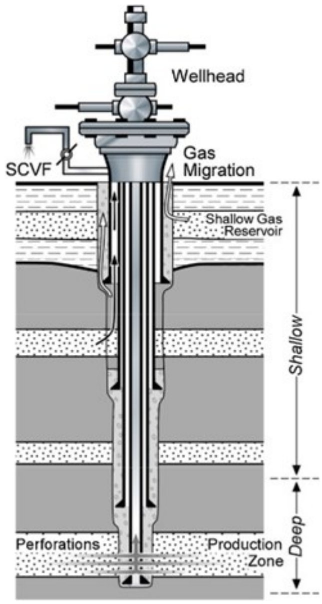

Figure 3: Schematic of a well-head showing SVCF and GM gas leak routes. On the left, fluid has escaped from a geological formation downhole and is flowing up between two strings of casing and out through the vent. On the right, fluid is escaping through the soil and in the space between casing and the ground. Source: Bachu (2017).

GM is more challenging to quantify because the gas leaks outside of the casing and migrates into the surrounding rock and soil (Bachu, 2017), testing is often done by digging a calibrated meter 50cm down into the soil. A serious case is one which poses an immediate public safety hazard or has caused off-lease environmental damage and, like SCVF, must be repaired within 90 days (AER ID 2003-01).

It should be acknowledged that the volume of greenhouse gas emissions being analyzed for this paper is a small fraction of total emissions. According to data from the 2016 Canadian National Inventory Report, of the 704 MT of GHG emissions in Canada, Methane represented 14% (96 MT) of this. In Alberta, 48% of oil and gas methane emissions are from intentional venting, while

46% are from the unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels, termed fugitive emissions (Alberta – Reducing Methane Emissions). Leaks from oil and gas wells are grouped with the unintentional and are thought to comprise a relatively small fraction of "fugitive emissions," but no specific data related to leaky wells is available (Bachu, 2017 & Environment and Climate Change Canada, 2018). While SVCF and GM are a small overall contributor to greenhouse gas emissions and climate change, they could remain critical to the economic decision making around suspended wells. Also, it is worth noting that empirical studies using regional airborne or ground-based measurement have indicated that well site methane emissions are significantly under reported (Johnson et al., 2017 & Zavala-Araiza et al., 2018).

3. THE SOCIAL COST OF METHANE

Any natural gas released from a well experiencing SCVF or GM is typically 95-99% methane (AER ST60B-2018), so when evaluating the costs and impacts from these leaks, it is an evaluation of the costs and impacts of methane. Methane is a member of the family of fluids known as greenhouse gases, which also includes Carbon Dioxide (CO2), Nitrous Oxide (NO2), Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3) (ECCC, 2018). While all greenhouse gases are considered contributors to the processes of climate change, they are not equal contributors. Variation in their molecular makeup results in the radiative forcing or warming effect from the release of 1 kg of each specific gas to be unique. The effect for each gas is termed its Global Warming Potential (GWP) and is expressed as a ratio compared to the warming effect of CO2. The Canadian government lists the GWP of methane as 25, so 1 kg of methane is thought to have an atmospheric impact equivalent to 25 kg of CO2 (Canada NIR, 2018).

The Social Cost of Carbon (SCC) is a well-established tool used by both the Canadian and US governments to provide a dollar value to the environmental damages caused by CO2; Environment and Climate Change Canada began using SCC as part of its decision-making process in 2010 (Wright, 2017). In 2015, a US Working Group established an SCC of $40.70/tonne ($CDN), which was subsequently adopted by the Canadian Working Group (Wright, 2016). The Social Cost of Methane (SCM) is an attempt to replicate this process for methane.

It is common to convert a non-CO2 gas to CO2 equivalent using its GWP and then value its economic impact using the SCC (Shindell et al., 2017 & Marten & Newbold 2012). However, because GWP only incorporates radiative forcing and ignores other impacts of gas release, this method tends to underestimate the social costs of methane. Methane has a shorter lifespan and interacts with other gases in the atmosphere to create further ozone and CO2, so GWP fails to capture the true contribution to climate change (Shindell 2017, Marten 2012, EPA 2016). Gases can also have different physical impacts; for example, lacking the fertilizing capacity of CO2, methane has greater negative impact on agricultural yields (Shindell 2017, EPA 2016).

