Unintended consequences of anti-flaring policies—and measures for mitigation

Raphael Calel[a,1,2] **and Paasha Mahdavi**[b,1]

Oil reservoirs contain significant quantities of methane, which leak out when the oil is extracted. At oil wells around the world, over 140 billion cubic metres (bcm) of this methane is burned off ("flared") every year, transforming it into carbon dioxide which contributes to global warming. Just as much gas is released directly as methane ("vented"), which makes as much as a 16-fold contribution to global warming. Flaring and venting waste 8% of global natural gas production annually, contribute 6% of global greenhouse gas emissions (1), and disperse a range of pollutants that harm human health (2, 3) and local environments (4). Capturing and using this gas would be a pro-development (5), cost-effective (6) means of reducing greenhouse gas emissions, yet current efforts to curtail the problem are struggling to make headway.

In 2015 the World Bank's Global Gas Flaring Reduction Partnership (GGFR) launched the "Zero Routine flaring by 2030" initiative (7), which promotes regulations on flaring and, to a lesser degree, the financing of new gas infrastructure. Both of these approaches are seriously flawed. The regulatory solutions appear to be mostly ineffective, and run the risk of being seriously counterproductive: since flaring is easily detected with high-resolution satellites while measurements of venting are either imprecise (medium-resolution satellites) or prohibitively costly at scale (aerial monitoring), restrictions on flaring can push oil producers towards greater venting. Even a small increase in venting would be enough to create a net increase in global warming. Meanwhile, although gas infrastructure financing does reduce the incentive to flare and vent, it is effectively a subsidy for oil and gas production, which creates incentives to increase downstream emissions. With current data, it is impossible to reliably quantify the full extent of these problems, but in rare cases, when more information unexpectedly becomes available, we can glimpse evidence that conforms closely to our expectations. Both regulatory and infrastructure solutions can be amended to mitigate these risks, we argue, with two all-important modifications. First, development of remote sensing techniques for detecting point-source methane emissions would significantly ameliorate the monitoring problem, giving regulators the technological tools they need to effectively curb both flaring and venting. Second, in order to counteract the effects on downstream emissions, new production taxes need to be adopted as the primary means of financing gas infrastructure.

Missed opportunities

Flaring activity has historically been concentrated in five countries—Russia, Nigeria, Iran, Iraq, and Algeria—which account for roughly half of all flaring. Flaring rose in the late 1990s and reached a peak in the early 2000s (fig. 1, left panel). By 2010 flaring had fallen by 20%, but discouragingly, there has been no decline since, even after the collapse of oil prices in 2014. One reason is that flaring reductions in the two top countries, Russia and Nigeria, have been offset by increases in the United States, which has quadrupled its flaring activity since 2010, driven by the shale boom.

Geographic concentration can sometimes make a problem easier to tackle, since only a small coalition of committed partners is needed to make significant progress. But it also can be a hindrance if it concentrates the problem in hard-to-reach places. Flaring falls in the latter category. The top five countries rank among the lowest in political stability, regulatory quality, and control of corruption (8, 9). Lower levels of government effectiveness are systematically associated with greater flaring, both across countries and across time (fig. 1, right panel). Dramatic changes in government effectiveness—improvement of state capacity in China, Kazakhstan, and Indonesia, deterioration in Venezuela—are associated with concordant changes in the fraction of flared gas (although this empirical association breaks down at very low levels of government effectiveness in conflict and post-conflict settings—such as the collapse of Libya, Iraq, Yemen, and Syria—where oil production often suffers a simultaneous collapse).

Although greater government effectiveness is associated with less flare waste, this relationship generally does not appear to be driven by anti-flaring regulations. The GGFR has emphasized regulatory reforms to decrease flaring (10). While this approach is seemingly effective in the United States (11), stricter permitting rules and gas re-injection requirements have not been effective globally (12). Even outright bans—as in Algeria in 2005 and Ghana in 2010—have not been followed by reductions in flaring (see fig. S1, and (13)). Nor, where offered, have site-level financial incentives to curb emissions decreased flaring (14). For example, we find that among all flaring sites that have applied for carbon credits under the Clean Development Mechanism (CDM), approved

DRAFT

---

[a]McCourt School of Public Policy, Georgetown University; [b]Department of Political Science, University of California Santa Barbara

[1] R.C and P.M. contributed equally to this work.

