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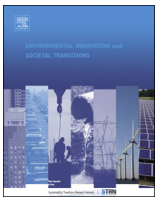

Eco-innovation to reduce biodiversity impacts of wind energy: Key examples and drivers in the UK

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ABSTRACT

Wind energy technologies deliver environmental benefits in terms of reduced greenhouse gas emissions. However, they can entail other environmental impacts such as on biodiversity. This article identifies fifteen examples of innovation in the UK wind energy sector that address biodiversity impacts, and seven drivers behind these innovations. Examples are categorised into six thematic areas covering eco-process, eco-organisational and eco-product innovations. Eco-process and eco-organisational innovations are found to be most sensitive to institutional and political influences (such as regulation), whilst eco-product innovations are most sensitive to supply-side factors (such as cost-saving). These findings contribute to theoretical debates on the determinants of eco-innovation, as well as having implications for policymakers addressing the dual policy objectives of renewable energy deployment and biodiversity conservation.

1. Introduction

Mitigating climate change demands a fundamental transformation of the global energy system (Intergovernmental Panel on Climate Change, 2014). It is widely recognised that the long-term substitution of fossil fuels with low-carbon energy sources such as renewable energy (RE) will be essential to reducing greenhouse gas (GHG) emissions from the world's energy supply (International Energy Agency, 2011). One of the most mature and affordable options is wind energy, which has undergone rapid deployment in many countries around the world (Leung and Yang, 2012). However, whilst wind technologies deliver environmental benefits in terms of reduced GHG emissions, they can lead to detrimental impacts on wildlife if inappropriately sited, designed or managed (Wang et al., 2015). For example, birds and bats can be killed or injured by colliding with turbines, or experience habitat loss or fragmentation as a result of wind energy infrastructure (Birdlife Europe, 2011). As such, conflict can emerge between climate change policy objectives and biodiversity conservation objectives. For instance, some major wind energy projects have been unable to obtain planning consent as they contravene regulation on protected species and habitats (see Gosden, 2016; Harvey, 2014). As the most suitable sites are exhausted, this type of conflict is likely to increase as fewer uncontroversial sites remain available (Gove et al., 2016).

This article explores the role of eco-innovation in helping to overcome this conflict in environmental objectives. Using the UK wind energy sector as a case study, it identifies examples of innovation which address the biodiversity impacts of wind energy technologies. It also identifies the main drivers behind these innovations to understand what motivates actors to pursue them, and what types of action would be required to increase innovation activity in these areas. In doing so, this article sheds light on examples of eco-innovation in the UK wind energy sector that could help to reduce conflict between the dual environmental policy objectives of renewable energy deployment and biodiversity conservation. Theoretical insights are drawn from the eco-innovation literature regarding the main determinants of eco-innovation activities, which are then tested in relation to this article's case study. The guiding

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research question of this article is whether the drivers of innovation in the case study differ from or align with those in the existing literature. Furthermore, it will also consider whether drivers differ across different types of eco-innovation such as 'eco-product', 'eco-process' and 'eco-organisational' innovation (Triguero et al., 2013).

Whilst some mitigation measures to reduce the ecological impacts of wind energy are discussed in the existing biodiversity conservation literature, such as the role of careful siting to avoid environmentally sensitive areas (e.g. Johnson et al., 2007; Langston and Pullan, 2003), an eco-innovation framing has not been applied to this area of research. Therefore, the potentially valuable role of innovation has so far been overlooked. It is emphasised that understanding of the interactions between biodiversity and wind energy technologies is evolving, meaning there are limitations to the confidence with which this article can affirm that the examples of eco-innovation identified will reduce impacts. Rigorous environmental assessment is required for all innovations which claim to reduce biodiversity impacts of any wind energy technology. Both onshore and offshore wind technologies are considered, though it should be noted that less is known about the interactions between wildlife and offshore developments than onshore developments (Powlesland, 2009), meaning the environmental effects of innovations relating to offshore wind are subject to greater uncertainty. The article focuses on *local* ecological impacts of wind energy technologies, such as bird and bat collision, rather than ecological impacts *embedded* within the supply chain or manufacturing process (such as the impact of using rare earth minerals in the production of turbines) which are beyond this article's scope.

The article is organised as follows. The following section reviews the literature on eco-innovation, providing definitions and outlining key determinant factors identified in the existing literature. This provides the theoretical framework that will be tested in the case study of the UK wind energy sector. The third section presents the material and methods used for data collection and analysis. The fourth section presents fifteen examples of eco-innovation which address the ecological impacts of wind energy technologies identified in this research, separated into six thematic areas of innovation, along with their main drivers. The fifth section discusses the significance of these empirical results, and the sixth section summarises with key conclusions and policy implications of the research findings.

2. Theory

2.1. Definitions of eco-innovation

There is a range of definitions for eco-innovation (Schiederig et al., 2012). One of the first, formulated by Claude Fussler and Peter James (1996), describes eco-innovation as 'new products and processes which provide customer and business value but significantly decrease environmental impacts' (cited from Bartlett and Trifilova, 2010, p. 2). Building on this definition, René Kemp and Peter Pearson define eco-innovation as: 'The production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives' (2007, p. 7). This understanding of eco-innovation is supported by the Organisation for Economic Co-operation and Development (Organisation for Economic Co-operation and Development (OECD), 2009), which defines it as 'the creation or implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which, *with or without intent*, lead to environmental improvements compared to relevant alternatives' (2009, p. 40, emphasis added). These definitions demonstrate three crucial elements to the concept of eco-innovation.

Firstly, they specify that the object of eco-innovation is not limited to environmental technologies: eco-innovation can refer to products, services, processes, business or management methods, organisational structures and institutional arrangements. Importantly, the innovation must lead to decreased environmental impacts (throughout its life cycle) in comparison to relevant alternatives. Secondly, as highlighted by Kemp and Pearson's definition, the innovation being developed or adopted does not have to be brand new to the market, but it must be new or novel to the specific organisation or context in which it is implemented. Thirdly, as the OECD definition highlights, it is not essential that the reduced environmental impact is intended; classification is based upon environmental performance rather than motivation. As Kemp and Pearson argue, focusing only on environmentally-motivated innovation overlooks the environmental gains made through 'normal' innovations, that is, innovations driven by 'normal market reasons of saving costs or providing better services to users' (2007, p. 5).

Based on these definitions, innovations which address the ecological impacts of wind energy can be understood as a type of eco-innovation. Such innovations help to reduce the local environmental impacts of wind energy generation, as well as contributing to the wider aim of lower GHG emissions. Importantly, this article assumes that by decreasing environmental impacts at the deployment stage, lifecycle impacts overall will be decreased. However, given that the ecological impacts embedded within the supply chain or manufacturing process are beyond the scope of this article, there are limitations to the conclusions that can be drawn. In line with the existing definitions, it is argued that the eco-innovation classification is applicable whether the outcome of reduced ecological impact is intended or not, and whether the innovation is a product, service, process, business or management method, organisational structure or institutional arrangement – provided it is novel either to the market or to the specific organisation or context in which it is applied.

2.2. Determinants of eco-innovation

A key debate within the eco-innovation literature is what the drivers (or 'determinants') are of eco-innovation activities (e.g. del Río González, 2009; Horbach et al., 2012). Jens Horbach suggests that because most environmental problems represent 'negative