Matters Arising Response

Jessica Jewell[1,2,3,4,*], Johannes Emmerling[5,6], Vadim Vinichenko[2,3], Christoph Bertram[7], Loic Berger[5,6,8], Hannah Daley[9], Ilkka Keppo[10], Volker Krey[11,12], David E.H.J. Gernaat[13,14], Kostas Fragkiadakis[15], David McCollum[16], Leonidas Paroussas[15], Keywan Riahi[11,17], Massimo Tavoni[5,6,18], Detlef van Vuuren[13,14]

[*] *corresponding author*: jewell@chalmers.se. [1]Chalmers University of Technology, SE-412 96, Gothenburg, Sweden • [2]Centre for Climate and Energy Transformations [3]Department of Geography, Faculty of Social Sciences, University of Bergen, Postbox 7802, 5020 Bergen, Norway • [4]Risk and Resilience Program, International Institute for Applied Systems Analysis, Schlossplatz 1, Laxeburg 2360, Austria • [5]European Institute on Economics and the Environment Milan Office, Via Bergognone, 34 20144 Milan, Italy • [6]Centro Euromediterraneo sui Cambiamenti Climatici, 73100 Lecce, Italy. • [7]Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, P.O. Box 60 12 03, D-14473 Potsdam, Germany. • [8]IESEG School of Management, CNRS, Univ. Lille, UMR 9221 - LEM, F-59000 Lille, France. • [9]University College Cork, College Road, Cork T12 K8AF, Ireland. • [10]University College London, WC1E 6BT, United Kingdom. • [11]Energy Program, International Institute for Applied Systems Analysis, Schlossplatz 1, Laxeburg 2360, Austria • [12]Industrial Ecology and Energy Transitions Programmes, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway • [13]Copernicus Institute for Sustainable Development, University of Utrecht, 3584 CS Utrecht, The Netherlands. • [14]PBL Netherlands Environmental Assessment Agency, The Hague, The Netherlands. • [15]National Technical University of Athens, 15773 Athens, Greece. • [16]Electric Power Research Institute, 3420 Hillview Avenue, Palo Alto, CA 94304, United States. • [17]Institute of Thermal Engineering, Graz University of Technology, 8010 Graz, Austria. • [18]Department of Management, Economics and Industrial Engineering, Politecnico di Milano, 20156 Milan, Italy.

In 2009, the G20 countries pledged to phase-out fossil fuel subsidies[1]. Our original article highlighted that about 95% of subsidies go to consumers and two-thirds are in the Middle East, Russia and Latin America[2]. We also found the largest emission reductions from subsidy removal would occur in those three regions, where low oil prices provided a unique political opportunity and the reforms would harm fewer poor people. Erickson et al. argue that we downplay the impact of subsidy removal and the effect of subsidies for oil producers, such as the US' intangible drilling cost (IDC) scheme. Here we show large variations in such schemes and estimate their impact to be within the range of the sensitivity analysis from our original article. The US IDC, may represent a unique political opportunity for producer subsidy reform, but reforming such schemes may not be effective in countries where they are applied in tandem with high taxes for oil production.

We estimated emission reductions from subsidy removal would be between 2-8% and 3-15% of those required by 2030 to achieve the 1.5°C and 2°C targets. We called this "unexpectedly small" because it contrasts sweeping statements that subsidy removal would have "significant"[3] effects and is "the missing link in the fight against climate change"[4]. Yet we agree with Erickson et al. that given the immensity of the climate challenge, these numbers are notable and certainly not an argument against subsidy reform.

Erickson et al. estimate the size and effect of the US IDC scheme which allows accelerated depreciation of drilling costs, essentially tax deferrals for oil producers. Their approach is different from ours in how subsidies are defined and measured. In our original article, we used government inventories[5–7] for our central estimate, because these are the very subsidies governments have pledged to remove. Erickson et al. consider any regulation which makes oil production more profitable a subsidy even if it does not involve net transfers from the government. This leads them to use data not from government inventories of subsidies but from analysing oil production economics. Thus, Erickson et al. analyse the hypothetical cash flow for 800 US oil fields and calculate the effect of the IDC scheme on the break-even price (BEP) of individual projects – we'll call this the "effective subsidy rate". They then assess the global impact of similar schemes by assuming all oil producers worldwide benefit from the same effective subsidy rate as in the US.

