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Sustainability of UK shale gas in comparison with other electricity options: Current situation and future scenarios

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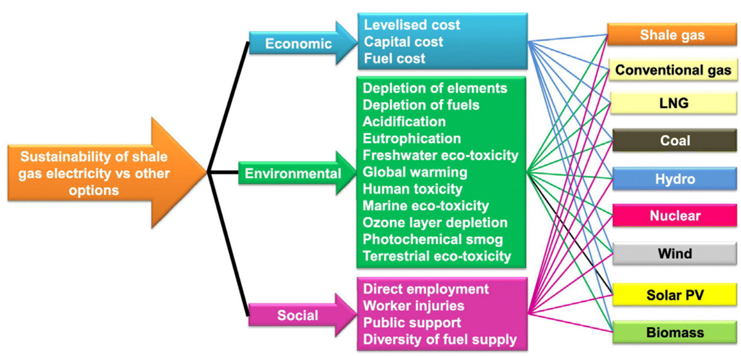
HIGHLIGHTS

- Shale gas ranks between the fourth and eighth relative to other electricity options.
- To become the most sustainable option, large improvements would be needed.
- This includes a 329-fold reduction in environmental impacts.
- A 16-fold increase in employment would also be needed.
- An electricity mix with less rather than more shale gas is more sustainable.

GRAPHICAL ABSTRACT



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ABSTRACT

Many countries are considering exploitation of shale gas but its overall sustainability is currently unclear. Previous studies focused mainly on environmental aspects of shale gas, largely in the US, with scant information on socio-economic aspects. To address this knowledge gap, this paper integrates for the first time environmental, economic and social aspects of shale gas to evaluate its overall sustainability. The focus is on the UK which is on the cusp of developing a shale gas industry. Shale gas is compared to other electricity options for the current situation and future scenarios up to the year 2030 to investigate whether it can contribute towards a more sustainable electricity mix in the UK. The results obtained through multi-criteria decision analysis suggest that, when equal importance is assumed for each of the three sustainability aspects shale gas ranks seventh out of nine electricity options, with wind and solar PV being the best and coal the worst options. However, it outranks biomass and hydropower. Changing the importance of the sustainability aspects widely, the ranking of shale gas ranges between fourth and eighth. For shale gas to become the most sustainable option of those assessed, large improvements would be needed, including a 329-fold reduction in environmental impacts and 16 times higher employment, along with simultaneous large changes (up to 10,000 times) in the importance assigned to each criterion. Similar changes would be needed if it were to be comparable to conventional or liquefied natural gas, biomass, nuclear or hydropower. The results also suggest that a future electricity mix (2030) would be more sustainable with a lower rather than a higher share of shale gas. These results serve to inform UK policy makers, industry and non-governmental organisations. They will also be of interest to other countries considering exploitation of shale gas.

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1. Introduction

Exploitation of shale gas is a contentious topic in many countries. At present, shale gas is exploited at a large scale only in the US, with other nations considering its development (Cooper et al., 2016). The UK is at the cusp of starting exploitation, with the government and industry keen to develop a shale gas industry, but with a strong opposition from numerous stakeholders, including non-governmental organisations, local residents and activists (Gosden, 2017; Johnston, 2017; Ward, 2017). The impacts on the environment are the main argument against the exploitation of shale gas while the supporters highlight improved national energy security and economic development as key aspects in its favour (House of Lords, 2014; Moore et al., 2014). Some of these sustainability aspects have been considered previously by the authors (Cooper et al., 2014; Cooper, 2017), but evaluated environmental, economic and social aspects in isolation of each other. This work builds on that research by integrating all three dimensions to assess the overall sustainability of shale gas in the UK using multi-criteria decision analysis (MCDA). The main goals of this study are:

i) to assess the overall sustainability of shale gas relative to other electricity options in the UK, including other fossil alternatives, renewables and nuclear power; and
ii) to investigate how its deployment could affect the sustainability of a future UK electricity mix, taking into account different levels of shale gas penetration.

In total, 18 sustainability indicators are considered, of which 11 are environmental, three economic and four social. While there have been numerous other studies on the sustainability of shale gas, they are almost exclusively based in the US and tend to focus on environmental aspects, typically considering only one or a limited number of impact categories; for an extensive review, see Cooper et al. (2016). Therefore, as far as we are aware, this is the first study internationally to provide an integrated assessment of shale gas and to compare it other electricity options.

The methods used in the study are outlined in the next section. The results are presented and discussed in Section 3 and conclusions are drawn in Section 4.

2. Methods

The environmental and economic sustainability assessments have been carried out using life cycle assessment (LCA) and life cycle costing (LCC), respectively; social sustainability has been evaluated by developing relevant social sustainability indicators. A brief overview of these is given below, followed by a description of the MCDA method used.

