Supplemental Material:
Active and inactive oil and gas sites contribute to methane emissions in western Saskatchewan, Canada

Judith Vogt[*,1,2], Justin Laforest[1], Mark Argento[1], Sarah Kennedy[1], Evelise Bourlon[1], Martin Lavoie[1], David Risk[1]

[1]Department of Earth Sciences, St. Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada

[2]Environmental Science Program, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X7, Canada

[*]jvogt@mun.ca

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Setup and instrument details

The inlet for the gas analyzer was located on the top of the roof, 2.55 m above the ground mounted on a fixed mast, together with the anemometer and compass (Figure S1). The anemometer and compass were both oriented facing the front of the truck. The motion-induced wind was removed using compass and GPS data to obtain true wind parameters. The compass was calibrated for local conditions each day as soon as all instruments were running to eliminate magnetic interference. The gas analyzer was calibrated in January 2020 and benchmarked daily. The gas samples were pumped through sample tubing from the inlet to the analyzer. In order to account for the time lag, we conducted a breath test on a daily basis and recorded the time the gas sample took from the inlet to the analyzer (approx. 10 s).

Figure S1. The mobile laboratory.

Snapshot of the truck during a stationary measurement in the Kindersley area.

Geolocations of oil and gas infrastructure

The three surveyed areas were each composed of thousands of single pieces of infrastructure. Geolocations, stati and production type of respective oil and gas wells were retrieved from AccuMap®, an IHS Markit product. Locations of facilities like storage tanks, pneumatic sheds etc. were extracted from a GIS database provided by IHS Markit. Since measured emissions were attributed to local oil and gas infrastructure, the accuracy of their geolocations was important for our approach. Geolocations of wells and facilities were provided by different vendors, and after visual inspection we deemed well geolocations accurate, while some provided facility geolocations deviated from actual locations. Thus, we improved geolocations of single-well batteries within the same dominion land survey as the associated oil or gas well by attributing the well geolocation to the facility geolocation. Upon subsequent visual inspection, we confirmed that the reattributed geolocations were improved. Since we observed several unlit flare stacks as emitting culprits in the field, we also complemented our infrastructure database with flare stack positions from provincial emission reports associated with flaring, and attributed respective geolocations of facilities to the flare stacks. That way, we carefully assembled a comprehensive infrastructure database from different sources with improved geolocations.

Surveyed routes and areas with enriched CH_4 concentrations

In the Swift Current area, we surveyed 438 km, 835 km in Kindersley and 718 km in Lloydminster. The driven routes and obtained excess CH_4 concentrations (above background) are shown in Figures S2 and S3. Excess CH_4 concentrations reached a maximum of 3.4 ppmv in Swift Current, 9.3 ppmv in Kindersley and 5.6 ppmv in Lloydminster.

In situ evidence of CH_4 leaks and vents

In order to confirm high emitters during mobile surveys and to find a suitable location for stationary CH_4 measurements (OTMs), we took optical gas images of the emitting infrastructure as evidence for CH_4 leaks and vents (Figure S4).

Oil and gas production history

The oil and gas production in the surveyed areas in the past years has partially experienced a slightly decreasing trend and was substantially affected by the COVID-19 pandemic in early 2020. By the time we surveyed the three regions, the oil and gas production rates had mostly recovered from impacts of the pandemic. The number of producing wells has been diminishing particularly in Kindersley and Lloydminster since 2018 (Figure S5).

Infrastructure types of sampled and emitting sites

CH_4 emissions can vary by fluid produced and by region (MacKay et al., 2021). Generally, most wells we surveyed produced oil, and accordingly most emitting wells were oil wells (Figure S6). The majority of sampled and emitting facilities were crude oil single-well batteries (in Swift Current and Kindersley) and heavy crude oil single-well batteries (in Lloydminster). Figure S8 shows per-facility emission factors based on the September 2020 report obtained from the Government of Saskatchewan. In Swift Current, highest emissions originated from gas plants and gas single well batteries, which we did not sample in Swift Current (Figure S7). Likewise, we sampled little to no crude oil multiwell proration or thermal in-situ batteries in Kindersley, which showed highest emissions according to the provincial report. However, in Lloydminster, we were able to capture a few of the highest emitting facilities, namely heavy crude oil paper, thermal in-situ and heavy crude oil multiwell proration batteries during surveys. This partially explains the deviation of our measured CH_4 emission rate estimates and reported emissions. Nonetheless, heavy crude oil single-well batteries, the facility