Further complicating the establishment of SCM is the impact of time; greenhouse gases linger in the atmosphere for many years, so a methane release today creates a cost that may occur many years in the future. In the attempt to fairly value that future cost today, economists will typically apply a discount rate to reflect economic inflation and the reduced impact a future event directly impacts us. Although methane remains in the atmosphere for a shorter period and thus is less affected by the chosen discount rate than CO2, the chosen rate can drastically affect the SCM. Demonstrating this, the SCM utilized by the US EPA is either $450, $1,000, or $1,400 depending on whether they applied a discount rate of 5%, 3%, or 2.5% respectively (EPA, 2016). Discount rates used by private industry to compare the profitability of various projects are often in the 10-15% range; applying this higher discount rate to the future impacts of greenhouse gases significantly reduces their present cost and has been used as an argument against emission regulations (Grantham Research Institute, 2018). Most scholars adhere to the belief that because the public is more patient than industry and place greater value on long-term environmental sustainability that a social discount rate (SDR) of 2-3.5% is more appropriate (Grantham Research Institute 2018, Caplin & Leahy 2004).

Attempts to model a SCM include work by Marten and Newbold (2012), which measures the expected loss in future global economic output due to rising temperatures and what amount of that loss can be attributed to the various greenhouse gases. They determine a SCM of $370/t at 5% discount, $810/t at 3% discount and $1100/t at 2.5% discount and their work is cited by the US Interagency Working Group on Social Cost of Greenhouse Gases in establishing their SCM of $450/t, $1000/t, and $1400/t at 5%, 3%, 2.5% discounts respectively (Interagency Working Group, 2016). A paper by Shindell et al. (2017) goes a step further and incorporates the damages to public health and reduced forestry and agricultural yields to ascertain a SCM of $2400/t at 5% discount or $3600/t at 3% discount. This wide range of SCM values indicate the uncertainty and unknowns inherent in such calculations.

4. CURRENT STANDARDS AND POLICY

4.1 Industry

The Canadian Association of Petroleum Producers, an organization of upstream Canadian oil and gas firms, states that natural gas producers in Canada are self-guided by a set of methane management principles to support research and public policy while collaborating with government and finding economic opportunities to reduce methane emissions. Further to this, a CAPP publication from 2017 states the industry is committed to reducing methane emissions by 45% by 2025, which is in line with government goals, and believes that technology is the key to reduction. Although they are cognizant of minimizing the costs of doing so, the Canadian petroleum industry does express a desire to reduce methane emissions.

4.2 Canada

The Canadian government has released the Pan-Canadian Framework on Clean Growth and Climate Change, which is an official plan for mitigating emissions while growing the economy. One of the core "pillars" of the plan to utilize carbon pricing applied to a broad set of emissions sources. The document mentions explicitly methane and a desire to reduce methane emissions by 40-45% by 2025. 80% of emissions come from 35 of the 175 identified sources of methane in Canada, so federal policy focuses on large abatement opportunities, specifically the deliberate venting and flaring of gas at oil wells and processing facilities (Environmental

Defense Fund, 2015). While the framework does indicate a range of prices per tonne of carbon, it mentions no specific price for methane.

4.3 Alberta

Alberta has also issued a Climate Leadership Plan which echoes the federal goal to reduce methane emissions by 45% by 2025. The plan focuses on the approach of applying new standards and regulations for design, leak detection, and repair; as with the federal plan, although this could apply to inactive wells, the focus seems to be on large facilities. Analysis of Alberta's Carbon Incentives reveals that intentionally vented methane is priced at the same rate as CO_2 ($50/t) which, based on a GWP of 25:1, results in a levy on vented methane of $2/t of CO_2 equivalent (Gorski and Kenyon, 2018). Fugitive emissions, such as those from SVCF/GM events, face no levy at all. Another challenge Alberta must contend with in order to reach its stated emissions reduction targets is that it likely does not know the true baseline volume. The research has demonstrated that reported values grossly understate the actual level of methane emissions. Perhaps in response to this, the AER has issued updated Directives 068 and 017 that will come into effect January 2020 and stipulate updated measuring and reporting requirements for methane release from oil and gas activities. While this seems likely to improve accuracy of reported emissions, these directives explicitly exclude release from SVCF or GM, which still fall under the guidelines of Interim Directive 2003-01, issued in January 2003.

