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The life cycle greenhouse gas implications of a UK gas supply transformation on a future low carbon electricity sector

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ABSTRACT

Natural gas used for power generation will be increasingly sourced from more geographically diverse sites, and unconventional sources such as shale and biomethane, as natural gas reserves diminish. A consequential life cycle approach was employed to examine the implications of an evolving gas supply on the greenhouse gas (GHG) performance of a future United Kingdom (UK) electricity system. Three gas supply mixes were developed based on supply trends, from present day to the year 2050. The contribution of upstream gas emissions - such as extraction, processing/refining, - is not fully reported or covered by UK government legislation. However, upstream gas emissions were seen to be very influential on the future electricity systems analysed; with upstream gas emissions per MJ rising between 2.7 and 3.4 times those of the current supply. Increased biomethane in the gas supply led to a substantial reduction in direct fossil emissions, which was found to be critical in offsetting rising upstream emissions. Accordingly, the modelled high shale gas scenario, with the lowest biomethane adoption; resulted in the highest GHG emissions on a life cycle basis. The long-term dynamics of upstream processes are explored in this work to help guide future decarbonisation policies.

1. Introduction

Gas has been widely touted, by both academics and policymakers, as a critical bridging fuel in society's transition to a lower carbon future [1,2]. Global organisations such as the *Intergovernmental Panel on Climate Change* (IPCC) and the *International Energy Agency* (IEA) see gas-fired generation as a vital bridging technology during this transition [3,4]. Gas is defined here as a gaseous combustible mixture of hydrocarbons, consisting largely of methane (CH_4), which may also contain colliery methane, shale gas and biogas. Compared to other fossil fuels, 'gas' contains the lowest quantity of carbon per unit energy of any fuel, i.e. it has the most favorable C:H ratio, leading to much lower carbon dioxide emissions during combustion. Moreover, gas-fired generation is an inherently flexible conversion technology; ideal for providing backup to intermittent power generation [5]. Accordingly, both gas power generation with and without '*Carbon Capture and Storage*' (CCS) [6] have been proclaimed as key generation technologies in the UK's energy transition [2,7]. Serious doubts have been raised over the future of CCS in the UK in the wake of the UK government scrapping a £1bn funding competition to help CCS reach full-scale development. Nonetheless, both the *Committee on Climate Change* and the *Energy Technologies Institute have* projected that failure to deploy CCS could double the cost of a low carbon transition [8,9].

Bringing primary fuel to a gas power plant requires many upstream processes, including extraction, processing/refining, and transport, all of which expend energy and material resources and result in the release of greenhouse gas (GHG) emissions. Additionally, significant fugitive methane emissions often occur during production activities, and during the transport and handling of the gas. A comprehensive review conducted by the *Sustainable Gas Institute* (SGI) [10], examining 424 papers in total, estimated a wide range in greenhouse gas emissions associated with different gas supply chains (both conventional and unconventional). The report estimated that the total gas supply chain emissions could range between 2 and 42 gCO_2eq/MJ (assuming a global warming potential of 34 for methane). Upstream emissions are not exclusive to gas-fired generation, indeed, all electricity generators come with such associated emissions, from coal generation to solar photovoltaics, although they vary depending on the nature of that given system. Gas-fired generation offers significant GHG saving on an

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Abbreviations

CC	Central Coordination
CCC	Committee of Climate Change
CCS	Carbon Capture and Storage
CHP	Combined heat and power
DECC	Department of Energy and Climate change
DUKES	Digest of UK Energy Statistics
EPSRC	Engineering and Physical Sciences Research Council
ESCO	Energy services company
ESI	Electricity Supply Industry
GHG	Greenhouse gas
GWP	Global-warming potential
HV	High voltage
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LNG	Liquefied natural gas
MR	Market Rules
NGO	Non-governmental organisation
PV	Photovoltaics
TF	Thousand Flowers
TP	Transition Pathways
UKCS	United Kingdom Continental Shelf

operational basis compared to coal, however, upstream emissions can vary greatly between gas source and geographical location [11]. Upstream processes will gain relative importance as the performance of combustion technologies improve over time and with increased penetration of CCS in the electricity sector. Consequently, it is hypothesized that the gas supply mix may have a considerable bearing on the cumulative emissions from the future UK electricity sector.