[2] To whom correspondence should be addressed. E-mail: raphael.calelgeorgetown.edu

The authors have no conflicts of interest to declare.

Action	Description	Emissions	GWP$_{20}$	GWP$_{100}$
Flare	*Burning one tonne of associated gas at the source produces 2.74 tonnes of carbon dioxide, as well as the equivalent amount elsewhere for consumption*	$5.49tCO_2$	5.49	5.49
Vent	*Venting one tonne of associated gas at the source results in one tonne of methane emissions, as well as 2.74 tonnes of carbon dioxide emissions elsewhere for consumption*	$1tCH_4 +$ $2.74tCO_2$	88.74	36.74
Capture	*Utilising one tonne of associated natural gas displaces approximately one tonne that would otherwise have been needed to meet consumption demand*	$2.74tCO_2$	2.74	2.74

Table 1. Global warming potential (GWP) of flaring, venting, and capturing one tonne of associated natural gas over 20- and 100-year horizons.

sites show no difference in flaring trends from other sites, even though those producers receive credits for every avoided tonne of emissions (fig. S2).

Unintended consequences

Regulations to limit flaring not only seem to be ineffective, but can also have the unintended consequence of driving firms to vent instead. Flares are highly visible both to the naked eye and to remote sensing instruments, allowing low-cost identification of point sources and estimation of the quantity of gas flared (15). Vented gas, on the other hand, is invisible. It can only be inferred remotely by measuring the methane concentration in the entire atmospheric column and comparing it to background levels. Even with state-of-the-art remote sensing tools, the resolution of these techniques is far too low—at best, 49 km^2 per pixel—and the uncertainty too great to identify specific venting sites (16–18). Aerial monitoring provides higher resolution measurements, but is too costly (and polluting) to use for continuous monitoring on a large scale. The result is a "multitask problem" (19), in which a firm substitutes from the easily observed task (in this case, flaring) to the other (venting) to avoid punishment.

It is inherently challenging to reliably quantify the degree of deliberate shifts from flaring to venting; the very essence of the problem is that venting is difficult to detect, and the multitask problem goes away wherever venting is specifically monitored. It is only in rare cases, when the right information unexpectedly becomes available, that we can glimpse evidence of the problem.

A recent episode in Turkmenistan is highly revealing. In 2019 the GHGSat-D satellite was monitoring a mud volcano in western Turkmenistan when it unexpectedly detected large volumes of methane near the edge of its measurement domain. This eventually led researchers to identify three large methane plumes coming from the Korpezhe oil and gas field (20). Two plumes were traced to a malfunctioning pipeline valve and leaks from a processing facility, both of which appear to have been accidental releases. The third plume originated from a compressor station near the wellhead, which it now appears has been venting methane since at least January 2017, the earliest date for which measurements are available from the TROPOMI satellite instrument. This is the sort of site that one might expect to be flaring, but Turkmenistan has a prohibition on continuous flaring (21), and indeed, there has been no evidence of flaring at this site since the VIIRS satellite began monitoring flares in 2012 (20). What is more, follow-up readings indicate that methane emissions from this site stopped after the plume was publicized (22). Without insider information, it is impossible to determine conclusively whether this venting was deliberate. But viewed through the lens of the multitask problem, these facts suggest that state-owned Turkmengaz, the field's operator, had been systematically venting natural gas rather than flaring it in order to evade detection.

This sort of shift from flaring to venting is detrimental for the climate. Taking into account differences in atomic mass, flaring one tonne of methane produces roughly 2.7 tonnes of carbon dioxide. If the methane is vented instead, it has the same global warming potential (GWP) as 86 tonnes of carbon dioxide over a 20-year horizon (23). A policy that causes venting instead of flaring, therefore, increases the GWP by a factor of $(86 + 2.7)/(2 \times 2.7) = 16.2$ (see tab. 1).