To prevent the cost of plugging and reclaiming orphan wells being borne by the public of Alberta, the AER has established methods of industry funding for the OWA that are outlined in AER Directive 006. First, there is an annual levy applied to all oil and gas producers; each firm pays a share of that levy equal to the estimated portion of the total province wide liability contributed by their petroleum wells. Second, the AER collects a $10,000 fee from new first-time licensees (new owners) of wells and this is transferred to the OWA. Third, the AER created the Liability Management Rating (LMR) program. Every producer firm receives an LMR rating equal to their deemed assets divided by deemed liabilities; if a firm has a rating of less than 1.0, they are at higher risk of becoming insolvent and must pay a security deposit to the AER for each well they drill. This deposit is used to offset the cost of well cleanup if the firm goes defunct.

Although this funding has been adequate thus far, there is evidence that pure industry funding of the OWA is becoming increasingly difficult. In the 2017-2018 OWA Annual Report, they recount that the industry levy has increased from $15 million in 2014 to $45 million in 2018 and is anticipated to reach $60 million in 2019 or 2020. Also, in 2017 the OWA took a $235 million repayable loan from the province of Alberta, the interest on this loan will be covered by a $30 million grant from the federal government. Clearly, the OWA is requiting an increasing amount of funding to pay for cleanup of inactive wells and industry payments are becoming insufficient.

5. METHODOLOGY

5.1 Cost Benefit Analysis (CBA) of Decision to Abandon and Reclaim or Leave Suspended

When establishing the potential liability of inactive wells in Alberta, Dachis et al. (2017) used average plugging and reclamation costs reported by the OWA and applied those costs to both active and inactive wells either orphaned or belonging to a firm with an LMR less than 2.0. While they referred to this value as a social cost under the preposition that taxpayers are ultimately liable for the cleanup if industry goes bankrupt, they do not include externalities such as the cost of health and environmental damage. Inspired by their work, as well as economic modelling work conducted by Muehlenbachs (2015, 2017) indicates that firms leave wells in the suspended state to avoid costs. This paper will compare the typical costs of leaving a well suspended against the costs of paying for abandonment and reclamation using both a private and social discount rate to garner further insight into why greater numbers of wells are being left suspended. Average abandonment costs will be established by averaging the past three years of data from the OWA, using three years increases the sample size of costs and should minimize outlier effects. Reclamation values are difficult to ascertain from OWA reports as the process can take place in several steps over multiple years, so estimated liability values provided by the AER in Directive 011 are used. Directive 011 states that abandonment and reclamation costs can vary by geographic area and outlines 6 different cost regions for abandonment and 7 separate cost regions for reclamation (figure 4). However, review of the cost values assigned to each region (see Appendix A) reveals that abandonment costs in Areas 1-5 all fall within a 5% range, with Area 6 is approximately $10,000 higher; although the reclamation regions display a slightly greater percentage variation in costs the Boreal Area, which overlaps with Area 6 from abandonment, is one of the least costly areas to reclaim. Given this offset, there is limited regional disparity in abandonment and reclamation costs; a provincial average is suitable for this paper. If the results are significant, a full regional analysis of private costs may prove insightful.

The following are values used when evaluating private CBA. Combined abandonment and reclamation costs in this paper ($98,821) are in line with the $100,000 per well used by Dachis et al. (2017). Annual surface lease payments are required to be paid by the well owner until full reclamation has occurred and the certificate received; the annual rate was obtained multiplying average surface lease costs per acre (Alberta Agricultural and Rural Development, 2010) by the typical lease size of 1 ha or 2.5 acres reported by Golder Engineering in Pasher et al. (2013). A private discount rate of 10% will be used, based on a survey of corporate hurdle rates in the oil and gas industry (The Oxford Institute for Energy Studies). A 3% social discount rate, which falls within the scholar's recommendation range, is the median value used by the US EPA and is used by Environment and Climate Change Canada for the SCC (ECCC, 2016).

