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Holding a candle to innovation in concentrating solar power technologies: A study drawing on patent data

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ABSTRACT

Improved understanding of the innovative pathways of renewable energy technologies is vital if we are to make the transition to a low carbon economy. This study presents new evidence on innovation and industry dynamics in concentrating solar power (CSP) technologies. Though CSP is undergoing a renaissance, existing innovation studies have explored innovative activity in solar technologies in general, ignoring the major differences between solar photovoltaic and CSP technologies. This study, based on patent data, examines the level and dynamics of innovative activity in CSP between 1978 and 2004.

Our unique contribution, based on engineering expertise and detailed datawork, is a classification system mapping CSP technologies to the International Patent Classification (IPC) system. The innovation performance of CSP is found to be surprisingly weak compared to the patent boom in other green technologies. Performance was strong around 1980 before falling dramatically, and has only recently begun to show signs of recovery. Innovation and R&D are concentrated in high-tech countries; the US, Germany and Japan, which do not necessarily have high domestic CSP potential. Large CSP potential is, therefore, not a sufficient condition for innovation. Innovators must possess economic and scientific capabilities.

1. Introduction

Concentrating solar power (CSP) technologies are undergoing a renaissance. In the 1980s many successful projects proved CSP to be a set of clean, reliable and economically promising technologies for power generation, but they have subsequently been outshone by other renewable energy (RE) technologies. However, it is increasingly apparent that CSP is again regarded as a technology set that can make a major contribution to a low-carbon and secure power system. Its potential is huge—scenarios predict a share between 12% (IEA, 2009b) and 25% of global electricity needs by 2050 (Greenpeace, 2009). Estimates of the size of the project pipeline vary, but one suggests that 980 MW are under construction and projects of a total of 7500 MW have been announced (Greenpeace, 2009). One project, the DESERTEC Industrial Initiative is particularly prominent and attracting high level support: initiated in 2009 by industry stakeholders, it envisions a sustainable electricity supply for the EU and the Middle East and North African (MENA) region based largely on harnessing solar power through the installation of CSP technologies in desert areas (DESERTEC Foundation, 2009).[1] The sheer volume of industry activity around CSP in these and other projects is striking, but academic research on technological progress in CSP technologies has failed to keep pace. The primary objective of this study is to fill this research gap by assessing for the first time the dynamics and geographic distribution of innovative activity in CSP. A secondary objective is to examine the actual outcome of the innovative behavior that we describe (CSP installations) and the firms that populate the industry that supplies the technology.

Empirical research can provide important insights on the characteristics of innovation in RE technologies and on how to enhance technological progress; this is the first empirical study to focus on innovative activity in CSP technologies. Accurate evaluation of individual technologies requires a precise technological definition, particularly if such evaluation is to inform the design of technology-specific policy instruments. Unfortunately existing research on solar energy technologies fails to differentiate between technologies such as solar photovoltaics (PV), heating

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[1] The DESERTEC Foundation originally launched this vision which was later complemented by the DESERTEC Industrial Initiative. For recent work related to these projects see Komendantova et al., in press or Williges et al. (2010).

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or CSP (Glachant et al., 2009; Johnstone et al., 2010; OECD, 2009a), which means that it "blurs" the innovation trends of any of these technologies. The unique contribution of this study which is based on engineering expertise and detailed data work, is the development of a classification system that enabled us to precisely define CSP and map it to the International Patent Classification (IPC) system. Filtering out non-CSP innovation in this way allowed us to overcome the shortcomings of prior work in the field, and to generate a more accurate picture of the temporal and geographical dimensions of innovation in CSP.

Patent data are a well-established metric of innovative activity in the general innovation literature, and are increasingly used as a measure of innovation in "green" technologies (Braun et al., 2010; Johnstone et al., 2010) since they exhibit distinct advantages over alternative measures such as R&D personnel (Griliches, 1990; OECD, 2009a).[2] A patent legally defines an invention as truly novel, a status which is assured by the responsible patent office. Patent documentation is rich with detail such as technical classification and documentation which can be exploited for techno-economic analysis such as this study.