To illustrate the consequences, consider a policy that caps flaring at 100 tonnes per day, half of what a particular oil field is currently flaring. If each barrel of oil is associated with one tonne of gas, the extraction rate would be limited to 100 barrels per day. Remote measurements will show a 50% reduction in emissions from flaring. But the ratio of oil to associated gas is variable and difficult for the regulator to observe, so if the firm increased production by even five barrels and vented the associated gas, which the regulator cannot see, the true effect would be a net 30% increase in CO$_2$-equivalent emissions.

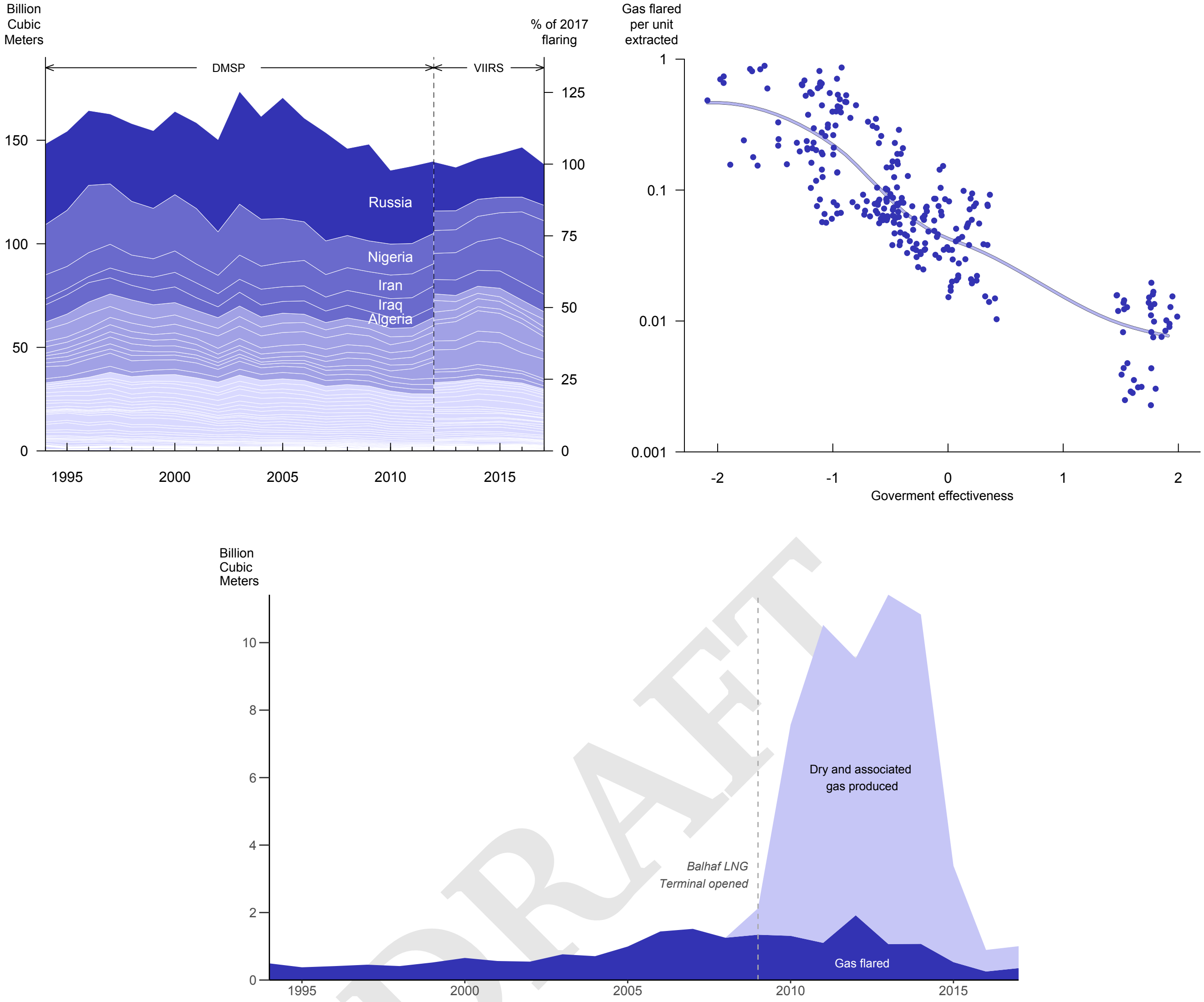
Solving the multitask problem

Gas infrastructure seems a promising way to solving the multitask problem. Constructing export terminals, compression facilities, re-injection wells, and pipeline networks makes it economically feasible to capture and utilise gas that would otherwise be flared or vented. By preventing the burning of an additional tonne of methane downstream, it allows the same gas demand to be met with half the GWP of flaring (see tab. 1, row 3).