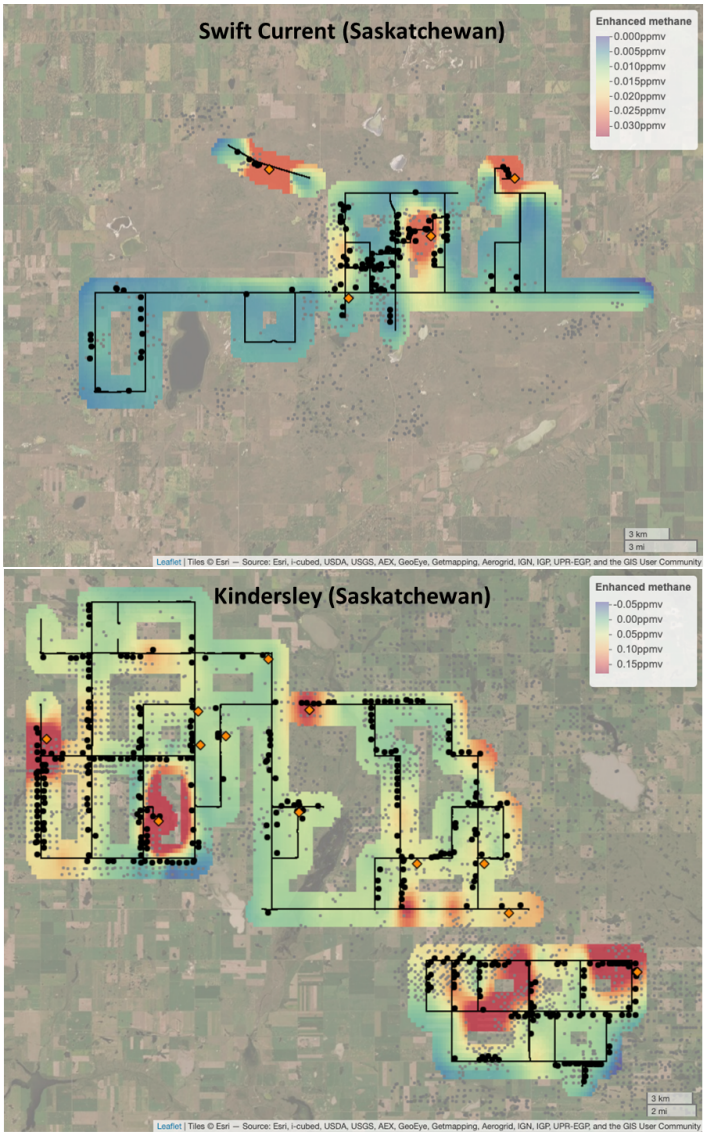

Figure S2. Surveyed routes in the studied areas.

Driven routes (black lines) in the Swift Current and Kindersley area in Saskatchewan, Canada. Gray dots represent present oil and gas infrastructure, black dots sampled infrastructure. Orange diamonds show the location of the truck during stationary CH_4 measurements (Other Test Method 33A, short: OTM). Elevated atmospheric CH_4 concentrations in ppmv above background (eCH_4) as shown in the maps were interpolated via averaging eCH_4 over $0.02 \times 0.02°$ grids and resampling over $0.0025°$.