Global IAMs can greatly benefit from such data if they are parameterized for long-term global scenarios. The first set of parameters defines how accelerated depreciation affects the effective subsidy rate. This depends on a project's BEP, discount rate, share of capital costs, the national tax regime, and the design of the accelerated depreciation scheme, all of which vary widely across countries and over time (Methods). To determine if Erickson et al.'s results would affect our original findings, we developed a discounted cash flow model to analyse the effective subsidy rate for the US IDC and for three additional countries with diverse institutional arrangements and geographies (Methods).

In the case of the US, our model provides results similar to Erickson et al. for the 2016 case, however, the 2017 tax cut reduced the effect by about half and the recent fall in the cost of North American tight oil reduced it by another 30% (Table 1, Methods). The effective subsidy rates from accelerated depreciation schemes in Canada, Norway and Russia under a range of plausible BEPs are between two and ten times less than the US 2016 case. Using this range, we estimate the global effective subsidy rate from accelerated depreciation schemes to be $0.3-$1.9/barrel [central: $1.0] (Table 1, Methods).

The uncertainty in estimating production subsidies is well-known[8,9]. That is why in our original article, we included a sensitivity analysis where we scaled up oil production subsidies ten times from those reported in government inventories based on an alternative estimate that included the US IDC scheme[9]. With the exception of the US-2016 case, these effective subsidy rates are all higher than the effective rates we estimate using the discounted cash-flow method (Table 1).

The second step in Erickson et al.'s analysis is to estimate the effect of accelerated depreciation schemes on global oil consumption with a simple oil market model. Their calculation is sensitive to supply and demand elasticities which are highly uncertain (Methods). Erickson et al. use a single value for demand elasticity and a single value for supply elasticity for each oil price. A range of supply and demand elasticities from previous studies which used the same simple oil market model[10,11] changes the results by almost by an order of magnitude even under the same effective subsidy rate (Table 1, Methods).

In the sensitivity analysis from our original article, we estimated a 10-fold increase in oil production subsidies would increase oil extraction by 590 mln barrel/year (Table 1). The higher production subsidies (including all production subsidies – not just oil) would increase emission reductions from subsidy removal by 0.3 $GtCO_2$/year in 2030 which is about 13% higher than that model's main estimate, or about 1% of the emission reduction required by 2030 to achieve the 1.5°C or 2°C target (Methods).

The final parameter which affects the effective subsidy rate is discount rates, which Erickson et al. assume varies between 10-20%. The upper end of this range is quite speculative since discount rates for the oil sector have generally varied between 9-11%[12] (Methods). Table 1 shows our results using a discount rate of 10%, however our conclusions are robust over Erickson's full range: a 20% discount rate increases the global effective subsidy rate to $0.4-2.7 [1.4]/barrel (Methods).

This exchange highlights the importance of improving IAM parameters by incorporating new data. However, such data are more meaningful to global long-term IAMs if it is clear whether and how they are applicable beyond a single country at a single point in time. The generalizability of such data can be improved if they extend to a wider and more representative sample[8,9], which IAMs can use as illustrated by the sensitivity analysis in our original article. Finally, these data should be relevant to the policy pledges they relate to as well as up-to-date and transparent about uncertainty and the policy environment.

Although the effect of accelerated depreciation schemes can be incorporated in IAMs through adjusting the effective subsidy rate, we also agree with Erickson et al. that IAMs should better represent oil and gas infrastructure in the same way as they model the vintage structure of the power sector[13]. Another promising avenue would be to depict oil and gas investments using a real options 'wait and see' approach[14] and to more realistically model price formation in the oil market[15]. These improvements may either dampen or amplify the effects of subsidies in IAMs, depending on whether infrastructural inertia, 'wait and see' behaviour, and strategic markets are more or less responsive to producer cost signals than in today's IAMs.