The experience of infrastructure development in Russia is instructive. At the Vankor oil field, the addition of compressor stations and connections to the Gazprom national gas transport network achieved a 77% reduction in flaring at nearby associated gas fields from 2012 to 2017 (fig. S3).

But infrastructure programs can fall prey to a kind of multitask failure, too. Because infrastructure is effectively a subsidy to oil and gas production, total production volumes may increase even as the rate of flaring declines. Prior to the construction of the Yemen LNG terminal at Balhaf in 2009, for example, all gas was flared and production was virtually non-existent. But flaring did not end

DRAFT



DRAFT

Fig. 1. ***Global trends in natural gas flaring***. *The* ***left panel*** *plots the quantities of flared natural gas (in BCM) by country, and shows them as shares of global flaring in 2017 (right axis). The numbers are calculated from satellite images collected by the US Defense Meteorological Satellite Program (DMSP) through 2012, and by the Visible Infrared Imaging Radiometer Suite (VIIRS) in later years. We display both sets of estimates for 2012, the only year for which both systems were active. The colour gradient, from darkest to lightest, indicates the largest, the top 5, and top 15 flaring nations in 2010. The* ***right panel*** *plots Government Effectiveness scores (8) against logged flaring efficiency (flared BCM / total extracted BCM) for the top 15 flaring nations annually from 1994 to 2017. The fitted curve shows a general negative association, and this holds within countries except for very low Government Effectiveness scores. The* ***bottom panel*** *shows the total gas extracted annually in Yemen, as a sum of all gas either flared (dark purple) or commercially produced (light purple) (Data source: DMSP). The vertical dashed line marks the completion of the LNG terminal at Balhaf. Total extraction steeply declines after civil war breaks out in March 2015, considerably damaging oil and gas wells.*

when Balhaf opened. Instead gas production rose sharply, and flaring did not decline until oil and gas production collapsed after the outbreak of civil war in 2015 (fig. 1, bottom panel). The Yemen case demonstrates the possibility of constructing gas infrastructure even in states with low capacity, but it also shows how the positive effect of that infrastructure can be wiped out in absence of re-enforcing policy. To disincentivise this kind of overproduction, it is critical that these gas infrastructure projects are financed through production taxes on oil and gas producers. Just as in a deposit-refund system, it is the pairing of a tax on production ("the deposit") with a subsidy for the safest form of disposal ("the refund") that provides a cost-effective solution to the multitask problem.

In sum, current approaches to curtailing flaring face potentially serious multitask problems. Regulatory restrictions and financial incentives to stop flaring run the risk of encouraging deliberate venting. Financing of gas infrastructure offers a promising alternative since it reduces the incentive to vent, but it can backfire by increasing downstream emissions instead.

Both approaches could have a brighter future, though. New remote sensing instruments such as the MethaneSAT satellite (24), set to launch in 2022, will take measurements at more than 300 times the resolution of current instruments, dramatically reducing the cost of measuring methane emissions from point-sources (25). Some private companies have recently begun offering oil producers localised remote monitoring of methane leaks, but governments and institutions should support the development of new

Calel *et al.* PNAS | **March 18, 2020** | vol. XXX | no. XX | 3

instruments and methodologies that will transform these data into reliable high-resolution measurements. This public good can be used by regulators the world over, making it feasible to monitor venting even for states with low government capacity. In the meantime, while the World Bank and its partners are working to eliminate flaring, they should be mindful of the risk that regulatory solutions might unintentionally drive up venting. To the extent that they pursue gas infrastructure development instead, they would do well to prioritise the adoption of new production taxes as the primary means of financing to mitigate the risk of increasing downstream emissions.

