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The carbon payback of micro-generation: An integrated hybrid input–output approach

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HIGHLIGHTS

- We apply novel lifecycle analysis methodology to solar PV and micro-wind technologies.
- We explore the implications of lifecycle emissions for meeting decarbonisation targets.
- A 50 gCO_2e/kW h target cannot be achieved for the case studies considered.
- Availability of renewable resource is critical to the carbon intensity of electricity generation.
- The effectiveness of feed-in Tariffs for driving decarbonisation in the UK is evaluated.

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ABSTRACT

Feed-in Tariffs (FiTs) in the UK have been introduced to stimulate growth in small-scale renewables such as photovoltaics and micro-wind. They form one of the UK's key policies to decarbonise electricity by 2030. However, the evidence used to inform the policy was predominantly related to costs, capacity and deployment; not contribution to meeting decarbonisation targets. This paper employs an integrated hybrid lifecycle assessment method, which overcomes boundary limitations of traditional process-based assessments, to measure the full lifecycle emissions of solar PV and micro-wind technologies eligible under FiTs. Environmental assessments of policies often do not take account of the lifecycle emissions of technologies, therefore underestimating their emissions contribution and overestimating the success of policies towards decarbonisation targets. Considering the full lifecycle emissions, the paper assesses the effectiveness of FiTs for driving the UK's low carbon transition. The results demonstrate that, while there is still significant variation and uncertainty with such estimates, even with the most conservative figures, both the technologies can offer substantial emission savings compared to fossil fuel alternatives when installed in suitable locations. However, the renewable resource of installation sites is critical to the carbon intensity that the technologies can offer. Under a poor renewable resource their impacts can be as high as fossil fuels alternatives. As FiTs makes no distinction between installation sites this should form part of the assessment of funding. Finally, despite their potential for carbon reduction, with the full lifecycle of the considered technologies taken into account, a target of 50 gCO_2e/kW h is not possible with the current technology generation efficiencies. The paper concludes that a complete re-assessment of the role of technologies in the decarbonisation of electricity is required to take into account the full lifecycle impacts to gain a more realistic picture of the mitigation potential.

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1. Introduction

Carbon budgets have been devised to ensure the UK is on track to meet its legislative 80% greenhouse gas emission reduction target by 2050 from 1990 levels [1]. Reasonable evidence exists that electricity generation will have to be at 50 gCO_2e/kW h for electricity by 2030 in order to meet these targets. The UK's electricity intensity in 2010 stood at 494 gCO_2e/kW h [2] and has climbed since then as the proportion of coal in electricity generation has increased. Of the 382 TW h of electricity generated in 2011, 7% was from renewable sources (26 TW h) [3]. The Committee on Climate Change suggests that 30–40 GW of additional low carbon supply is needed to meet the decarbonisation target by 2030 [4].

Feed-in Tariffs (FiTs) are one of a package of policies aiming to drive innovation in low carbon technologies and stimulate growth by providing price certainty in the market. Feed-in Tariffs are available for a range of renewable electricity generating technologies up

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Nomenclature

CCS	carbon capture and storage	kWp	Kilowatt peak
CSP	Concentrated Solar Power	LCA	lifecycle analysis
FiTs	Feed-in Tariffs	m	metres
gCO_2e	grams of carbon dioxide equivalent	m/s	metres per second
IPCC	International Panel on Climate Change	PV	photovoltaic
kW h/MW h/TW h	Kilowatt hour/Megawatt hour/Terawatt hour	UK	United Kingdom

to a 5 MW rating and are the main incentive for the installation of micro-generation technologies. Since their introduction in April 2010 they have caused a revolution in uptake of solar photovoltaics (PV), resulting in significant growth in installations to the current installed capacity of over 1.5 GW by the end of May 2013 (rising from under 1 MW of capacity before its introduction) [5].