For a precise technology definition, we draw on engineering expertise and a careful assessment of the features of CSP technologies, and develop two schemes which map the technologies to the patent classification: one based on a narrow definition of CSP focusing on solar heat, and the other on a broader definition which encompasses the development of components that are crucial to CSP (e.g. high-temperature heat exchange, boilers). Classifying patents in this way allowed us to construct a unique dataset on CSP which contains the number of annual patent applications filed at both the European patent office (EPO) and the United States (US) patent office (USPTO) over the years 1978–2004.[3]

Our paper relates to recent work on the empirical foundations of technological change in energy technologies (for an overview, see Popp et al., 2010). Some of these contributions have also considered CSP, but few make an explicit distinction between the latter and PV technologies. One strand of research studies the link between environmental policy and the direction and level of technological change, often using patent data. Lanjouw and Mody (1996) were the first to apply patent data to the issue, identifying environmentally benign technology patents and finding a positive link between environmental regulation and innovative activity. Recently, Johnstone et al. (2010) investigate the influence of policies promoting renewable energy such as green certificates schemes on patent activity. Feed-in tariffs were found to be particularly strong drivers of innovation in solar technologies, but the approach adopted does not distinguish between solar PV and solar thermal technologies. Experience curves are another analytical tool used to infer the influence of R&D and particularly capacity expansion, on the costs of a technology (CSP is covered by, e.g. Neij, 2008; Jamasb, 2007). A third focus is the diffusion of new technologies over time and across regions or countries (for an application with patent data refer to Dechezleprêtre et al., 2009).

We begin with an overview of the evolution of the technology and the supplying industry in Section 2. Section 3 describes the dataset and derivation of classification scheme for CSP technologies. Subsequently we discuss the public R&D support background against which these innovations have occurred (Section 4). Based on the methodological work of Section 3 and the R&D background laid out before in Section 4, Section 5 will discuss our findings on patenting activity. In the final section we draw together these strands and conclude.

2. CSP technologies, installed capacity and industrial structure

2.1. CSP technologies

Solar thermal systems are based on the physical principle of energy conversion from short-wave solar radiation into heat, also described as photo-thermal conversion. Although solar thermal systems work on a common principle, the technical designs and materials required vary significantly depending on the required process parameters for different applications, i.e. the temperature and pressure of the working medium. Room and water heating in residential solar thermal systems is a common application for low-temperature solar heat utilization. These systems are in most cases based on non-concentrating solar thermal technologies, i.e. they do not amplify the direct solar irradiation by collecting and focusing the solar radiation in a focal point or line, and show a solar concentration ratio $CR=1$, which describes the ratio of the optically active collector to the absorber area exposed to solar radiation. In recent years the production of process heat, water desalination, and power generation have become important applications, or at least show a high potential for solar thermal energy conversion. These processes require high temperatures and therefore technologies must incorporate devices which concentrate the sunlight's direct normal irradiance (DNI) in a focal point or line ($CR>1$). Apart from water desalination, the highest potential for the future of CSP technologies lies in electric power generation. Estimated global cumulative installed CSP capacity is shown in Fig. 1.

CSP systems exhibit a wide range of technical designs which differ with respect to a range of characteristics; the underlying thermodynamic cycle (e.g. Clausius–Rankine-, Stirling-, Brayton-cycles), applied heat transfer media (oil, steam, air, other gases), its working temperatures and working pressures, heat storage technologies (e.g. molten salt, phase change materials, concrete, ceramic, pressurized gases) among others. The major CSP technologies are studied in this paper: (1) parabolic trough systems, (2) linear Fresnel reflectors, (3) solar towers with a central receiver, and (4) parabolic dish/engine systems. Fig. 2 gives a diagrammatic representation of the technologies, which are described in turn:

- Parabolic trough systems: shaped as semicircular mirrors which reflect the sunlight along a focal line on a tube. The receiver tube contains a heat transfer fluid (normally thermal oil) that absorbs the 70–100 times concentrated sunlight. The heat transfer fluid produces steam in a heat exchanger at a temperature of almost 400 °C which drives a turbine-generator unit for electricity generation. The underlying thermodynamic cycle is a Rankine cycle, which is similar to conventional thermal power plants. Parabolic trough systems dominate the global market for CSP plants with more than 95% share in the estimated 560 MW of operating CSP plants in mid-2009 (Greenpeace, 2009).
- Linear Fresnel reflectors: similar to trough systems being a line-focus technology that reflects the solar radiation from fixed ground mounted mirrors onto a receiver pipeline carrying a heat transfer medium. Current designs use water directly in the receiver tubes at pressures up to 50 bar and temperatures of 280 °C or molten salt fluids (DOE, 2008). Its relatively lower optical and thermal performance compared to parabolic trough systems is compensated for by reduced investment, and operational and maintenance costs. This technology promises further cost savings through the use of less expensive reflector materials and absorber components than parabolic mirror systems. Linear Fresnel collectors are still in the demonstration phase, with two operating

[2] Patent data are a strong indicator for innovation, but they are not exhaustive. We will return to this issue in Section 3.1.

[3] We will briefly elaborate on the patenting activity at the Japanese Patent Office (JPO) in the Appendix.