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Energy transition in Germany and regional spill-overs: The diffusion of renewable energy in firms☆

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ABSTRACT

The success of transitioning energy consumption towards renewables highly depends on the willingness and ability of firms to adopt energy technologies that use renewable sources. Existing studies focus on the role of regulation and energy markets to explaining the diffusion of green energy. This paper looks at the specific role of the firms' regional environment in this process. We use a unique database combining the Community Innovation Survey 2014 for Germany and district-level data on renewable energy plants, the attitudes of a region's population towards 'green issues' and other control variables. We find that geographical proximity to electricity production based on renewable energy sources and the orientation of a region towards 'green issues' are both correlated to such innovations. Therefore, not only "hard" regulation measures such as the renewable energy law are relevant for renewable energy innovations. Our results show that subsidies for eco-innovation, high energy costs and regional knowledge spill-overs are linked to a rapid adoption of renewable energy by firms.

1. Introduction

Shifting energy consumption from fossil sources to renewables is a key policy objective in many countries, including Germany. In 2016, Germany attained a share of 29% of renewable energy sources in gross electricity generation while fossil energy sources contributed 53.6% (hard coal 17.2%, lignite 23.1%, natural gas 12.4%, oil 0.9%) (BMWi, 2017a). Following the goals of the German federal government, the share of renewables shall rise up to 45% in 2025 (BMWi, 2017a). For 2050, a share of 80% is targeted. To reach these ambitious goals, innovations are required which substitute fossil energy sources by renewables.

At first glance, regulations such as the German renewable energy law seem to be one of the most important determinants to introduce renewable energy innovations (see Gawel et al., 2014; Frondel et al., 2010; Rammer et al., 2017; Stucki et al., 2018) but the importance of this nationwide law cannot explain the significant regional differences in renewable energy innovation activities. In the innovation literature, regional spill-overs (see Cantner et al., 2016) and tacit knowledge receive more and more attention as drivers for technology diffusion, whereas the growing literature on the determinants of eco-innovation widely neglects these effects. The present paper tries to assess the relevance of regional factors for innovation in renewable energy, which is an important subfield of eco-innovation. We use a unique database combining three data sources. The main source is the Community Innovation Survey (CIS) 2014 for Germany which contains detailed information on eco-innovation activities and their drivers at the firm level, including information on eco-innovations that substitute fossil by renewable energy sources in a firm's internal processes, and the role of environmental regulations or government subsidies for introducing these eco-innovations. This firm-level database is matched with regional data on renewable energy plants (solar, water, wind and biomass) as well as data on the attitudes of a region's population towards green issues at the geographical level of German districts ('*Kreise*' and '*kreisfreie Städte*'). The regional data enables the analysis of likely spill-over effects on the introduction of renewable energy innovations resulting from the green orientation of a region, or the regional endowment with a green energy capital stock. Our econometric models attempt to assess the importance of these effects while controlling for the relevance of environmental policy measures, energy costs and the technological capabilities of a firm.

The paper is organized as follows. Section 2 describes the theoretical framework of the relevance of regional spill-over effects on renewable energy innovations. Furthermore, the section contains an overview of

