Highlights

Lessons for Regulating Flaring and Venting: Results from Alberta, Canada

Adrian Guerin, Phuong Ho, Nouri Najjar, Brandon Schaufele

- Economic dynamics of flaring and venting remain under-explored in methane regulation.
- Alberta's two-decade data offers five key lessons for flaring and venting policies.
- Flaring and venting are distinct activities requiring different regulatory approaches.
- Infrastructure availability alone does not eliminate flaring and venting.
- Regulations reduce emissions but can induce leakage effects.

Lessons for Regulating Flaring and Venting: Results from Alberta, Canada

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Abstract

Regulating methane from the upstream oil and gas sector is seen as a low-cost method to reduce emissions. Yet, surprisingly few papers study the economic dynamics of flaring and venting, key sources of these emissions. Learning from regions with a history of regulating these activities is important for future policy design. Using data from Alberta, Canada, a jurisdiction that has regulated flaring and venting for more than two decades, we present five lessons. These lessons are: (i) Flaring and venting are distinct activities, requiring different rules; (ii) The large majority of gas can be conserved; (iii) Flaring and venting are positively correlated with production but the relationship is less than proportional; (iv) Infrastructure availability does not eliminate flaring and venting; (v) Regulation dramatically reduces flaring and venting, but can induce leakage. Appreciating these results supports policy-makers as they create rules to control emissions from the sector.

Keywords: Flaring, Venting, Emissions, Oil, Natural gas

1. Introduction

Methane regulation has received widespread attention as a low-cost method to rapidly reduce emissions that contribute to climate change. Countries like the United States, Canada, and the European Union have committed to cutting methane emissions by regulating the upstream oil and gas sector, focusing on operators that burn or release "associated gases" recovered during oil production (U.S. Environmental Protection Agency, 2023; Government of Canada, 2023; European Parliament, 2023). These practices, known as flaring and venting, contribute to both climate change (Plant et al., 2022) and local air quality issues (Tran et al., 2024). Flaring involves the combustion of methane and other gases trapped in oil reservoirs, while venting is the direct release of gases into the atmosphere. The World Bank's Zero Routine Flaring by 2030 initiative and other "global methane initiatives" exemplify international efforts to eliminate the

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wasteful burning of associated gas, instead promoting their conservation and use (World Bank, 2024; Aiming for Zero Methane Emissions Initiative, 2024; Global Methane Pledge, 2024).

Spurred by global methane reduction initiatives, recent research has studied the sources, measurement methods, and control technologies for methane emissions (Johnson, 2023). However, less attention has been given to the economic dimension of flaring and venting (Agerton et al., 2023). Understanding the market dynamics of existing regulations is crucial, because effective regulation requires an interplay between the science of methane management and the behavior of companies involved in these activities. Moreover, the limited economics and policy literature has focused on the potential impacts of emissions taxes on flaring and venting (Agerton et al., 2023; Lade and Rudik, 2020; Marks, 2022). Examining the outcomes of non-price regulations in regions with long-standing policies is equally important. To this end, we present novel data and analysis on key aspects of flaring and venting, summarized in five "lessons." These findings range from simple correlations to estimates of regulatory effects. All are made possible by the comprehensive data on oil and gas operations for two decades (2002–2023) in Alberta. In 2023, Alberta accounted for 84% of Canada's crude oil production, while Canada was the world's fourth largest oil producer (Energy Institute, 2024). Several of these results complement prior research from the U.S. (Agerton et al., 2023; Lade and Rudik, 2020). Others offer entirely new insights into the effects of regulating flaring and venting, including evidence of leakage.

2. Data and methods

Our primary source of data is flaring and venting volumes at facility-month level in the Canadian province of Alberta. Alberta was among the first oil and gas producing jurisdictions to enact regulations on emissions from flaring. The data are from the ST60 and ST60b reports of the Alberta Energy Regulator (AER). According to AER rules, operators are required to truthfully submit data under threat of penalty under Directive 60 (Alberta Enery Regulator, 2024).[1]

In Lesson 1, we explore sources of flaring and venting activities using data from the ST60b report for 2022. These data include flaring and venting volumes for all oil and gas facilities, such as crude oil batteries (including bitumen), natural gas batteries, and natural gas processing infrastructure (including compressor stations, gathering pipelines, and processing plants). The data also detail the sources of vented gas at each site, which include pneumatic devices, compressors, fugitive emissions (i.e., non-routine releases), and other sources of routine emissions. To compute CO2e emissions, we adopt the World Bank's flaring efficiency rate of 98% (The World Bank, 2024a) and methane warming potential of 28 times that of CO2 (The World Bank, 2024c). We also assume a methane content in natural gas of 90% (U.S. Energy Information Administration, 2024b) and a methane density of 0.68 kg/m^3 (Alberta Enery Regulator, 2020).

