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Analysis

# Technology Diffusion and Climate Policy: A Network Approach and its Application to Wind Energy☆

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ABSTRACT

The role of technology transfer in the mitigation of climate change has been strongly emphasized in the recent policy debate. This paper offers a network-based perspective on the issue. First, we propose a methodology to infer from technology adoption data the network of diffusion and apply it to a detailed dataset on wind energy technologies installed globally since the 1980s. We then perform a statistical analysis of the network. It highlights a relatively inefficient organization, characterized in particular by the weakness of South-South links, which leads to relatively long lags in the diffusion process. Against this background, we characterize optimal transfer/seeding strategies for an agent that aims to introduce a new technology in a developing country in view of further diffusion. Our results suggest in particular that CDM projects have been too concentrated in large emerging economies and that developed countries should put a stronger weight on the positive externalities in terms of technology transfer of cooperating with less prominent developing countries.

## 1. Introduction

Technology transfers are put forward prominently, both in the Intended Nationally Determined Contributions (INDCs) and in the text of the COP21 Paris Agreement, as necessary conditions for the implementation of an effective mitigation policy at the global scale. Explicitly, the Paris Agreement emphasizes the need of "***technology** and capacity-building **support by developed country Parties**, in a predictable manner, to enable enhanced pre-2020 action by developing country Parties*.[1]" This requirement implicitly assumes that technology transfers can be heavily influenced or even controlled by the governments of developed countries. This might be true in some very specific industries such as defense and aerospace. Yet, for most of the technologies that are of concern for climate policy, notably renewable energy, the diffusion process is the outcome of interactions between private firms. Moreover, transfers take a wide variety of forms (e.g. material or immaterial) and employ a variety of vehicles (see Haug, 1992 for an extensive discussion). In this complex landscape, it is much less clear what policy can do and how it can operate.

The existing literature on the transfer of climate related technologies has mainly emphasized the role that domestic policy in developing countries can play by providing enabling conditions for adoption and development of technologies (see e.g., de Coninck and Sagar, 2015 and references therein). This is an important conclusion but it does not provide any insight on the measures developed countries should take in order to fulfill the commitment to support technology transfers that they have taken in the framework of the Paris Agreement.

In order to address this issue, a prerequisite is to understand the existing dynamics of technological diffusion. Therefore, this paper proposes a methodology to infer, from adoption data, the structure of the network of technology diffusion between countries. A first type of policy measures that can then be analyzed in this framework is the subsidization by developed countries of the installation of certain technologies in developing countries, in view of fostering their further diffusion. This is one of the direct objectives of the Global Environment Facility (see e.g., GEF, 2014) and an indirect objective of the Clean Development Mechanism (see e.g., UNFCCC, 2010). A broader issue is the extent to which policy-makers can, individually or collectively, modify the network of diffusion. This is however beyond the scope of this paper as it requires to infer the determinants of network formation rather than the network per se.

Accordingly, wind energy being one of the most important

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[1] Our emphasis; see also articles 66 to 71 of UNFCCC (2015).

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technologies for climate change mitigation (e.g., see IPCC, 2011), we apply our methodology in this context, using a comprehensive database on wind turbines installed globally from 1983 onwards. We hence provide an empirical contribution by identifying existing inefficiencies in the wind technology diffusion network and by characterizing how policy can best operate given the existing network structure.

Our main conceptual innovation is to adopt a network-based approach, whereas the existing literature has mainly focused on bilateral transfers in the Clean Development Mechanism (CDM) framework (see de Coninck and Sagar, 2015 and references below). This allows us to provide a systemic perspective that accounts for the impact of each country not only on its direct connections, but also on the global diffusion process. Indeed, a country might be quantitatively neither the most important source nor the most important adopter of a technology, but still play an important role as a hub in its diffusion. The fundamental role of such network effects has been identified in a wide range of contexts such as epidemics (see e.g., Pastor-Satorras and Vespignani, 2001), social dynamics (see e.g., Castellano et al., 2009), spatial econometrics (see e.g., LeSage and Pace, 2009; Elhorst, 2014), or the diffusion of innovations (see e.g., Rogers, 1983).

From the methodological point of view, an important difficulty is that technology diffusion networks are generally not directly observed. To address this issue, we build on the independent cascade model of Gomez-Rodriguez et al. (2010, 2011, 2014) and infer the structure of the network by maximizing the likelihood of the observed patterns of technology adoption using a parametric model of diffusion. This allows us to reconstruct the global wind diffusion network and its evolution over time. We then perform a statistical analysis of the network. It highlights a relatively inefficient organization, characterized in particular by the weakness of South-South links, which leads to relatively long lags in the diffusion process. Against this background, we characterize optimal transfer/seeding strategies for an agent, such as the GEF or a developed country engaging in development policy, that aims to introduce a new technology in a developing country in view of further diffusion. The more structural question of how policy can modify the structure of the network in order to increase the efficiency of the diffusion dynamics is not addressed here although we recognize its importance.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 outlines the methodology and Section 4 its application to the diffusion of wind energy, followed by quantitative analyses of the network. Section 5 then aims at appraising efficient strategies for technological diffusion in the context of climate policy. Section 6 concludes and raises ideas for further research.