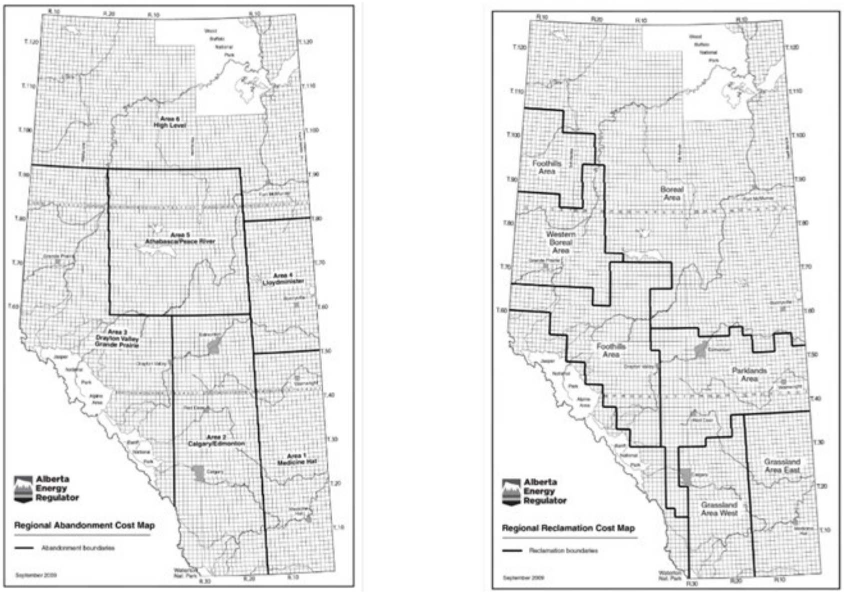

Figure 4: AER Regional Cost Maps. Source: AER Directive 011. Available from: https://www.aer.ca/documents/directives/Directive011_March2015.pdf

5.2 Establishing the Volume and Cost of Methane Release from SVCF/GM in Suspended Wells

When determining the factors contributing to well leakage, Watson and Bachu (2009) utilized a dataset from the AER (then called the ERCB) outlining SVCF/GM volumes and dates. Using a current dataset from the AER with a full history of recorded SCVF and GM migration data to calculate the expected methane emissions from a typical suspended well.

The SVCF/GM dataset contained a total of 34,186 reported cases of either form of gas leakage; 11,779 of which belong to suspended wells. Of these, 5,148 are "open" or active cases of gas release, while 6,631 are considered "closed." It should be noted that the 2017 AER Flaring and Venting Report (Table 1) indicates 9,736 cases of suspended wells having gas leakage, this number is less than what is reported in the dataset can be attributed to several wells having more than one separate instance of gas leakage. The dataset provides daily release values in cubic metres per day which will be converted to tonnes based on the molecular weight of methane at Normal temperature and pressure which is a ratio of 0.668kg/m3 (Engineering Toolbox, 2003). Several reported cases of SVCF or GM list no value for release volume; for these following the AER protocol and assigned these a flow rate of 1 m3/day (AER ST60B-2018). Suspended wells do not leak indefinitely; some are repaired while others die out and cease gas release when downhole pressure decreases sufficiently. The total gas release is dependent upon the duration of release; suspended open wells have been leaking for 3426 days (9.4 years) on average (calculated in Excel using the "DAYS" formula ending March 1, 2019). The average of daily release from open cases 15m3/day, which corresponds with data reported from 2015 of 13m3/day (Ho et al., 2016). However, a weighted average of release [(∑ daily release x days leaking)/total days leaking] is 22.9m3 per day (3426 days x 22.9m3/day = 78,455m3) was felt to be a more appropriate measure as it seems likely that a well with lower emission volumes will die out sooner. Somewhat surprisingly, for the closed cases, only 906 were repaired while 4026 were allowed to leak and eventually die out. Establishing the length of time a closed case well was actively releasing is challenging, many of the reported cases have resolution dates which precede the onset date; unable to find a certain answer for this, but these wells may have had multiple reports of leakage resulting in a cycle of being an open or closed case. To prevent bias data, negative or zero-day cases for estimating volumes have been excluded. This left 3,117 closed case wells which died out and leaked a weighted average of 6.95m3/day for 1939 days (13,476m3 over 5.3 years). 487 cases closed due to repair (including the categories "Problem Repaired" and "Repaired – SVCF/GM") released a weighted average of 96.4m3/day for 1020 days (98,328m3 over 2.8 years). The relatively small volume of emissions from wells which "died out" supports my position that a weighted volume is more appropriate. Given the uncertainty in duration for closed cases, the data from open cases only (78,455m3) for SCM evaluation was used. No information exists or is publicly available regarding leaked gas composition (Bachu, 2017), but regional emissions analysis showed that gas releases are comprised of 97% methane (Johnson et al., 2017), so this paper will factor estimated gas emissions by 0.97 translating to 76,101m^3 of methane.

