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Public policy and financial resource mobilization for wind energy in developing countries: A comparison of approaches and outcomes in China and India

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ABSTRACT

We analyze and contrast how China and India mobilized financial resources to build domestic technological innovation systems in wind energy. To that end, we identify distinct stages of technology diffusion in the two countries in the period 1986–2012, and analyze the interplay between public policies and the development of the technological innovation system across the different stages. We show that the two countries' distinct development strategies for wind energy – China developed wind energy largely through its state-owned enterprises, while India opened up wind energy investment to the private sector in the early 1990s – influenced system outcomes in terms of technology diffusion, domestic industry structure, competitiveness, and ownership. By unraveling the interplay between public policies, investment risks and returns, and actor characteristics, we explain the differences in system outcomes and identify important policy trade-offs between the two strategies. Our analysis provides novel insights about the process of financial resource mobilization in technological innovation systems, the dynamics of innovation-system growth, and the policy trade-offs that must be reconciled by countries that aim to promote the diffusion of a particular technology.

1. Introduction

Avoiding dangerous climate change will require a rapid up-scaling and redirection of energy infrastructure investments. Global investment in renewable energy has grown from $39.5bn to $214.4bn in the decade between 2004 and 2013 (Frankfurt School-UNEP Centre/BNEF, 2014), but will have to further increase to more than twice the current amount for the world to stay on track for mitigating dangerous climate change. Much of this investment will have to occur in developing countries, a term which we use as describing low- and middle-income countries (The World Bank, 2013). Their contribution will have to increase from roughly 40% in 2013 to almost 60% of the cumulative investments between 2015 and 2035 (IEA, 2014). This growth will have to occur in spite of the often underdeveloped financial markets and regulatory frameworks in the developing world, which make it difficult for investors to raise capital (Khanna and Palepu, 1997; Rodrik, 2009). How governments in developing countries can create conditions that stimulate the diffusion and market penetration of renewable energy technologies into their existing power systems is therefore keenly debated among academics, governments, and international organizations (Huenteler, 2014; Jakob et al., 2014; UNEP, SEFI, SEF, 2008).

Two separate streams of literature are addressing the question of how governments in developing countries can enable the diffusion of renewable energy. On the one hand, a growing body of literature analyzes how public policies affect investors in clean energy in developing countries (Bhattacharyya, 2013; Friebe et al., 2014; Frisari and Stadelmann, 2015; Schmidt, 2014; Shrimali et al., 2013; Waissbein et al., 2013). These studies provide an analytical framework to analyze the influence of different policy instruments on the ability by investors to mobilize financial resources (Wüstenhagen and Menichetti, 2012). But they often pay relatively little attention to the enabling systemic conditions – e.g., local technology supply chains, actor networks, and informal institutions – that need to be in place for technologies to diffuse. On the other hand, a growing number of studies apply the technological innovation systems (TIS) concept to analyze how actors, networks, and institutions interact in the diffusion of

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technology in the context of developing countries (for a review, see (Blum et al., 2015)). The TIS concept provides a powerful framework to analyze the systemic conditions that collectively enable technology diffusion (Bergek et al., 2008; Hekkert et al., 2007). But the TIS literature so far has developed only a rudimentary understanding of the detailed processes and determinants of financial resource mobilization in innovation systems and how they interact with other system functions and outcomes (Musiolik et al., 2012).

This paper integrates the two literature streams to study how public policies affect the diffusion of clean energy in developing countries. In particular, we study the policy strategies pursued by China and India to develop their wind energy sectors. The aim is to analyze the relationship between government policies and what we call 'system outcomes' of the diffusion of wind energy in the two countries. In particular, we analyze (i) the timing and rate of wind energy diffusion, (ii) the size and competitiveness of the wind turbine manufacturing industry, and (iii) the degree to which wind energy is integrated in the larger electricity system. We adopt a systemic perspective anchored in the TIS literature, and add to this a detailed model of financial resource mobilization anchored in the literature on renewable energy investment. Using the two cases, we analyze (i) the patterns of technology diffusion in the two countries; and (ii) how the process of financial resource mobilization and diffusion enabled by actors in the TIS was impacted by the interplay between public policies, actor characteristics, and investment determinants.