2.1. Sustainability assessment

The results of the LCA, LCC and social sustainability assessment are summarised in Table 1, based on the previous work by the authors (Cooper et al., 2014; Cooper, 2017); for definitions of the indicators, see Table S1 in the Supporting Information (SI). In addition to shale gas, the following electricity options are also considered: conventional gas, liquefied natural gas (LNG), coal, nuclear, hydro, wind, solar photovoltaics (PV) and biomass. These options have been chosen as they are currently used in the UK and are expected to play a role in a future electricity mix.

Both the current electricity mix and future scenarios are considered. As commercial production of shale gas is not expected in the UK until post-2020 (Lewis et al., 2014), the year 2030 has been selected for the evaluation of a future electricity mix. Two 2030 electricity scenarios are considered: one with low penetration of shale gas (1%) and another with the highest possible contribution (8%) to the mix; for details, see Table 2. The results of the LCA, LCC and social sustainability assessment for the current and future electricity mixes are given in Table 3 (Cooper et al., 2014; Cooper, 2017).

2.2. Multi-criteria decision analysis

The Simple Multi-attribute Rating Technique (SMART) method has been chosen for the MCDA in this work because it is relatively simple to implement and can accommodate a large number of criteria and alternatives being considered. SMART involves the following steps (Edwards, 1977):

1. identification of the options to be compared;
2. identification of the decision criteria;
3. scoring of the criteria in the order of importance (increasing from a score of 10 for the lowest importance onwards) and estimation of their weights of importance;
4. rating of the options on a scale of 0 (worst) to 1 (best);
5. estimation of the overall scores and ranking of the options on a scale from 0 (worst) to 1 (best); and
6. identification of the best option.

Table 1
Sustainability indicators and their estimated values for different electricity options[a].

Sustain-ability aspects	Indicators	Shale gas	Conven'l gas	Liquefied natural gas	Coal	Nuclear	Hydro	Solar PV	Wind	Biomass
Environmental[b]	ADP_e (mg $Sb_{-Eq.}$/kWh)	0.68	0.24	0.26	0.04	0.07	0.01	10.91	0.22	0.14
	ADP_f (MJ/kWh)	6.58	6.33	7.43	11.70	0.09	0.04	1.05	0.15	0.62
	AP (g $SO_{2-Eq.}$/kWh)	0.35	1.71	3.41	5.13	0.06	0.01	0.43	0.06	1.39
	EP (g $PO_{4-Eq.}$/kWh)	0.17	0.06	0.06	1.86	0.02	0.01	0.29	0.03	0.49
	FAETP (g $DCB_{-Eq.}$/kWh)	13.10	2.47	4.02	287.90	21.20	1.65	63.90	14.70	20.90
	GWP (g $CO_{2-Eq.}$/kWh)	455.78	420.00	490.00	1078.84	7.79	3.70	88.91	12.35	58.51
	HTP (g $DCB_{-Eq.}$/kWh)	54.30	38.00	39.50	294.86	111.43	6.15	205.47	61.81	208.50
	MAETP (kg $DCB_{-Eq.}$/kWh)	37.42	0.50	0.90	1577.32	43.66	2.70	205.69	23.08	42.48
	ODP (μg $R11_{-Eq.}$/kWh)	17.30	18.90	5.51	5.59	19.00	0.23	17.40	0.74	5.16
	POCP (mg $C_2H_{4-Eq.}$/kWh)	83.80	34.40	66.60	285	5.55	2.04	67.00	6.97	131
	TETP (g $DCB_{-Eq.}$/kWh)	1.70	0.15	0.22	1.75	0.74	0.19	1.12	1.81	4.26
Economic	Levelised cost of electricity (pence/kWh)	9.59	8.00	7.62	13.85	7.70	14.60	6.70	9.73	11.75
	Capital cost (pence/kWh)	0.81	0.90	0.81	4.60	7.00	11.29	5.70	7.70	4.50
	Fuel cost (pence/kWh)	6.51	4.90	4.53	3.60	0.50	0.00	0.00	0.00	5.30
Social	Direct employment (person-yr/TWh)	47.70	62.00	326.88	191.00	87.00	782.35	653.00	368.00	385.79
	Worker injuries (no. injuries/TWh)	0.53	0.54	2.10	4.50	0.59	14.59	4.84	2.30	2.98
	Public support index (%)	5.60	34.00	14.50	−7.00	9.00	72.00	75.00	59.00	57.00
	Diversity of fuel supply (no units)	1.00	1.00	0.04	0.86	0.85	1.00	1.00	1.00	0.96

[a] Data for the environmental indicators sourced from Cooper et al. (2014) and the economic and social from Cooper (2017).
[b] For the acronyms, see the caption for Fig. 1.