[1] The data excludes volumes from confidential and experimental facilities, however these volumes are minimal.

This results in a $CO2_e$ of 2.6 kg per cubic meter of flared gas and 17.1 kg per cubic meter of vented gas.

In Lessons 2-5, we analyze trends in flaring and venting and assess the implications of regulations on these practices. For this, we use the ST60 reports (Alberta Enery Regulator, 2024) covering the years 2002-2023. These reports provide facility-month-level data on flaring, venting, production and deliveries for oil and gas at crude oil and bitumen batteries in the province of Alberta, Canada.[2] Lesson 2 also incorporates estimated annual flaring volumes by country from the World Bank's Global Flaring and Methane Reduction Partnership (The World Bank, 2024b) and total annual dry natural gas production by country for 2022 from the U.S. Energy Information Agency (US Energy Information Administration, 2024).

When analyzing data from Alberta, the total emissions rates for year i are calculated as the sum of natural gas flaring and venting emissions across all N facilities in year i divided by the sum of annual gas production for those facilities in that year, multiplied by 100%:

$$\text{total emissions rate}_i = \frac{\sum_{n=1}^{n=N}(\text{flaring}_{in} + \text{venting}_{in})}{\sum_{n=1}^{n=N}(\text{gas production}_{in})} * 100\%$$

Flaring and venting emissions rates are calculated in the same manner but with only either the sum of flaring or venting emissions in the numerator.

For country-level flaring rates, while the World Bank reports flaring intensity as the amount of natural gas flared per barrel of oil produced (The World Bank, 2024b), we adopt an alternative measure that incorporates natural gas production. This ensures consistency with the measures used for Alberta and better reflects the degree of gas conservation across countries. We compute flaring rates as the volume of gas flared divided by the volume of natural gas produced.[3]

To estimate the extensive and intensive margins of flaring and venting in response to monthly oil and gas production at a battery during the period 2002-2023, we use the following regression:

$$y_{imt} = \alpha \ln(\text{Gas Production})_{imt} + \beta \ln(\text{Oil Production})_{imt} + \delta_{jmt} + \lambda_i + \epsilon_{imt}, \quad (1)$$

where y_{imt} is either whether the battery i releases the gas in month m in year t or the intensive margin of flaring and venting at the battery ($\ln(\text{Gas Emissions})_{imt}$). We regress each margin on the natural log of gas production ($\ln(\text{Gas Production})_{imt}$) and the natural log of oil production ($\ln(\text{Oil Production})_{imt}$). We exclude flaring and venting patterns in the first 12 months of oil and gas extraction at batteries to estimate the regular patterns of releasing. We control for battery fixed effects (λ_i) to account for the difference in emissions across batteries during the whole period due to, for example, the geological features at the battery location. We further include township-by-time fixed effects (δ_{jmt}) to capture many important shocks on emissions, ranging

[2]As of May, 2024, data from January 2011 onwards are available online. We received historical data dating back to 2002 from the AER by special request.

[3]The World Bank does not report venting volumes and to the best of our knowledge, there is no consistent data source for country-level venting volumes.

from seasonality to local economic factors and local regulatory factors at the township level (an area of 36-by-36 miles). For example, the township-by-time fixed effects first absorb all common weather shocks, the Alberta economy conditions, and the market prices of oil and gas that may affect oil and gas production. Even though the oil and gas producers face the same spot prices of oil and gas, different producers can have different oil and gas production rates and costs for capturing gas, affecting their decisions on flaring and venting. The township-by-time fixed effects account for different extraction rates due to varying productivity in different areas from geological nature and different infrastructure costs due to geographical features across townships. Further, the fixed effects also account for different flaring and venting regulations over time in different areas (at the township level). For instance, a pilot regulation on flaring and venting began in 2013 in the Peace River area in Alberta, as we investigate in Lesson 5.

3. Results and discussion

Lesson 1: Flaring and venting are different problems, likely requiring different regulation.