The final factor in determining expected methane emission from a suspended well is an estimate of the percentage likelihood a suspended well will develop a leak. AER ST60B (figure 5) reports that 7.2% of all drilled wells in the province report a SVCF or GM, that increases to 10.9% for suspended wells. An independent study revealed a lower 4.6% chance of any well leaking in 2005 (Watson & Bachu, 2009) with the odds rising to 6.6% in 2013 (Bachu, 2017). The work of Bachu and Watson also indicates that older wells are more likely to develop leaking due to lack of technology and regulations, but when comparing newer wells those with suspended status are not more likely to leak than active wells. Given that these studies found a lower percentage of leaks, but an increasing trend, I will apply the SVCF/GM percentage of 7.0% which is in line with the overall likelihoods presented by both the AER and Bachu & Watson.

Well Status	Number of Wells	Number of Wells that Reported SCVF or GM	Percentage of Wells that Reported SCVF or GM
New Drills	1362	28	2.1%
Active	175508	9325	5.3%
Inactive	89053	9736	10.9%
Total	265923	19089	7.2%

Figure 5: Reported cases of gas leakage in 2017. (Note: Inactive cases for this chart do not include Abandoned status wells) Source: AER ST60B-2018: Upstream Petroleum Industry Flaring and Venting Report, 2017. Available from: https://www.aer.ca/providing-informa

Papers that worked to establish a SCM yielded very different values, US$810 (established by Marten & Newbold, 2012 and adapted for use by the US EPA), and US$3,600 (drafted by Shindell, 2017 to incorporate human health and agriculture loss costs) at 3% discount rate; rather than attempt to determine which of these values is more appropriate, using them as low and high case scenarios to see how each impacts the CBA of suspended well. All US dollar values will be converted to Canadian dollars using the 2018 annual US/CDN exchange rate reported by the Bank of Canada at 1.2957.

6. RESULTS

6.1 Private Costs and Decision Making

Does it make economic sense for a well owner to leave a well suspended? To conduct this analysis, calculation of the present value of the costs to abandon and reclaim a well and compare them to the costs necessary to maintain a well in suspended status. Abandonment ($70,500) takes place in year one, reclamation ($28,321) occurs in year two, and annual surface lease payments will be paid through year 5 to account for the 2-4 years that typically elapse before a reclamation certificate has been received from the AER (OWA, 2017). Suspension costs will consist of annual surface lease payments, along with a well site inspection every three years, in perpetuity (See Appendix for full breakdown of costs used). All annual costs are discounted by the private discount rate of 10% to present day. The results (full year-by-year breakdown in appendix B) are striking; even after 50 years of surface lease payments, the cost of abandoning and reclaiming a well site exceeds the cost to leave a well suspended by over $42,000. Using the lower social discount rate of 3% does result in suspension costs being greater than abandonment and reclamation, but this does not occur until year 24. As an additional test, the expected cost of repairing a well was factored. AER directive 011 lists costs for typical cost of repair for an SVCF or GM event (figure 6). Based on a 6.3% chance of SVCF and 0.7% chance of GM (Bachu, 2017), the expected repair cost for any given well is $11,142. Acknowledging that, because many incidences of SVCF/GM do not require repair, this estimate is likely too high, including it in year 6 of suspension costs, which maximizes its impact by minimizing the discount to present value, does not significantly change the outcome of a private CBA. At 3% discount rate, suspension and abandonment/reclamation costs balance during year 21.