Ending the practices of flaring and venting provides an opportunity for rapid low-cost emissions reductions, thus slowing the near-term accumulation of greenhouse gasses and reducing the risk of crossing climatic tipping points. Development of remote-sensing technologies, production taxes, and investments in infrastructure are essential to this project, but only as a waypoint on the road to a zero-carbon future.

Acknowledgments

This work was supported by the Georgetown Environment Initiative's Impact Program. We thank the editor and anonymous reviewer for their helpful feedback, Levi Marks for comments on earlier drafts, and Gregory Lyons for research assistance.

1 D Victor, et al., Introductory chapter in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. O Edenhofer, et al. (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA), (2014).

2 O Maduka, C Tobin-West, Is living in a gas-flaring host community associated with being hypertensive? Evidence from the Niger Delta region of Nigeria. *BMJ Glob. Heal.* **2**, e000413; e000413–e000413 (2017).

3 L Fleischman, J Banks, J Graham, Fossil fumes: A public health analysis of toxic air pollution from the oil and gas industry, Technical report (2016).

4 TE Ologunorisa, A review of the effects of gas flaring on the Niger Delta environment. *Int. J. Sustain. Dev. & World Ecol.* **8**, 249–255 (2001).

5 F Gerner, B Svensson, S Djumena, Gas flaring and venting: A regulatory framework and incentives for gas utilization, (World Bank), Technical report (2004).

6 M Fischedick, et al., Industry in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. O Edenhofer, et al. (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA), (2014).

7 World Bank, Guidance on upstream flaring and venting: Policy and regulation, Technical report (2009).

8 MG Marshall, TR Gurr, K Jaggers, POLITY IV project: Political regime characteristics and transitions, 1800–2017, Technical report (2017).

9 World Bank, Worldwide Governance Indicators (WGI) Project, Technical report (2017).

10 World Bank, Regulation of associated gas flaring and venting: A global overview and lessons from international experience, Technical report (2006).

11 GE Lade, I Rudik, Costs of inefficient regulation: Evidence from the Bakken, (National Bureau of Economic Research), Working Paper 24139 (2017).

12 MF Farina, Flare gas reduction: Recent global trends and policy considerations, Technical report (2010).

13 F Allen, *Implementation of oil related environmental policies in Nigeria: Government inertia and conflict in the Niger Delta.* (Cambridge Scholars Publishing), (2011).

14 B Buzcu-Guven, R Harriss, Extent, impacts and remedies of global gas flaring and venting. *Carbon Manag.* **3**, 95–108 (2012).

15 CD Elvidge, et al., A fifteen year record of global natural gas flaring derived from satellite data. *Energies* **2**, 595–622 (2009).

16 S Houweling, et al., A multi-year methane inversion using SCIAMACHY, accounting for systematic errors using TCCON measurements. *Atmospheric Chem. Phys.* **14**, 3991–4012 (2014).

17 O Schneising, et al., Remote sensing of fugitive methane emissions from oil and gas production in north american tight geologic formations. *Earth's Futur.* **2**, 548–558 (2014).

18 AJ Turner, et al., A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations. *Geophys. Res. Lett.* **43**, 2218–2224 (2016).

19 B Holmstrom, P Milgrom, Multitask principal-agent analyses: Incentive contracts, asset ownership, and job design. *J. Law, Econ. organization* **7**, 24 (1991).

20 D Varon, et al., Satellite discovery of anomalously large methane point sources from oil/gas production. *Geophys. Res. Lett.* **46**, 13507–13516 (2019).

21 T Haugland, et al., Associated petroleum gas flaring study for Russia, Kazakhstan, Turkmenistan, and Azerbaijan. *Eur. Bank for Reconstr. Dev.*, 80 (2013).

22 H Tabuchi, A methane leak, seen from space, proves to be far larger than thought. *The New York Times* **16 December** (2019).

23 G Myhre, et al., Anthropogenic and natural radiative forcing in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. T Stocker, et al. (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA), (2013).

24 EDF, EDF Announces Satellite Mission to Locate and Measure Methane Emissions (2018).

25 DJ Jacob, et al., Satellite observations of atmospheric methane and their value for quantifying methane emissions. *Atmospheric Chem. Phys.* **16**, 14371–14396 (2016).

DRAFT