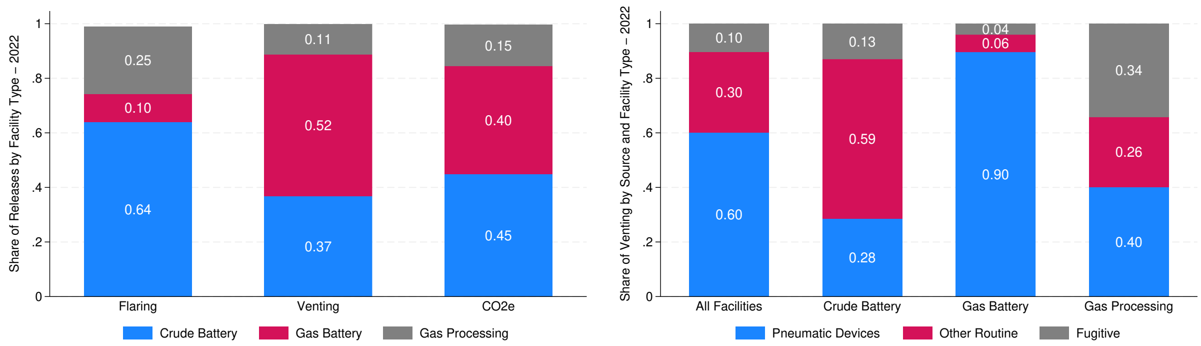
Our first lesson is that flaring and venting are fundamentally different problems generated by different economic forces. Though both contribute to climate change, different management of these releases and regulatory tools may be required.

Figure 1 highlights the distinct sources of flaring and venting activities. Panel (a) shows the share of flaring, venting, and CO2e emissions in 2022 from Alberta's oil and gas sector, categorized into three facility types—crude batteries (including oil and bitumen), natural gas batteries, and natural gas processing infrastructure (including gathering pipelines, processing plants, and compressor stations).[4] Nearly two-thirds of flaring occurred at crude batteries, while less than 10% happened at gas batteries. This suggests that flaring is largely driven by the joint production of crude oil, where associated gases are a less valuable by-product. Joint production is a fundamental problem of gas emissions during oil extraction. The key regulatory challenge in reducing flaring is to create rules and incentives that encourage crude oil producers to capture associated gases.

In contrast, more than half of vented methane comes from gas batteries, which specifically extract gas for processing. Since these batteries account for the majority of venting in Alberta, it suggests that joint production plays a minimal role in venting compared with flaring. To better understand this, Panel (b) decomposes venting emissions by source within the facility into fugitive emissions (e.g., leaks), pneumatic devices,[5] and other routine sources. Results reveal that 60% of vented releases across all facilities stem from pneumatic devices, and at gas batteries, 90% of vented emissions are due to these devices. This highlights that venting, unlike flaring, results from the technology used in gas extraction. Pneumatic devices are central to the venting problem. Put differently, because gas is more difficult to manage than oil, it is more

[4] All other sources, which contribute less than 1% of overall releases, are omitted from the chart.

[5] Pneumatic devices use compressed gas to operate and then vent the gas.



(a) Releases by Facility-Type

(b) Venting by Source and Facility-Type

Figure (1) Flaring and Venting by Facility-Type and Source, 2022

prone to leaks. The key policy challenge in reducing venting is to promote the development and adoption of alternative technologies for gas producers.

Another subtle point emerges from Figure 1. Nearly three-quarters of gas releases in Alberta occurred through flaring. However, because methane is a more potent greenhouse gas than CO2 (U.S. Environmental Protection Agency, 2024), the climate impact of venting is substantial. Panel (a) shows the share of each facility type in total emissions, measured in CO2 equivalents.[6] Both crude and gas batteries contribute similarly to climate change, with crude batteries accounting for 45% and gas batteries for 40% of emissions.

Overall, lesson 1 provides an overview of flaring and venting across both crude oil and gas batteries in Alberta, Canada. For the remaining four lessons, we concentrate on associated gases releases from crude (and bitumen) batteries, because this aligns with global policy priorities, such as the Zero Routine Flaring Initiative (World Bank, 2024), which targets upstream emissions. We stress, however, that other segments of the oil and gas value chain, namely gas batteries, are equally important.

Lesson 2: A large majority of associated gas can be conserved.