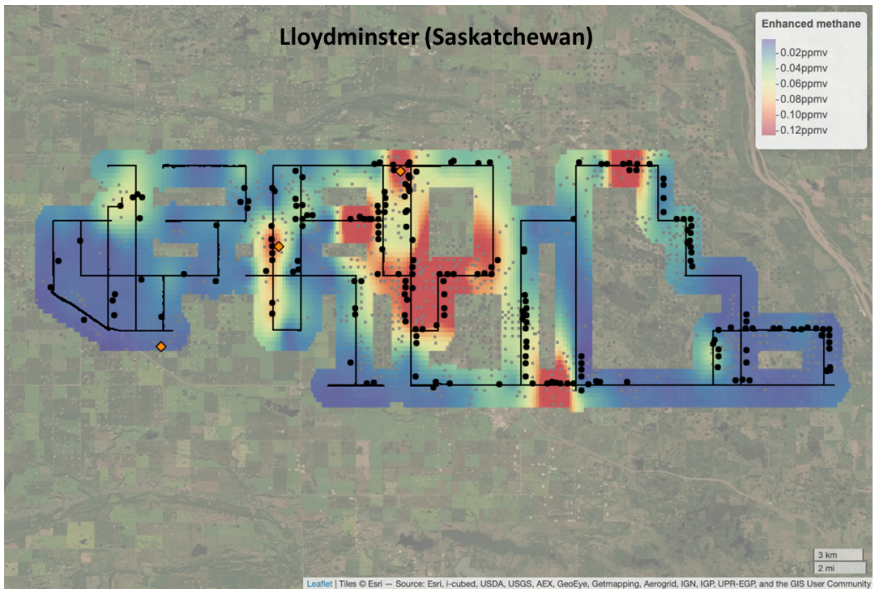

Figure S3. Surveyed routes in Lloydminster, Saskatchewan.

Same as for Figure S2.

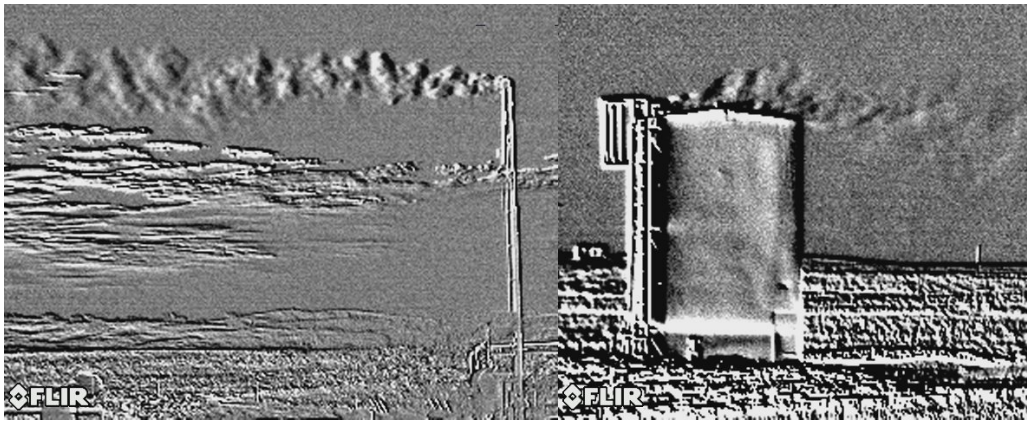

Figure S4. Optical gas images taken with a forward-looking infrared camera.

The images show CH_4 plumes from an unlit flare in Swift Current and a venting tank in Kindersley (also shown in Figure S1).