FiTs do not discriminate between different generation technologies, despite the fact that the lifecycle emissions in their production could vary significantly. For example, where technologies are deployed in locations with a poor renewable resource the carbon intensity per kilowatt hour generated increases due to the fact that their lifecycle emissions are fixed. The implications of this have not been considered in discussions related to the possibility of achieving an electricity emissions target of 50 gCO_2e/kW h. There is a major concern that past analyses of the lifecycle emissions of micro-generation technologies provide a significant underestimate of emissions. This paper addresses these issues by:

- Employing a novel Integrated Hybrid Lifecycle Analysis (LCA) to calculate the lifecycle emissions of PV and micro-wind case studies.
- Developing a number of scenarios that forecast the changing carbon intensity of PV and micro-wind supply chains up to 2030.
- Considering the extent that micro-generation technologies and supporting policy incentives contribute towards decarbonising the electricity sector in the UK.

1.1. Aims and objective

The objective of this paper is to determine the carbon payback of solar PV and small-scale wind technologies under different installation conditions. It then goes onto assess the extent to which the FiTs scheme encourages the maximisation of their decarbonisation potential. FiTs forms part of a policy framework to decarbonise the UK energy system, however, the evidence used to inform the policy was predominantly related to costs, capacity and deployment; not the contribution to meeting decarbonisation targets. When calculating the UK's electricity intensity it is important to recognise and monitor the embedded emissions of such technologies to ensure that their full impact is taken into account. The following aims are met:

- To conduct a detailed lifecycle assessment measuring greenhouse gas emissions of solar PV and micro-wind using integrated hybrid LCA;
- Considering the full lifecycle emissions, to determine whether or not decarbonisation policy includes an overly optimistic appraisal of the role of technology in emissions reduction now and in the future; and
- To assess the feasibility of FiTs contributing towards such a low emission target for electricity generation in the UK.

2. Materials and methods

The following section outlines the methods used to conduct the analysis of micro-wind and solar PV generation technologies. A context for existing studies of such technologies is given and the need for use of the integrated hybrid LCA methodology is outlined. Finally, the case study data and assumptions about the technology lifecycle are detailed.

2.1. Context and background – Lifecycle impact of energy technologies

Lifecycle assessment (LCA) methods are intended to capture the resource inputs and environmental impacts at every stage in the lifecycle of a process or product, in this case electricity production from solar PV and micro-wind. It is a flawed assumption to presume that renewable energy technologies are zero carbon as they rely on existing fossil fuel infrastructure for material extraction, fabrication, assembly, delivery and so forth. Without conducting a lifecycle analysis of the full supply chain impacts of energy technologies, only the direct emissions from combustion will be captured, leading to an underestimate of their impact. Lifecycle assessment is the dominant method for quantifying the environmental impacts generated throughout a products lifecycle.

A review of lifecycle emissions of energy technologies by the International Panel on Climate Change (IPCC) [6] indicates the potential lifecycle emissions of renewable electricity generation technologies in comparison to conventional fossil fuels (Table 1). It should also be noted that, particularly for wind technologies, reviews show that power ratings tend to result in higher carbon intensity of electricity generation [7]. Whilst this perspective attaches emissions to renewable electricity technologies, they are still overwhelmingly more favourable than production from fossil fuels.

It is difficult to compare the results of each technology due to methodological diversity, differing data sources and technological characteristics assumed across studies. For example, both process-based and economic input–output methods are used for lifecycle analysis; when bottom-up product specific inventories are not available they are compiled from different lifecycle databases; and processes deemed significant to be included in an inventory are subjective (compiler judgement). Some studies adopt a cradle-to-gate perspective where decommissioning activities are excluded; others include these but make different assumptions on recycling and disposal options. Published standards for LCA (ISO14040 and PAS 2050) provide guidelines, but no consistent method is defined. A methodology that reduces discrepancies between comparable studies is therefore desirable.

Hybrid LCA methods provide an opportunity to overcome elements of error inherent in traditional LCA methods. Supply chains associated with energy technologies are numerous and complex. Additionally, their global nature means pressures are dispersed, creating a large and distant web of suppliers and a near-infinite number of possible production layers. Conventional LCA methods have had to set a system boundary since it is near impossible to col-

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