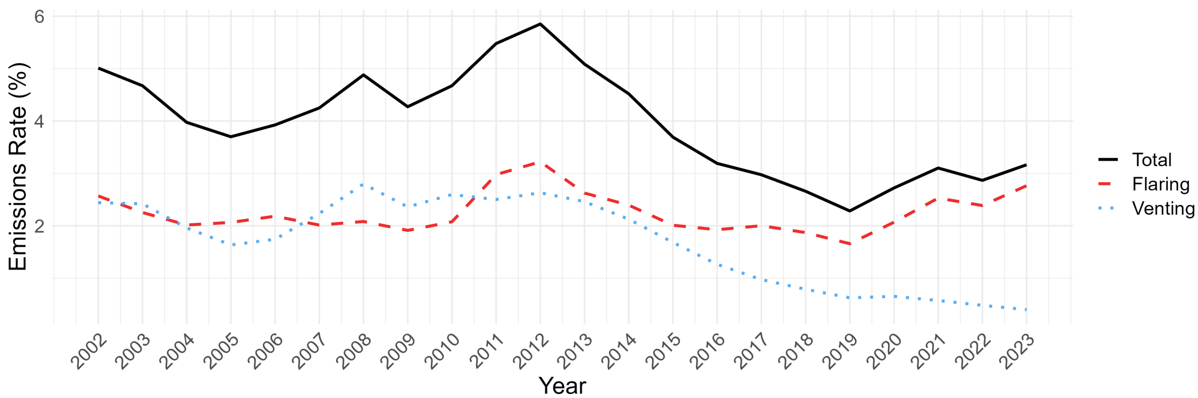
Flaring and venting have attracted increased attention due to the perception that these activities are fundamentally wasteful. Methane, instead of being released, could serve as a valuable energy source for electricity generation, space heating, or industrial processes (Environment and Parks, 2021). Squandering such a resource appears clearly inefficient. Lesson 2 confirms this intuition in Alberta: The vast majority of associated natural gas is conserved and marketed to end consumers.

Figure 2 shows the time series of flaring and venting rates in Alberta from 2002 to 2023. Total emissions peaked at 6% of associated gas but have leveled off at approximately 3% for

[6]We adopt the World Bank's flaring efficiency rate of 98%, assumed methane content in natural gas of 90%, and methane warming potential of 28 times that of CO2. We also assume a methane density of 0.68 kg/m^3. This results in a CO2-e of 2.6 kg per cubic meter of flared gas and 17.1 kg per cubic meter of vented gas.

the 2015-2023 period. The flaring rate remained relatively steady at 2-3%, while the venting rate dropped from a peak of 3% in 2008 to about 0.5% in 2023. Conservation rates, calculated as one minus the emission rate, show that roughly 97% of associated gas is conserved, meaning a large majority of associated gas is not flared or vented but effectively used.

Figure (2) Flaring and Venting Rates



Regulations aiming to further reduce flaring and venting in a region like Alberta, where conservation rates are already high, must target the tail of the phenomenon, those last few percent of flared and vented gas. Unfortunately, firms tend to implement the cheapest abatement measures first, meaning that reducing the final few percent of emissions may be more expensive and challenging to control.

Alberta's long history of flaring and venting regulation makes its experience aspirational for other jurisdictions. Emission rates vary significantly worldwide. Table 1 compares flaring rates across selected countries in 2022, suggesting where reducing flaring and venting may be more achievable.[7] Australia has the lowest flaring rate, at just 0.5%. The U.S., China, and Saudi Arabia—ranked among the top-fifteen of global flaring volumes—also have relatively low flaring rates (0.8%, 1.1%, and 1.5%, respectively). By contrast, Nigeria and Mexico exhibit substantially higher flaring rates of 13.3% and 18%, respectively. Globally flaring rates are relatively modest at 3.3%, but this does not account for venting, which may be substantial.

Lesson 3: Flaring is positively correlated with oil production, but the relationship is less than proportional.

Flaring and venting are due to gas and oil production. Understanding the extent and nature of this relationship is essential for effective regulatory design. The third lesson from Alberta's experience demonstrates that, as expected, flaring and venting of associated gas are positively

[7]Replicating comparable time series for most countries is not possible due to the lack of data on on venting volumes and associated gas production. Table 1 only reports the flaring rates for selected countries in 2022. Venting, which could be substantial, is not reflected in the table.