AER Repair Costs	
Vent Flow Repair	$ 169,309
Gas Migration	$ 67,868
Average	$ 118,589

Figure 6: Well repair costs in Alberta 2015. Source: AER Directive 011

This demonstrates that, based on internal economic factors, well owners have a clear economic incentive to leave a well in the suspended state.

6.2 Reduced Abandonment Costs

The AER has found that costs can be reduced by up to 40% if a program is undertaken to abandon multiple wells in one region (AER, Area Based Closure). If a firm can reduce its abandonment cost by 40% ($42,300), could that change the business decision for them? At 10% discount, abandonment and reclamation costs are still greater than suspension costs after 50 years. At 3% discount, the costs are equivalent in year 15. This indicates that programs designed at lowering abandonment costs may influence socially conscious firms to plug and reclaim their wells but are unlikely to affect the decision of a private CBA.

6.3 Internalizing the Externalities: Factoring in the Social Cost of Methane

From an analysis of the dataset obtained from the AER, open cases of SVCF/GM reported in suspended wells released an average of 22.9m3/day for 3426 (9.4 years) days, resulting in an estimated total emission per well of 78,455m3. At 97% methane content and converted to tonnes using the molecular weight of methane:

78,455 x 0.97 x 0.668kg/m3 / 1000kg/t = 50.8 tonnes of methane emission

Spread over 10 years = 5.08t/year

Applying the cost of these emissions at the SCM suggested by Marten & Newbold (2013) of US$810:

US$810 x 1.2957 exchange rate x 5.08t = $5,332/year

Applying the cost of these emissions at the SCM suggested by Shindell (2017) of US$3600:

US$3600 x 1.2957 exchange rate x 5.08t = $23,696/year

In the original scenario, or base case, when methane emissions were not accounted for, the present value of the cost to leave a well in the suspended state, including an expected repair cost, did not exceed the present value of abandonment costs within 50 years using a 10% discount rate. Upon lowering the discount rate to 3%, suspension costs surpass abandonment and reclamation costs in year 21.

If we could predict the future and knew that a well would develop a SCVF/GM leak, what would be the impact of adding SCM to suspended well costs? For the public, the answer is simple, the higher the SCM, the sooner they will benefit from A & R. For a private firm, a conservative SCM does not change the CBA unless the higher value is used (see figure 7).

When Cost of Suspension Equals Cost of Abandonment		
	10% Discount Rate	3% Discount Rate
Base Case (No SCM)	N/A	year 21
US$810/t SCM	N/A	year 15
US$3600/t SCM	year 5	year 4

Figure 7:Years until present value costs of a suspended well are equal to the present value cost of abandoning and reclaiming. Values assume a 100% likelihood of having SCVF/GM

However, it is expected that only 7% of suspended wells will develop SVCF or GM, and this must be factored into expected costs. Factoring the emitted tonnage by 0.07 creates costs attributed to methane of $373.21/year using conservative SCM and $1,658.70/year using the higher SCM; results are shown in figure 8. While the public may be slightly more inclined to abandon and reclaim a well using a high estimate of SCM, it would not be expected to have any impact on private firm decision making.

When Cost of Suspension Equals Cost of Abandonment		
	10% Discount Rate	3% Discount Rate
Base Case (No SCM)	N/A	year 21
US$810/t SCM	N/A	year 21
US$3600/t SCM	N/A	year 18

Figure 8: Years until present value costs of a suspended well are equal to the present value cost of abandoning and reclaiming. Values assume a 7% likelihood of having SCVF/GM

7. DISCUSSION AND POLICY RECOMMENDATIONS

An oil and gas firm with a suspended well in Alberta will choose to leave that well suspended based on a CBA using private costs and discount/investment hurdle rate. It makes far more economic sense for a firm to pay the ongoing surface lease costs, which after 50 years and accounting for the risk of paying for a well repair, are far less than the immediate capital costs of abandonment and reclamation. This same conclusion is also shown by Muehlenbachs (2015 & 2017) and reinforced by the rising number of suspended wells relative to abandoned wells occurring in Alberta since 2014. The government and public, which gives more value to the future and favours a lower discount rate (the social discount rate) for future costs, are more inclined to favor abandonment and reclamation (A &R) as the cost of a suspended well exceeds A & R within 21 years.