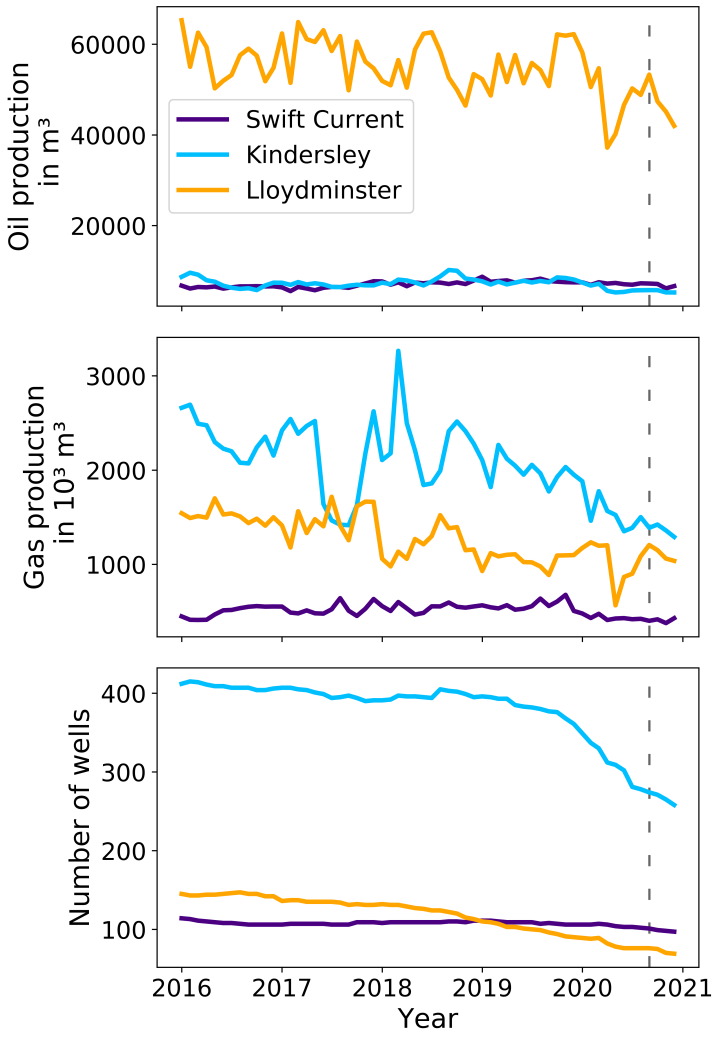

Figure S5. Production history of wells.

Total monthly oil and gas production history of wells that were sampled during mobile surveys, and the number of producing wells in Swift Current, Kindersley and Lloydminster from 2016 to 2020. The dashed vertical line shows the month we conducted measurements in the studied areas in September 2020.

type sampled most during our surveys in Lloydminster were among the highest emitters according to emission reports, as well as crude oil single-well batteries which were most abundant in our Kindersley and Swift Current surveys.

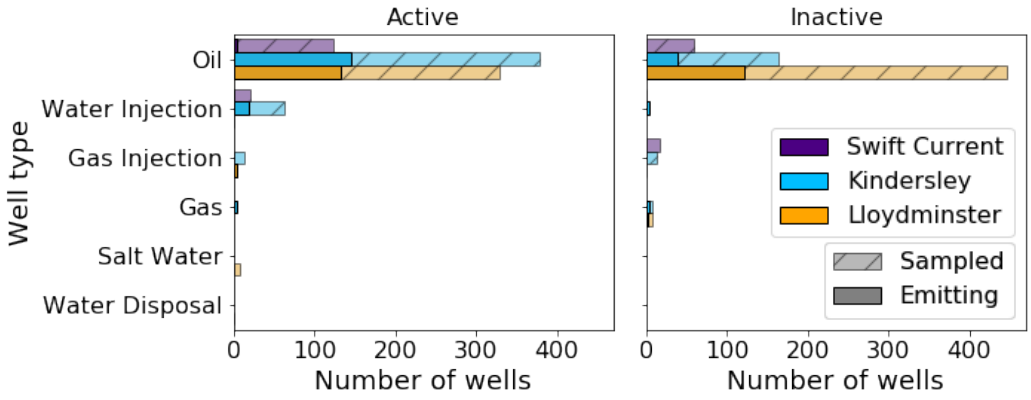

Figure S6. Well characteristics.

Number of sampled and emitting wells associated with different types of fluids in each region divided into active and inactive infrastructure groups.

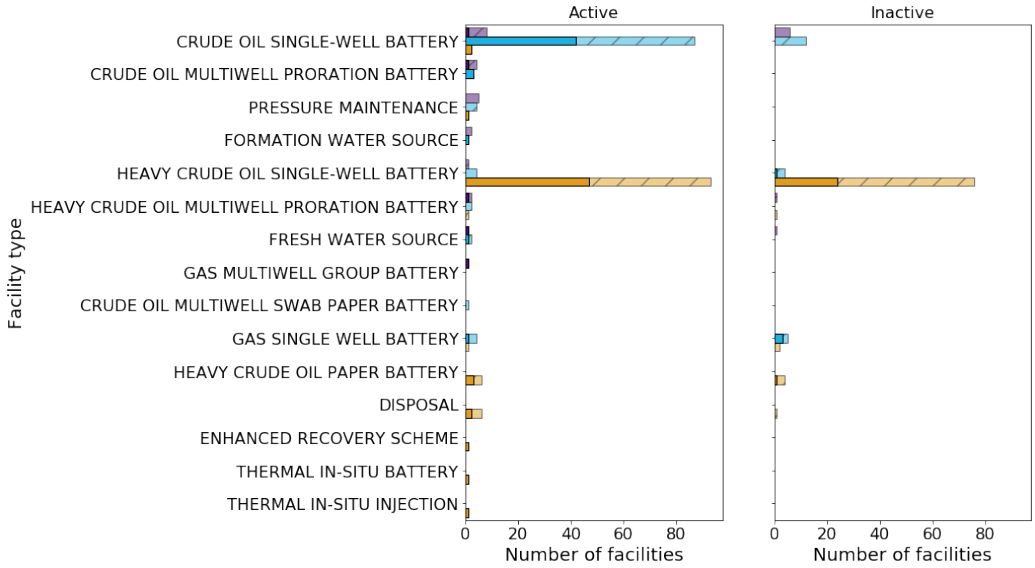

Figure S7. Facility characteristics.