Table (1) Global Flaring Rates - 2022

	Flaring Rate	Global Volume Rank
Russia	4.1%	1
Iran	6.5%	3
United States	0.8%	6
Mexico	18.0%	8
Nigeria	13.3%	9
China	1.1%	10
Saudi Arabia	1.5%	14
India	4.7%	18
Brazil	3.9%	28
Australia	0.5%	31
Global	3.4%	-

Table presents flaring rates and global flaring volume rank for ten countries, listed in descending order by emitter rank. Flaring rate is the total volume flared divided by the total volume of natural gas extracted. Countries are ranked by the total volume flared in 2022. The final row shows the total global flaring rate.

correlated with oil production. Importantly, however, the emissions elasticity with respect to output is less than one. As oil production increases, flaring and venting also rise, but at a less-than-proportional rate.

Table (2) Flaring and Venting Elasticity of Gas and Oil Production

	(1)	(2)
	$\mathbf{1}\{\text{Emitting}\}$	$\ln$(Gas Emissions)
$\ln$(Oil Production)	0.0259***	0.0890***
	(0.0016)	(0.0071)
$\ln$(Gas Production)	0.0163***	0.6853***
	(0.0015)	(0.0066)
Observations	1,697,024	1,147,736
Adjusted R^2	0.597	0.773

Table reports emitting elasticities after the first 12 months of production. Regressions include battery and township-by-time fixed effects. Standard errors in parentheses.

Table 2 presents the results of two regressions representing the relationship between monthly gas emissions (the sum of flaring and venting) and monthly oil and gas production at the battery level during the period 2002–2023. Column (1) estimates the extensive margin, where the dependent variable equals one if a battery flares or vents that month. The results show that gas emissions are positively correlated with oil and gas production, even after accounting for seasonality and various local economic and regulatory factors through battery and township-by-month-by-year fixed effects. Specifically, a 1% increase in oil production leads to a statistically significant 2.6 p.p. increase in the likelihood of flaring or venting. The relationship falls to 1.6 p.p. for gas production. Column (2) reports estimates of the intensive margin, where the dependent variable is the natural log of monthly gas emissions. The elasticity of emissions with respect to oil production is 0.09: A 10% increase in battery-level oil production results in only a 0.9% increase in flaring and venting volumes *at that same battery*. The elasticity with respect to gas production is higher, at 0.69, but still less than 1.

The significant positive correlation between gas emissions and oil production emphasizes that flaring and venting are a by-product of oil extraction and can routinely occur during oil extraction activities (World Bank, 2023). Hence, flaring and venting are the result of economic decisions of oil extraction, not merely the consequence of external geological factors. However, the emitting elasticities of both gas and oil production are less than one: A 1% increase in production leads to less than a 1% increase in emissions. This less-than-proportional-relationship result reinforces lesson 2 on the possible success of achieving high conservation rates. Further, incentives for increased production – and greater conservation – are likely to be associated with higher prices.

Lesson 4: Collection infrastructure does not eliminate flaring and venting.

Infrastructure is required to capture and deliver associated gas. Gas infrastructure is more extensive and specialized than comparable midstream oil infrastructure (Coburn, 2020). Yet, although infrastructure is necessary to capture gas, data in Alberta show that natural gas infrastructure is not enough, on its own, to eliminate flaring and venting.

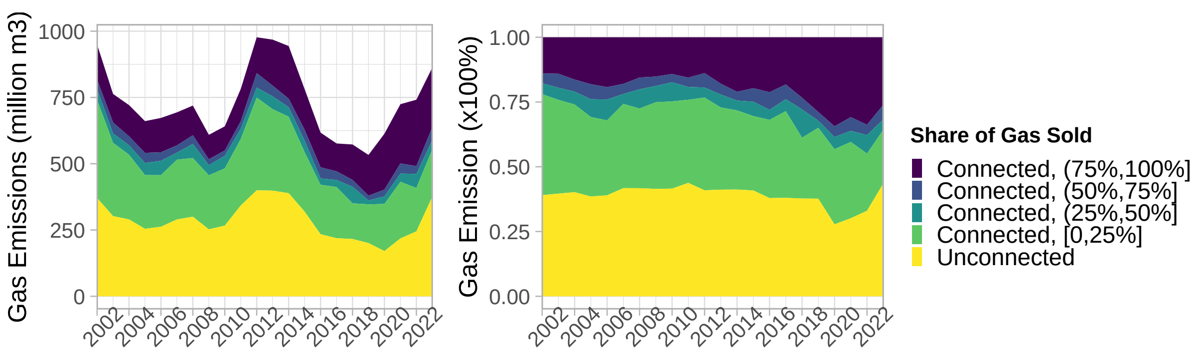


Figure (3) Gas emissions by share of gas sold

Figure 3 illustrates why this is the case. The figure characterizes gas flaring and venting by two classes of locations: those connected to collection infrastructure and those that emit all the gas they produce due to a lack of connections to infrastructure.[8] Unconnected locations contribute less than half of all emissions in every year between 2002 and 2023. Moreover, the volume and percentage of emissions from unconnected locations remain nearly constant over time. In contrast, emissions from locations that sell most of their gas (i.e., greater than 75%) have increased. Similar patterns are observed in the U.S. Bakken and Permian basins (Agerton et al., 2023).