Since 2004, the UK has been a net importer of gas [12], relying increasingly on international gas markets. Gas will be increasingly sourced from more geographically diverse sites, and/or more unconventional sources, such as shale and biomethane. The reshaping of the gas supply, as explored in this paper, could lead to an increase in the life cycle emissions of gas-fired generation, which are not currently fully addressed by legislation. Presently, only domestic emissions are included in the national GHG inventory, neglecting all non-domestic upstream activities and associated emissions which would be connected to any product chain [13]. Accordingly, upstream GHG emissions associated with the gas supply have not been well accounted for by the UK government. Previous analysis by both the independent *Committee of Climate Change* (CCC) and the then Chief Scientific Advisor to the *Department of Energy and Climate Change* (DECC) have regarded total upstream emissions as 'fixed', and 'inconsequential' in terms of their contribution to overall life cycle emissions associated with gas-fired generation [14,15]. However, both DECC and CCC are wrong in this assertion given that UK gas upstream emissions are set to change over the coming years, in response to a large transformation of the gas supply, as domestic natural gas diminishes [16]. Furthermore, their contribution to the GHG performance of UK electricity will become increasingly significant, as upstream gas emissions rise and are contrasted against an increasingly decarbonised electricity sector.

Decarbonisation of the 'Electricity Supply Industry' (ESI) forms the cornerstone of the UK Government's strategy to tackle climate change, as part of its transition towards a low carbon economy [2]. Current decarbonisation policies may lead to a shift in practices and adoption of production routes with unintended adverse effects upstream, which would not be accounted for under current UK carbon budgets [17]. The effect of an evolving gas supply on the future GHG performance of the ESI has not been fully explored to date, with only the implications of the shale gas penetration been previously considered by others in the field [18]. Wider trends in the gas market have been overlooked, such as the possible introduction of biomethane and shale gas, or in the long-term, the potentially infiltration of Russian gas. Indeed, in a letter to the House of Commons' *Environmental Audit Committee*, the CCC highlighted the need to adequately capture the 'life cycle emissions of shale gas and alternatives' in future evaluations of the UK's net carbon accounting [19]. In addition to addressing recognised gaps in knowledge [20], this work aims to inform policymakers of the potential implications a changing fuel supply, particularly the uptake from alternative sources such shale gas and biomethane out to 2050. Increased understanding of the intricacies and dynamics of future energy systems, will better frame future decarbonisation policies, avoiding unintended, adverse cause and effects. This work is founded upon earlier life cycle environmental appraisal of the UK ESI, it forms part of an ongoing research effort, evaluating and optimising the performance of various sustainable energy systems [17,24].

A consortium was established to examine the role of electricity within the context of 'Transition Pathways to a Low Carbon Economy' across nine university partners. This multi-disciplinary team developed three socio-technical scenarios or 'transition pathways' towards a UK low carbon energy system as summarised in Table 1 [25,26]. Each pathway was characterised by different dominant governance 'logics': driven by the market, central government intervention, and local community initiatives respectively. A full account of these pathways and their development can be found in Foxon (2013) [7]. Previously, an environmental appraisal was performed for the 'transition pathways' of the UK ESI on a life cycle basis [17]. Upstream emissions were calculated assuming present day static fuel supply chains, a limitation when assessing a future system. In this present study, the 'transition pathways' have been paired with three future gas supply mix scenarios, which were developed to examine the uncertainties, and impact of dynamic upstream processes on decarbonisation strategies.

2. Methods

2.1. Dynamic life cycle emissions approach

A more dynamic LCA methodology was applied in this paper to investigate the likely environmental implications of the gas supply fuel evolution out to 2050. Consequential (change-oriented) LCA methodology was chosen to investigate the environmental implications of these likely potential choices [27] over time, in order to limit risk when undertaking strategic technological selection. Consequential LCA evaluates the change in flows in respect to a given decision or market, and subsequently the corresponding change in environmental impact beyond the foreground system.

In this paper, the reduced availability of domestic natural gas supplies causes a shift in demand for new sources of gas, such as shale gas and biomethane. These gas resources have different associated activities and processes, outside the original boundary of

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