We also strongly agree with Erickson et al. that the social and political impacts of subsidy removal should always be examined in tandem with their emission impacts. However, it is time for social scientists to go beyond listing various negative effects of subsidies which are well documented in the literature and clearly extend beyond economics[16–19] and instead identify opportunities and pathways for reform. That is why in our original article, we complemented energy and emissions analysis with a discussion of the socio-political impacts of subsidies to identify a political opportunity for reform in oil and gas exporting countries under low oil prices, where reducing consumption subsidies would affect fewer poor people, relieve squeezed government budgets and lead to the largest emission reductions.

A lesson from our original article is that the environmental and socio-political impacts of and obstacles to consumer subsidy reform vary between countries. This is almost definitely the case for producer subsidies as well. In the US, the original rationale (energy security and uncertainty in oil drilling) for the IDC subsidy is outdated, and it does little more than confer an unfair advantage on a polluting, privately-owned and profitable industry. Reforming this subsidy is complicated by the political clout of the industry, but at least its public benefits and endpoint are clear.

However, such subsidies are much more difficult to identify, much less reform, in countries like Norway and Russia where oil producers pay very high taxes – over 70% on profits. These taxes are a major source of government revenue used to fund public services. Would reforming accelerated depreciation in these contexts also mean tax reductions for the industry? Would the endpoint be to bring the oil industry in line with the rest of the economy, something clearly not desirable either socially or environmentally? And if not, what would be the goal and the strategy for reform?

Generalizing insights from the US worldwide is misleading both in terms of science and policy. Finding effective strategies to meet the Paris Agreement requires a detailed understanding of how oil production and other carbon-intensive sectors are embedded in national socio-political and economic contexts.

References

1. IEA, OPEC, OECD & The World Bank. *Joint report by IEA, OPEC, OECD and World Bank on fossil-fuel and other energy subsidies: An update of the G20 Pittsburgh and Toronto Commitments*. (2011).
2. Jewell, J. *et al.* Limited emission reductions from fuel subsidy removal except in energy-exporting regions. *Nature* **554**, 229–233 (2018).
3. IPCC. Technical Summary. 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. Edenhofer, O. et al.) 33–107 (Cambridge University Press, 2014). doi:10.1103/PhysRevD.70.106002
4. Friends of Fossil Fuel Subsidy Removal. *Briefing Note July 2015: Fossil Fuel Subsidy Reform and the Communiqué.* (2015).
5. OECD. *Companion to the Inventory of Support Measures for Fossil Fuels 2015*. (2015). doi:10.1787/9789264239616-en
6. IEA. World Energy Outlook 2016 - LubaValby7566.pdf. (2016).
7. International Energy Agency. *World Energy Outlook 2014. ISBN 978-92-64-20804-9*. (2014).
8. Bast, E., Doukas, A., Pickard, S., Burg, L. Van Der & Whitley, S. *Empty promises: G20 subsidies to oil, gas and coal production.* (2015).
9. Gerasimchuk, I. *et al.* Zombie Energy: Climate benefits of ending subsidies to fossil fuel production. *Int Inst Sustain Dev Work Pap* (2017).
10. Erickson, P., Down, A., Lazarus, M. & Koplow, D. Effect of subsidies to fossil fuel companies on United States crude oil production. *Nat Energy* **2**, 891–898 (2017).
11. Erickson, P. & Lazarus, M. Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions. *Nat Clim Chang* **4**, 778–781 (2014).
12. Damodaran, A. Cost of equity and captial (updateable). (2019). Available at: http://www.stern.nyu.edu/~adamodar/New_Home_Page/data.html%09%09%09%09%09. (Accessed: 15th July 2019)
13. Johnson, N. *et al.* Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants. *Technol Forecast Soc Change* **90**, 89–102 (2015).
14. Compernolle, T., Welkenhuysen, K., Huisman, K., Piessens, K. & Kort, P. Off-shore enhanced oil recovery in the North Sea: The impact of price uncertainty on the investment decisions. *Energy Policy* **101**, 123–137 (2017).
15. Ansari, E. & Kaufmann, R. K. The effect of oil and gas price and price volatility on rig activity in tight formations and OPEC strategy. *Nat Energy* **4**, 321–328 (2019).
16. Victor, D. G. *The Politics of Fossil-Fuel Subsidies. Ssrn* (Global Subsidies Initiative and International Institute for Sustainable Development, 2009). doi:10.2139/ssrn.1520984
17. Inchauste, G. & Victor, D. G. *The Political Economy of Energy Subsidy Reform Public Sector Governance*. (World