These findings have several important regulatory implications. First, the absence of capturing infrastructure does not fully explain flaring and venting. Economic factors, such as midstream congestion or inefficient midstream markets, can play important roles in explaining flaring and venting. Second, regulating routine flaring needs to address not only primary extractors but also midstream players. Third, constant flaring and venting rates at unconnected sites, alongside the rising emissions at locations selling most of their gas, suggests weak investment incentives for building or expanding infrastructure. The absence of infrastructure is not the dominant limiting factor. This suggest the risks of potential carbon infrastructure "lock-in," given uncertain future demand for natural gas amid the transition to renewable energy (Bogmans et al., 2024; Achakulwisut et al., 2023; Kemfert et al., 2022; McGlade et al., 2018).

Lesson 5: Regulations can be effective at reducing flaring and venting, but can induce leakage.

In 2022, the U.S., Australia, and Canada were among the countries with the lowest flaring rates. All have federal and regional policies regulating venting and flaring, suggesting regulation plays a significant role in promoting natural gas conservation. We provide additional evidence from a unique policy experiment in Alberta. Starting in 2013, the AER began regulating venting and flaring emissions from heavy oil and bitumen batteries located in the Peace River region of the province. Batteries in this region were subject to regulations not imposed elsewhere in the province.

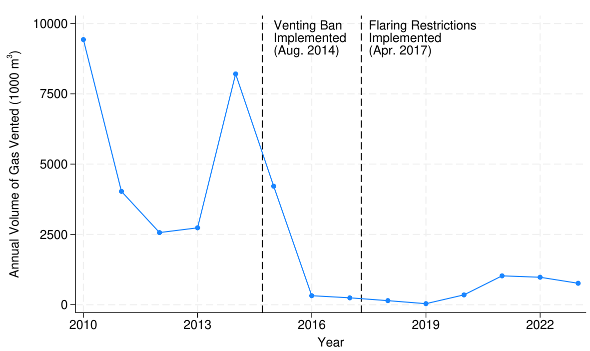
This policy experiment is instructive for several reasons. First, it unexpectedly introduced new rules, following a provincial panel investigating odor complaints in the province's Peace River region. The panel's deliberations took less than a year, and neither the regulator nor local operators anticipated the outcome.[9] Second, the rules exclusively applied to a relatively small region within a province, allowing for comparisons with nearby unaffected areas.[10] Third, the

[8]Connected locations refer to batteries that have sold associated gas either in the same year or previously (dating back to January 2002). Unconnected locations refer to batteries that have never sold associated gas (since January 2002). For connected sites, we further classify batteries according to their gas sold as a share of total associated gas production within the same year.

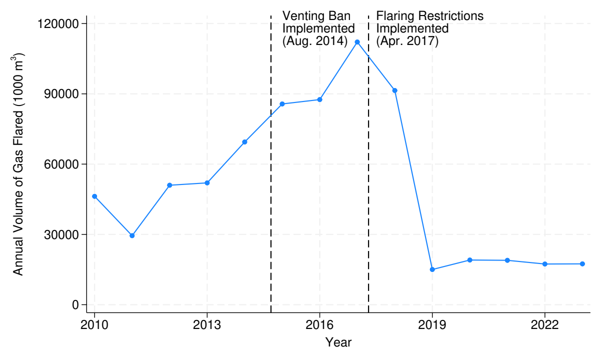
[9]In 2013, the AER established a panel of Hearing Commissioners to investigate odour complaints in the Peace River region. The panel's report, issued in March of 2014, recommended banning venting and restricting flaring in the region (Alberta Enery Regulator, 2014). In April of 2014, the AER announced it's intent to accept all panel recommendations (Yahoo! Finance, 2014). The AER subsequently amended Directive 060 in May 2014 to ban venting in the region.