Suspended wells are also prone to SCVF and GM leaks which release methane emissions into the atmosphere; these emissions contribute to climate change, impact human health, and reduce agriculture yields, all of which poses an additional cost on the public which has been termed the Social Cost of Methane. Both a conservative SCM, adopted by the US EPA, and a higher SCM that attempts to incorporate the indirect effects of methane, have been suggested in the literature. Analysis of a SVCF/GM dataset obtained from the AER shows that open cases of suspended wells having gas leakage emit an average of 22.9m^3/day for 9.4 years, which yields 50.8 tonnes of methane for a typical leaking well. However, studies have indicated that 7% of suspended wells will experience SVCF/GM. If the expected value of 7% of those 50.8 tonnes of methane is added to the costs of a suspended well spread over 10 years of release time, there is no significant impact to the CBA and is unlikely to alter the business decision of a firm.

While the province, through the AER and OWA, has implemented an industry levy to pay for the costs of orphan wells and the LMR to serve as a form of contingent bonding on new wells owned by firms at higher risk of insolvency, there remains a significant risk to the taxpayer. In an era of continuing lower petroleum prices, the liabilities of orphaned wells may get funneled to fewer and fewer firms until the industry can no longer pay and the province is left responsible. Dachis et al. (2017) have suggested several policy options for reducing the public liability of inactive wells. Implementing a firm time limit on well suspensions, adding or increasing the bonding required to drill a new well, or a disincentive in the form of a monthly levy or requiring firms to purchase and hold insurance on a suspended well are all options that could be investigated further. An alternative solution may be to adapt suspended wells for production of geothermal energy, allowing the well to remain in use and in the hands of private ownership and responsibility. Co-generation of geothermal electricity could also serve to enhance the economic lifespan of mature petroleum wells, mitigating the number of suspended, poorly monitored wells throughout the province. Methane emissions from SVCF/GM present very real harm to the public, but incorporating their cost is not likely to change the corporate decision to leave a well suspended. Alternative solutions and government policy will likely be required to mitigate the risks presented by these wells.

On aggregate, reported SVCF/GM release equalled 83 million m^3 of natural gas in 2017, translating to 53,781 tonnes of methane emitted to the atmosphere (AER ST60B-2018). This has a social cost of between $56-250 million depending on which SCM you choose. While these numbers seem significant, it needs to be kept in mind that they represent less than 3% of the oil and gas contributions to methane emissions in Canada (Environmental Defense Fund, 2015). There may explain why SVCF/GM source methane emissions seem to garner very little attention from a government focused on emissions reduction. Wells with reported leaks of less than 300m^3/day is not considered serious and do not require repair; the owner is only under obligation to monitor the well on an annual basis to ensure that rate is not exceeded. Also, when a repair is required, firms are given 90 days in which to do so; however, the AER dataset used in this paper shows 130 suspended wells currently reporting leaks classified as serious, on average they have been leaking for 3121 days. More frequent inspections and stricter regulations on repairing gas leaks could help remove 16.4 tonnes of methane emissions per day.

8. CONCLUSION

Faced with a potential future economic burden estimated to be as high as $8 billion as the result of orphaned oil and gas wells, and inspired by the stated Government of Alberta goal of reducing methane emissions by 45%. This paper set out to investigate if incorporating the social cost of methane from leaking suspended wells into corporate cost benefit analysis could influence firms to promptly abandon and reclaim their wells instead of letting them sit indefinitely. While the aggregate release of methane from SVCF/GM presents a substantial cost and risk, distributing that cost amongst all suspended wells reduces the cost to the point that it is unlikely to incentivize the firm to abandon and reclaim. Charging a fee equal to the expected social cost of methane will not change company behavior because a firm remains economically advantaged leaving the well in a suspended state. The fee may recover the cost of methane leaks but fails to stop the emission or remove the potential abandonment burden.

To reduce methane emissions, tighter regulations and increased monitoring, along with enforcement of repair timelines would help to reduce gas leak volumes, but the most effective solution may be converting wells to other usages, such as geothermal energy production, to reduce the number of inactive wells. Reducing the number of suspended wells will mitigate the potential future burden of clean up and decrease methane emissions helping the province achieve it is 45% methane reduction goal.

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