Type and number of sampled and emitting facilities in each region divided into active and inactive infrastructure groups. The same legend as in Figure S6 applies.

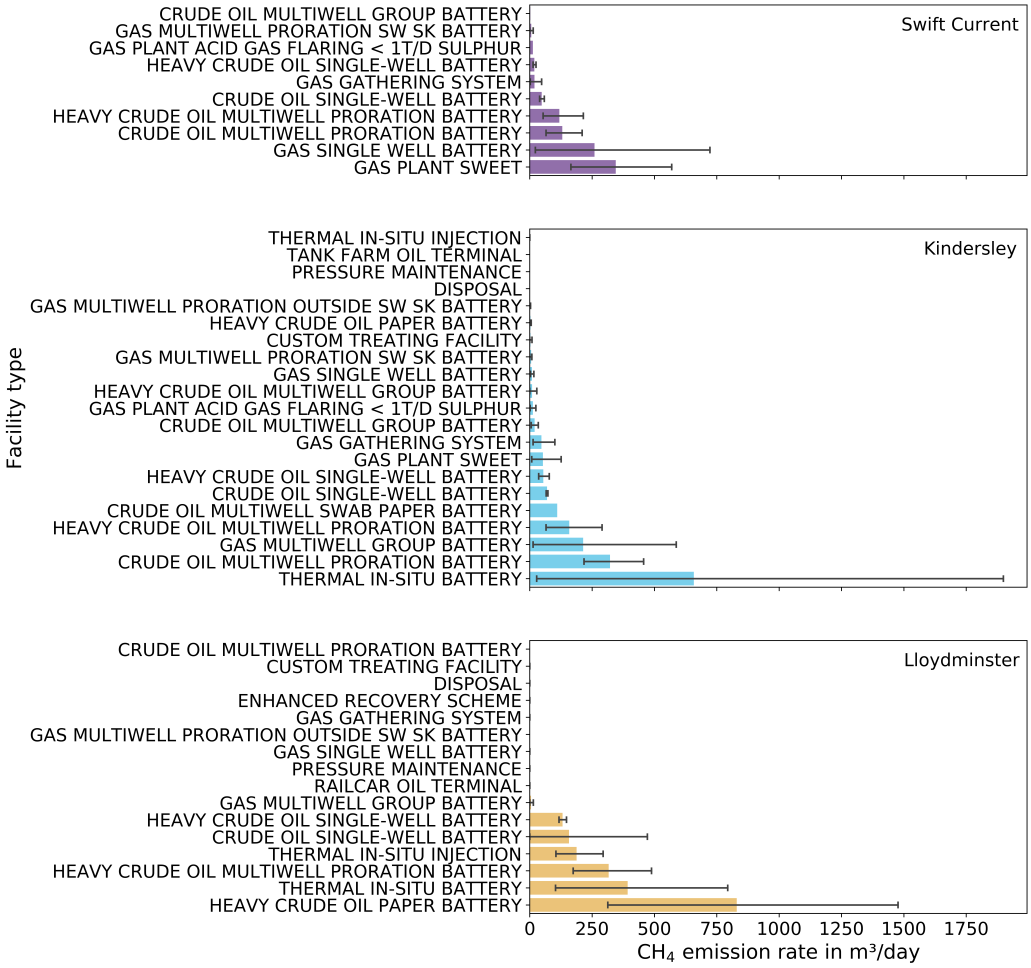

Figure S8. Emission factors of facility types.

Reported CH_4 emissions per facility type in each area based on the monthly report of September 2020. The bars show mean per-facility emissions with errorbars representing the 95% confidence interval. Some facility types did not emit CH_4 following the provincial report.

References

MacKay K, Lavoie M, Bourlon E, Atherton E, O'Connell E, et al. 2021. Methane emissions from upstream oil and gas production in Canada are underestimated. *Scientific Reports* **11**(8041). doi:10.1038/s41598-021-87610-3.