[10]We define these unregulated batteries as those covered by the same AER field offices (the Grand Prairie and St. Albert/Slave Lake offices) as the regulated batteries, but that are located outside of the Peace River jurisdiction.

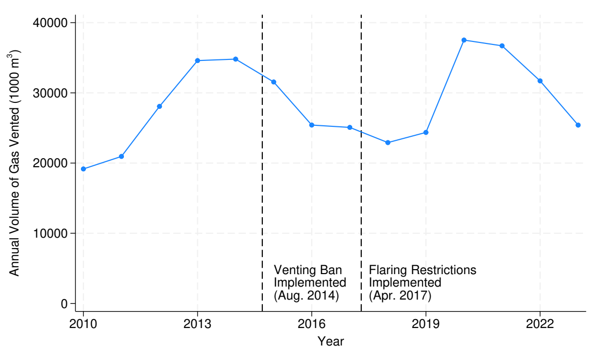
regulations were introduced in stages. A venting ban began in May 2014 and was fully phased in by 2016, while additional flaring restrictions—including a 5% total emissions cap and a 3% cap on non-routine flaring—were introduced in April 2017 and phased in over two years. These staggered rollouts allows us to assess the impact of the venting ban in isolation as well as in combination with additional flaring restrictions.



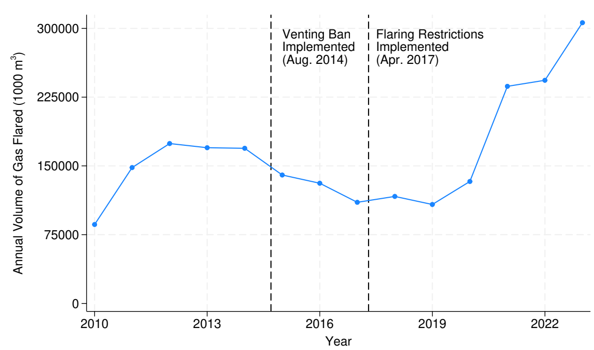
(a) Venting at Batteries in Regulated Region



(b) Flaring at Batteries in Regulated Region



(c) Venting at Nearby Unregulated Batteries

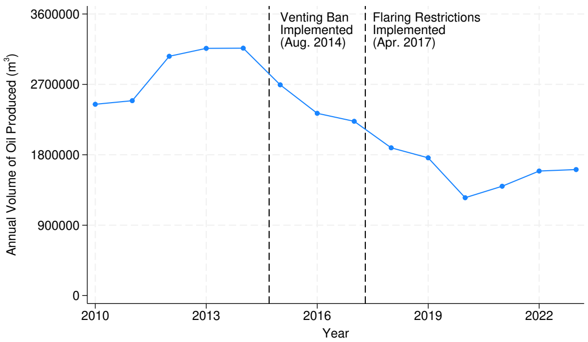


(d) Flaring at Nearby Unregulated Batteries

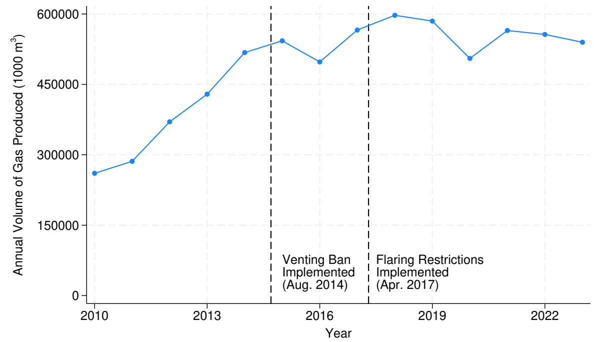
Figure (4) Emissions at Regulated Batteries and Nearby Unregulated Batteries

Figure 4 shows average annual volumes of gas vented and flared at batteries in the regulated region and nearby unregulated batteries.[11] Panel (a) shows that venting fell by 97% following the ban, while Panel (b) highlights that flaring dropped by 84% after the supplementary flaring restrictions. Panels (c) and (d) show small reductions in emissions at nearby unregulated batteries following the venting ban, likely tied to a global reduction in oil prices (U.S. Energy Information Administration, 2024a). In contrast, there was a substantial increase in flaring following the additional flaring restrictions. Flaring and venting are substitutes. During the venting ban, but before the supplementary flaring restrictions were implemented, regulated batteries vented less but flared more.