Bank, 2017).
18. Sovacool, B. K. Reviewing, Reforming, and Rethinking Global Energy Subsidies: Towards a Political Economy Research Agenda. *Ecol Econ* **135**, 150–163 (2017).
19. Lockwood, M. Fossil Fuel Subsidy Reform, Rent Management and Political Fragmentation in Developing Countries. *New Polit Econ* **20**, 475–494 (2015).

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Author contributions
The change in order and composition of the author list in the Matters Arising from the original article reflects the contributions to the Matters Arising response, which relied on a discounted cash flow model and additional empirical research in order to validate the assumptions we used in the original article. J.J., J.E., V.V. and C.B. wrote the response with contributions from L.B., H.D., I.K., V.K., D.E.H.J.G., K.F., D.M, L.P., K.R., M.T., and D.V. The numerical model was conceived and designed by J.J. and V.V. conceived and implemented by V.V. The results were analysed by J.J. and V.V.

Author information
The authors declare no competing declarations.

Data availability
The authors declare that the data supporting the calculations are available are available in the Methods or from publicly available sources cited in the Methods.

Code availability
No custom code or algorithms were developed for the discounted cash flow results reported in this paper.

Table 1. The effect of oil production subsidies on producer costs and global oil consumption. Columns [A] and [B] contain estimates of all oil production subsidies from our original article[2]. In our sensitivity case the subsidy rate and its effect on oil production is higher than in under accelerated depreciation schemes [C]. For the US, the results for the 2016 case are in italics including from Erickson et al. [D]. “Canada” is the “CAJAZ” (Canada, Japan, Australia and New Zealand) region whose oil production is dominated by Canada (over 98%). “MENA” refers to the Middle East and North Africa region.

	IAM analysis of all producer subsidies in Jewell et al.[2] (low oil price scenario)		**Discounted cash flow model of accelerated depreciation schemes (10% discount rate except for final row - see Methods)**	
	Main Estimate of production subsidies from ref. [5] [A]	Higher production subsidies from ref. [8,9] [B]	Variations in tax rates, capital cost, accelerated depreciation schemes, BEPs & elasticities (our analysis) [C]	Erickson et al. [D]
Effective production subsidy rate ($/barrel)				
US	0.6	2.4	*4.9 (2016 case)* 1.9 (2019 case)	*4.2 (2016 case)*
Other Regions	Canada: 1.1 Europe: 0.4 Russia: 0 MENA: 0	Canada: 1.5 Europe: 2.2 Russia: 5.2 MENA: 2.3	Canada: 0.5 –1.4 [0.9] Norway: 0.9 – 2.0 [1.5] Russia: 0.9 – 2.1 [1.6] Saudi Arabia and Nigeria: 0	
Global	0.2	2.6	0.3 – 1.9 [1.0]	
Change in global oil extraction/consumption, mln barrels/yr (low oil price scenario)				
Change in extraction due to higher production subsidy estimate		590		*440*
Variation due to effective subsidy rate using elasticities in Erickson et al. and 10% discount rate			30 – 200 [110]	
Variation due to elasticity assumptions using central effective subsidy rate and 10% discount rate			20 – 140 [90]	
Variation due to discount rates using central effective subsidy rate for discount rates ranging from 7.5% – 20% central 15% (Methods) and elasticities in Erickson et al.			90 – 150 [130]	*440 – 770 [620]* *10% – 20% discount rate*