## 2. Related Literature

The importance of technological diffusion processes for the achievement of climate policy objectives has been emphasized at least since the Kyoto Protocol (see e.g., Blackman, 1999). Within the scientific community, the Intergovernmental Panel on Climate Change (IPCC) has repeatedly put forward its central role for climate policy and sustainable development (see e.g., IPCC, 2014). In the policy debate, technology transfers are strongly emphasized in the INDCs prepared for the COP21 and their relevance is recognized in the Paris Agreement which puts forward in its preamble "*the urgent need to enhance the provision of finance, technology and capacity-building*" and devotes a full section to its decisions on "technology development and transfer," hence putting it on an equal footing with mitigation and adaptation.[2] Despite this emphasis, our understanding of how technology diffuses globally and of how policy can influence the process remains very partial. This is explained in part by a lack of detailed data on technology transfer, as well as by the fact that the process itself is complex, making policy in this area especially challenging (cf. Maskus, 2004; de Coninck and Sagar, 2015).

Three main market channels of technology transfer have been distinguished in the literature (cf. Glachant et al., 2013): (i) international trade in intermediate goods (e.g., export and import of equipment), (ii) foreign direct investments including joint ventures, and (iii) licensing.[3] Accordingly, there has been a focus on explaining bilateral flows of environmentally friendly technologies using measures such as international trade data, FDI, and patents (e.g., Popp, 2005; Popp et al., 2011; Glachant et al., 2013; Dechezleprêtre et al., 2013). In particular, Dechezlepretre and Glachant (2014) investigate the role of policy in fostering technology transfer in wind energy, where technology transfer is defined as a patent application filed by an inventor residing in a country that is different from the one in which protection is sought. In terms of encouraging transfer, public policy support is highlighted, but it should be pointed out that annual wind power generation in each country is used as a proxy measure for demand-pull policies.[4] Also to keep in mind is that certain types of knowledge that are tacit are not patentable, and that innovation activity is highly concentrated in a few countries (cf. ibid).

In the specific context of climate policy, the Clean Development Mechanism has been considered as an important, and well-documented source of technological transfers leading to a number of studies on the magnitude and the drivers of bilateral transfers of renewable energy technologies (in particular Dechezleprêtre et al., 2008, 2009; Popp, 2011; Schneider et al., 2008; Weitzel et al., 2015; Murphy et al., 2015). The focus there is on transfers of low-carbon technologies from developed to developing countries. It should be stressed, however, that technology transfer was only a secondary focus of CDM projects whose main objective rather was to reduce abatement costs. In particular, it should be noted that not all CDM projects entail an actual international technology transfer; in fact, it has been shown that transfers take place in less than half of CDM projects (Dechezleprêtre et al., 2008). Though they have contributed to implementing wind power projects (see e.g., Timilsina et al., 2013), there has also been much debate on the effectiveness to enhance transfers, with critiques including the profit-maximizing view of behavior underlying the institutions and that technology transfer is not solely a developed or developing country issue (cf. Zografos and Howarth, 2010; de Coninck and Sagar, 2015). Considering the dominant North-South focus, and as stressed in Brewer (2008) who proposes a shift to a 'global paradigm,' it is interesting to explore South-South transfers, and altogether not make such dichotomous distinctions.

Another important issue is that most CDM projects have been directed to the large emerging economies, mostly China, India, and Brazil (Dechezleprêtre et al., 2008; Rahman et al., 2016).[5] This leaves out a significant amount of smaller low and middle-income countries. In this respect, the data and approach we use is more inclusive in terms of geographical coverage with countries that are less in the spotlight in the technology transfer and climate policy domains, and also allows going beyond a bilateral North-South transfer perspective. Also, though data from the project design documents of the CDM is detailed, a significant limitation is that data of projects are usually registered during a very short period (around 2 years; ibid), thereby not allowing to analyze the *dynamic* aspects of diffusion, being the accumulation of technology across adopters and over time arising from adoption decisions (Comin

[2] As with technology, the role of finance in inducing the low-carbon transition is also receiving increased attention and for a recent paper on this latter issue see for example, Campiglio (2016).

[3] Non-market channels such as migration are much less explored.

[4] For the EU, Serrano-Gonzalez and Lacal-Arantegui (2016) also find barriers to wind energy (note they do not study technology transfer specifically), relate mostly to the political and economic framework, such as abrupt changes and retroactive measures including suspension of support schemes.

[5] Rahman et al. (2016) find that respectively, China, India and Brazil are the three largest host countries, with more than 72% of the projects in the CDM portfolio.