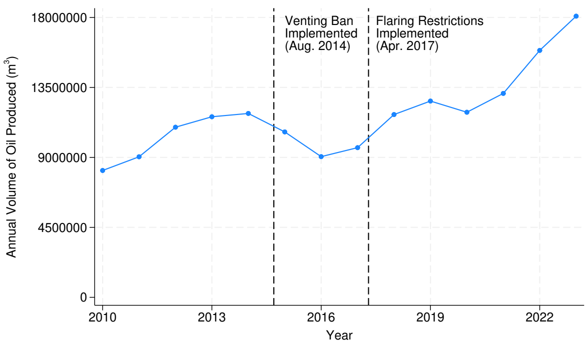
[11]The nearby unregulated batteries are defined as those covered by one of the same regulatory offices (called Field Centers) as the Peace River batteries.



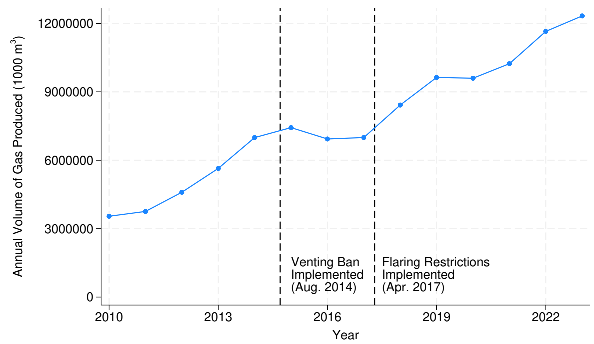
(a) Oil Production at Batteries in Regulated Region



(b) Gas Production at Batteries in Regulated Region



(c) Oil Production at Nearby Unregulated Batteries



(d) Gas Production at Nearby Unregulated Batteries

Figure (5) Oil and Gas Production at Regulated Batteries and Nearby Unregulated Batteries

Figure 5 explores the implications of the flaring and venting regulations on oil and gas production. Panel (a) shows that oil production at regulated batteries fell by 30% following the venting ban, followed by an additional decrease of 28% after the flaring ban. Panel (c) highlights a corresponding decrease at proximate, unregulated batteries during the venting ban; however, the decline is attenuated, equal to only 20% of pre-regulation production, relative to the regulated region. Panel (c) also shows that the decline reverses, illustrating how oil production increases in subsequent years.

Figure 5b indicates that, except for a small initial dip, gas production remained largely unchanged after the both the venting and flaring bans. Panel (d), likewise, shows few changes in gas production immediately following the venting ban. In the latter part of the decade, however, the unregulated regions experienced meaningful growth in gas production, while production in the regulated region remained flat.

Figures 4 and 5 suggest unilateral regulation of flaring and venting has two unintended consequences. First, limits on flaring and venting may reduce oil production. Reduced production has economic implications for workforces and communities that depend on energy output. Second, there may be leakage of production *and* emissions. That is, attempts to regulate only one source of emissions (e.g., venting) may lead to increases in the other (e.g., flaring) within the same region. Further, attempts to regulate both flaring and venting in one jurisdiction may shift production and emissions elsewhere, offsetting the total desired emissions reductions. Consequently, the final lesson is that effective regulation must address both flaring and venting to prevent substitution, and consider cross-regional effects to avoid leakage. While this lesson has also been noted in previous research (Calel and Mahdavi, 2020), we provide the first empirical evidence of these unintended consequences that undermine the regulatory impacts.

4. Conclusion

Regulating upstream methane and other greenhouse gas emissions from flaring and venting in the oil and gas sector is viewed as an easy win in the battle against climate change. Many countries are considering more stringent regulations to limit these activities. We provide five lessons on the opportunities and challenges of flaring and venting regulation using extensive and comprehensive data spanning over two decades. These data come from the Canadian province of Alberta, a jurisdiction with over twenty years of experience regulating flaring and venting. Our analysis leverages the novel data and offers unique insights into the potential consequences of enforcing regulations on flaring and venting.

The five lessons are:

1. Flaring and venting are distinct issues that likely require different regulatory approaches.
2. A large majority of associated gas can be conserved.
3. Flaring is positively correlated with oil production, but the emissions elasticity is less than one.
4. Collection infrastructure alone does not eliminate flaring and venting.
5. Regulations can effectively reduce flaring and venting, but they also risk inducing leakage. Effective policy measures should address both flaring and venting to prevent substitution between emitting means and control leakage across regions.

These lessons learned from Alberta's experience can help other jurisdictions develop effective strategies to reduce flaring and venting emissions.

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