Response to the Comment by Westaway et al. (Applied Energy, available online 20 March 2015) on the paper "Life cycle environmental impacts of UK shale gas" by Stamford and Azapagic (Applied Energy 134 (2014) 506-581)

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Response to the Comment by Westaway et al. (*Applied Energy*, available online 20th March 2015) on the paper "Life cycle environmental impacts of UK shale gas" by Stamford and Azapagic (*Applied Energy* 134 (2014) 506–518)

Laurence Stamford and Adisa Azapagic*

School of Chemical Engineering and Analytical Science, Room C16, The Mill, Sackville Street, The University of Manchester, Manchester M13 9PL, UK

*Corresponding author: adisa.azapagic@manchester.ac.uk

Highlights

- The claim that we exaggerated the impacts of shale gas in the UK is unsupported
- Our assumptions and results are well in line with the literature
- The Comment exaggerates the legal situation with respect to shale gas

Abstract

In the recent Comment on our paper 'Life cycle environmental impacts of UK shale gas' (*Applied Energy* 134 (2014) 506-518), Westaway et al. (*Applied Energy*, available online 20th March 2015) allege that we exaggerated the potential impacts of shale gas extraction in the UK. They first take an issue with our inclusion of worst case scenarios despite our clear declaration in several places in the paper that this is indicative of what *could* happen within the confines of a very ill-defined and highly variable future reality. Secondly, Westaway et al. claim that key assumptions in the modelling reflect illegal practices that would not occur, when in fact this is an exaggeration of the legal situation and these practices are still viable. This rebuttal addresses some of the claims made by Westaway et al. while welcoming further open and impartial discourse in this area.

1. Introduction

In 2014, we published in Applied Energy the results of our research which estimated, for the first time, the full life cycle environmental impacts of shale gas extraction and use in the context of a potential future UK shale gas industry [1]. In response, Westaway et al. [2] have argued that our paper exaggerates the environmental impacts of shale gas.

The environmental consequences of shale gas are a rapidly evolving and contentious issue. As stated several times in our paper, the nascent state of the UK shale gas industry – not yet at commercial production – means that further refinement of the research would be needed as more information became available: this point was deliberately prominent in the conclusions of our paper. Therefore, we welcome further discussion in this area.

As part of that, we would like to respond to some of the assertions made by Westaway et al. They allege that we have done the following:

i. underestimated the estimated ultimate recovery (EUR) per well and emphasised the worst-case scenario;

ii. assumed that "various dirty environmental practices… will operate in the UK"; and
iii. suggested too restrictive regulation which would hamper shale gas developers.

We address these assertions below.

2. Discussion

2.1 On EUR

Our best-, central- and worst-case scenarios (3 bcf, 1 bcf and 0.1 bcf, respectively) are based on some of the most thorough data available from the USA [3]. The United States Geological Survey (USGS) dataset consists of 26 'assessment units', each comprising hundreds to thousands of individual wells with a grand median of 0.35 bcf and a grand mean of 0.66 bcf: both, in fact, less than our central assumption of 1 bcf. The overall range of the dataset is 0.01-20 bcf, which we truncated to 0.1-3 bcf to exclude some outliers. Moreover, in their response, Westaway et al. cite the Barnett shale as having a range of 0.02-10 bcf and a mean of 1.0 bcf. This particular 'assessment unit' is in fact the most favourable of the Barnett assessment units within the dataset, the others having values of 0.02-8 (mean 0.84); 0.02-5 (mean 0.446) and 0.02-5 (mean 0.334) bcf: all much less favourable than our central estimate (1 bcf).

Westaway et al. also claim that the more modern approach of increased horizontal drilling and multiple fracturing events increases EUR and reduces the likelihood of very low EUR wells. While we agree, we also point out that fracturing multiple times increases the energy demand for pumping as well as the volume of fracturing fluid, going some way to counteract the benefits. To test this assumption, we had carried out a follow on work [4] based on more recent data from the Haynesville play which, despite assuming considerably higher EURs than in our original paper, estimates a very similar range of the carbon footprint values (420-930 g CO_2-eq./kWh c.f. 412-1102 g CO_2-eq./kWh in our original paper). These values also sit well within the range reported in the literature (416-2878 g CO_2-eq./kWh), as discussed in our paper [1] (see pages 507-508).