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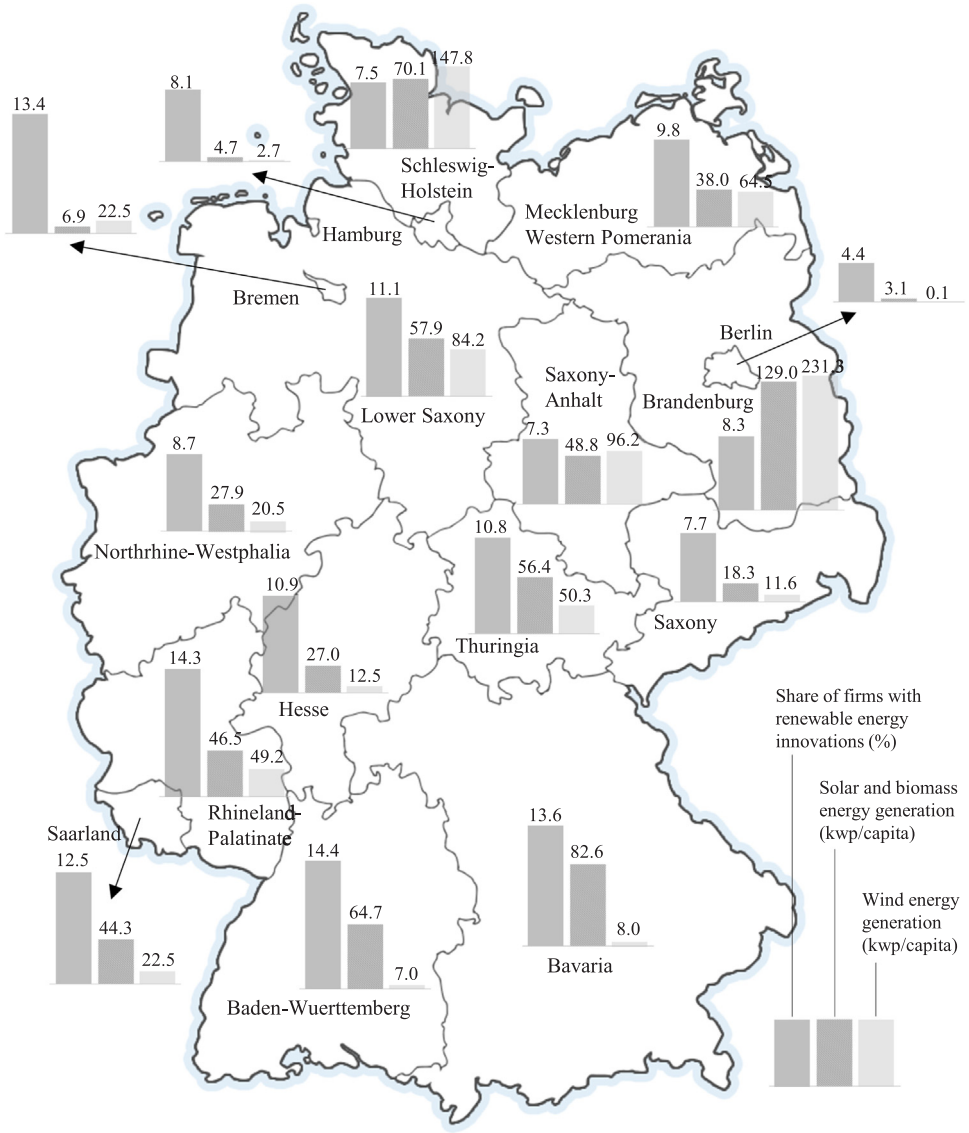

Fig. 1. Diffusion of renewable energy innovations in firms, and renewable energy generation per capita in German States 2014. Source: Statistisches Bundesamt (2017), German CIS 2014, own calculations.

empirical literature related to our research. Section 3 discusses the database, descriptive statistics and the econometric estimation strategy. Section 4 presents the estimation results. Section 5 concludes and develops policy recommendations.

2. Determinants of renewable energy innovations

In this paper, renewable energy innovations are defined as process innovations that lead to a substitution of fossil energy sources by renewable sources within firms. In most cases, this substitution is cost-intensive and will be undertaken by firms only if costs of fossil energy sources rise significantly, or if governments provide subsidies for renewable energy innovations (see Popp et al., 2010; Horbach et al., 2012). In addition, firms may be pushed to substitute fossil by renewable energy sources if regulation on emissions (e.g. CO_2) become more stringent. While these factors usually affect all firms with a similar energy consumption pattern in the same way, substantial regional differences in renewable energy innovation can be observed across the Federal States of Germany (see Fig. 1). States in the western part of Germany tend to show a higher diffusion of renewable energy technologies among firms, especially Rhineland-Palatinate, Baden-Wurttemberg and Bavaria. The two last-mentioned states also show a disproportionately high stock of solar and biomass plants per capita whereas the wind plants are more concentrated in the Northeast of Germany. North Rhine-Westphalia, Hesse, Hamburg and Berlin all report rather low shares of firms with renewable energy innovations and a low level of energy generation based on renewables. However, there are also states with a high level of renewable energy generation and a low innovation activity of firms in the field of renewable energy technologies like Brandenburg and Schleswig-Holstein.

The main aim of this paper is to explain the regional differences and to identify regional determinants of eco-innovations in the field of renewable energy. As the geographical level of states is too heterogeneous in terms of size and the regional situation for adopting renewable energy technologies, the analysis is conducted at the much more disaggregated level of districts, covering almost 400 geographical units.

While the literature on the determinants of eco-innovation is growing fast (see e.g. Barbieri et al., 2016 for a recent overview), the inclusion of regional aspects still remains rare (see Antonioli et al., 2016; Cantner et al., 2016, Horbach, 2014 as exceptions). We argue