The remainder of the paper is structured as follows. Section 2 describes the theoretical perspective. Section 3 describes our case, data, and methods used. Section 4 presents an analysis of the stages and timescales of technology diffusion, and the interplay between public policies, actor characteristics, and investment determinants. Section 5 discusses the dynamics of system building and the processes for financial resource mobilization followed by the relevant public policy trade-offs. Section 6 concludes with a brief summary of our analysis.

2. Theoretical perspective

2.1. Resource mobilization in technological innovation systems

This paper adopts a systemic perspective anchored in TIS literature. Technological innovation systems (TIS) are defined here as "socio-technical systems focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both)" (Bergek et al., 2008). The structural components of TIS are actors, networks of actors, institutions (or rules that govern interactions, such as public policies), and technology. The TIS approach, historically used to analyze the emergence of specific clean energy technologies in industrialized countries (Markard et al., 2012), is increasingly being used to understand the diffusion of renewable energy technologies in the context of developing countries (for a review, see (Blum et al., 2015)). This increased coverage of developing countries has also led to a greater emphasis on the geographical dimensions of TIS, i.e., the national or regional context of technology diffusion in developing countries taking into account the global contexts of technology and development (e.g., Binz et al., 2014; Coenen et al., 2012).

The TIS literature has shown that analyses of system *functions* can usefully point policymakers toward specific strengths or weaknesses of the TIS that enhance or limit diffusion of a technology and that may benefit from policy intervention (Bergek et al., 2008; Hekkert et al., 2007). The functions of TIS are knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, resource mobilization, market formation, legitimation, and development of positive externalities (Bergek et al., 2008; Hekkert et al., 2007).

The TIS function of resource mobilization describes the extent to which different actors are able to mobilize human and financial capital. Resource mobilization can be analyzed over time by evaluating the volume of domestic or foreign capital investment (Bergek et al., 2008; Gosens and Lu, 2013), or by interviewing involved actors (Hekkert et al., 2007). Despite its clear importance in the growth of an innovation system around a new technology, there has been little research on resource mobilization (Farla et al., 2012; Karltorp, 2014; Musiolik et al., 2012). In particular, the "underlying concepts did not receive much attention" (Musiolik et al., 2012). Especially in developing countries – where underdeveloped capital markets and regulatory frameworks often make it difficult to raise financial resources to start a new technology sector (Rodrik, 2009) – better understanding the process of *financial resource mobilization* and the underlying concepts is important to inform policymakers.

The development and diffusion of a technology is often conceptualized as a multi-stage process in TIS with a formative phase and a growth phase (Jacobsson and Lauber, 2006). For the purposes of this paper, diffusion refers to the market penetration of a particular technology within a specific country where the formative stage encompasses pre-commercial and early-commercial deployment of the technology; the growth phase encompasses the commercialization period after the takeoff in which diffusion accelerates rapidly, followed by a last period of widespread diffusion (see Table 1). In our description of widespread diffusion, the market for the technology in that country may continue to grow (in absolute terms and also as a percentage of the total demand) and may experience another wave of rapid growth depending on domestic factors or external factors that reflect trends in the global industry. Indeed, the patterns, drivers, and stages of wind market penetration in specific countries must be understood in the wider context of the wind energy industry, which is evolving and maturing at a global level in terms of the emergence of a dominant design and interactions between manufacturers, for example.

The transition between stages of diffusion depends critically on the extent to which actors across the system are able to mobilize resources. In the case of renewable energy technologies in the power sector, these actors include (i) users of technology (project

Table 1
Conceptualization of stages of technology diffusion for the purposes of this paper.

Stages of technology diffusion	Formative stage		Growth stage	
	Pre-commercialization	Early commercialization	Commercialization	Widespread diffusion
Description	Scattered, non-commercial deployment, often in the form of highly subsidized demonstration projects	Limited deployment, first commercially oriented entrants, often attracted by significant government subsidies	Period of strong growth in market size, with rapidly growing number of actors, technology diffusion is widespread	Stable or gradually growing market for established technology (rapid growth may still occur due to global or industry-external trends)
Key resources	Relatively modest financing needs, mostly for R&D, demonstration and early deployment		Large-scale financing needs for widespread diffusion	