Ultimately, Westaway et al.'s main concern is the inclusion of the 'worst case' of 0.1 bcf, argued on the basis that such a well would be uneconomic. This is precisely a point that we state several times in our paper: "this is an extreme case that is probably not realistic…"; "it seems unlikely that the site would be economically attractive…". Therefore, it was intended to be a worst case scenario, indicative of what *could* happen within the confines of a very ill-defined and highly variable future reality.

We do not accept the authors' claim that the worst case is emphasised in the paper. We took particular care to focus on the central case, giving ranges of possibilities to provide context while avoiding undue focus on either negative or positive outcomes. This is illustrated by the phrase 'central case' appearing 42 times in the paper compared to 22 times for 'worst case'. Furthermore, contrary to the assertion by the authors of the Comment, we also clearly commented on both the best and worst cases in the highlights.

Finally, Westaway et al. derive figures for the carbon footprint of 60, 67 and 161 g CO_2-eq./MJ for our best, central and worst cases, comparing them to 2.8-6.9 g CO_2-eq./MJ in MacKay and Stone's earlier work [5]. This is a spurious comparison: MacKay and Stone give values of 55.6-70.3 g CO_2-eq./MJ (200-253 g/kWh chemical energy), similar to our central case of 67 g CO_2-eq./MJ. The similarity is reinforced by their result of 423-535 g CO_2-eq./kWh for shale gas-fired electricity, aligning very well with our central estimate of 462 g CO_2-eq./kWh.

2.2 On the assumption of "dirty" environmental practices

Westaway et al. comment that the UK Government's response [6] to MacKay and Stone's paper accepted all of their recommendations (many of which overlap with our own) and that our central and worst cases are no longer valid. While there was some time cross-over – our paper was submitted to Applied Energy in November 2013 while the Government document in question was not released until 24th April 2014 – our conclusions are still valid. On the other hand, the assertions by Westaway et al. are not, as they have exaggerated the implications of the Government's position. For instance, they claim that "venting or flaring will be prohibited" whereas, as stated in our paper and in the aforementioned Government document, the policy is that "venting should be kept to the minimum that is technically possible" and that "the preferred alternative… is that gas should be flared" but that "flaring should be reduced to the economic minimum". Clearly, these conditions do not equate to a ban on venting and flaring. Similarly, the disposal of drilling waste to land (landfarming) is not strictly illegal and may still occur in some cases [7] (and it is certainly common internationally).

Much of the remaining comments by Westaway et al. fundamentally agree with our original assumptions. For instance, we do not know with certainty how much (if any) 'sweetening' of gas will be needed in UK shale plays. The difference in approach is that we favoured the precautionary principle in the face of uncertainty, while Westaway et al. focus on techniques that *could* be adopted to solve certain problems: in reference to preventing H_2S formation, different biocides *could* be used; in reference to reducing NOx emissions, brand new equipment *could* be used, but these are not guaranteed.

2.3 On the rigour of EUR estimation before commissioning of wells

We agree with Westaway et al. that it is in the interests of the operator to avoid low-producing wells. However, given the large shale gas resource in the UK and the probable inability of the nation to fully exploit it without breaching the UK's carbon budgets [8] and the legally-binding 2050 reduction target [9], perhaps it is time to consider more stringent measures that would set a minimum EUR level below which wells could not be exploited.

3. Conclusion

Finally, a paper such as this inevitably provokes lively discussions and can be used to support both pro- and anti-shale gas arguments. To quote another extreme reaction to our paper, some national media reported that our research found that fracking is "greener than solar panels" [e.g. 10]. This has led to various discussions in the social media, with those supporting shale gas agreeing with the findings and those in favour of renewables, objecting.

We wish to take this opportunity to emphasise that our research is technology-neutral and that we have no personal involvement with any businesses or ventures that might be biased towards shale gas, renewables, nuclear power, or any other energy technology.

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