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Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands

Roald A.A. Suurs *, Marko P. Hekkert

Department of Innovation Studies, Copernicus Institute for Sustainable Development and Innovation, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

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ABSTRACT

The support of sustainable energy innovations has become a dominant topic on the political agenda of many countries. Providing this support remains difficult, since the processes constituting such innovation trajectories are poorly understood. To increase insight in such processes, this paper takes the historical development of biofuels in the Netherlands as the topic of study. Special attention is paid to the simultaneous development of two technology generations within the field: a first generation (1G) and a second generation (2G) of biofuels. A critical question asked is whether deployment programmes for a 1G technology may have positive effects on the development of later generations. Two archetypical support strategies are identified: one is to keep investing in R&D concerning 2G technology, where the expected outcome is a fast move from one technology generation to the other. The other strategy is to focus on learning-by-doing in the 1G technology. In that way progress can be made in 1G technologies but the effects on 2G technologies are uncertain. We apply a Technological Innovation System perspective to analyse the strategies followed and their effects. From the results we draw lessons of relevance for practitioners who aspire to understand and influence emerging energy technologies.

1. Introduction

Supporting the development and diffusion of sustainable energy innovations has become a dominant topic on the political agenda of many countries. However, providing this support remains a difficult task for decision makers with a need to influence the course of technological change [1–3]. A traditional method for policy makers to stimulate energy innovation trajectories is to stimulate investments in research and development (R&D), thereby supporting learning processes often labelled as learning-by-searching [4,5]. This is an effective method to improve the technological performance of pre-commercial technologies and to increase their variety. However, investments in R&D alone do not explain the outcome of technological trajectories in the energy sector. Additional efforts to promote market diffusion of new energy technologies play a crucial role, especially when it comes to translating results of R&D to changes in the energy system [4–6]. Practical experiences in the market allow for learning processes to take place that are not stimulated by R&D; these are often labelled as learning-by-doing [5]. Learning-by-doing has proved to be critical in solving technological problems and establishing cost reductions for new technologies.

It is important to find the right balance between investments in R&D and investments in technology deployment by market formation measures [6]. This idea has been well established in the evolutionary economics literature, which stresses the importance of continued interactions between the activities of basic science, technology development and market formation, in technological change processes; see Kline and Rosenberg [7] for an overview. Scholars of evolutionary economics have since long rejected the so-called linear model of R&D, which considered technological change a unidirectional process, starting with basic research, followed by applied R&D, and ending with production and diffusion; see Godin [8]. The linear model does not fit the actual complexity of technological change [7]. In reality, technological change is a non-linear development which is constituted by numerous processes. These include R&D, and also production and market formation, running in parallel, and thereby reinforcing each other through feedback mechanisms.[1] If such feedbacks are neglected, by policy makers or entrepreneurs, this is likely to result in the failure of support policies [4,7,12,13].

This balancing exercise becomes even more challenging when one realises that a technological trajectory, in many cases, does not consist of a single technology being invented, developed and

* Corresponding author. Tel.: +31 30 253 2782x1625; fax: +31 30 253 2746.
E-mail address: r.suurs@geo.uu.nl (R.A.A. Suurs).

[1] Alternative models employed within the evolutionary economics field are the chain-linked model [7] or the innovation system model [5,9–11].

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diffused in the market, but of various technologies in different development stages: technology generations. Take for example the technological trajectory of photovoltaic solar cells: here two technology generations can be discerned: thick crystalline silicon cells and thin films. New cell types like organic dye solar cells or spiral technologies might invoke even more generations. These technology generations have some commonalities with respect to the service or societal function they provide, but differ strongly in technology base, and in their (expected) distance to the market. With the existence of technology generations, energy policy is not only a matter of balancing R&D vs. market formation, but also a matter of dividing resources across multiple technological options. So far little research has been done that focuses on the effect of such technology dynamics on the outcomes of innovation trajectories.

The situation may be regarded an opportunity to combine and interlink these two processes within one technological trajectory. A critical question is then whether deployment programmes for a first generation (1G) technology may have positive effects on the development of a second generation (2G) technology. Two archetypical strands of policy making may be discerned. One strategy is to keep investing in R&D on 2G technology. The expected outcome is a fast move from one technology generation to the other. The other strategy is to focus on learning-by-doing in the 1G technology. In that way progress can be made in 1G technology but the effects on the 2G technology are uncertain. The 1G technology may pave the way, in terms of markets and infrastructures, for the 2G technology, but there is also the risk of early lock-in: 1G technology driving 2G technology out of the market before it ever stands a chance.

To increase our insight in the possible implications resulting from these strategies, this paper takes the development of biofuel technologies in the mobility sector as the topic of study. The biofuels domain offers a prime example of different technology generations competing for support. The 1G biofuels have limited performance in terms of CO_2-reduction and require much land, but they are already in a (near-) commercial stage of development [14]. Examples are biodiesel from rapeseed, ethanol from corn, sugar beets and sugar reed. The 2G biofuels are expected to perform much better in terms of costs, land use and CO_2 emissions reductions. However, they are in a pre-commercial stage of development. Examples are ethanol from lignocelluloses (woody biomass) and synthetic diesel from woody biomass, based on the Fisher–Tropsch process. See Schubert [14] for an overview.

The aim of this study is to analyse and evaluate the dynamics involved in the development of biofuel technologies and to relate these dynamics to the effect of strategies followed by policy makers and entrepreneurs with respect to 1G and 2G technologies. Based on this analysis we provide a general discussion that is also relevant when dealing with other sustainable technological trajectories.

As an analytical framework we take up a conceptual model that is firmly rooted in the evolutionary economics literature: the Technological Innovation Systems (TIS) approach [9]. The TIS is a social network, constituted by actors and institutions (rules of the game), that is constructed around a specific technology. The TIS literature stresses the fact that most emerging technologies will pass through a so-called formative stage before they are subjected to a market environment [15]. During this formative stage actors are drawn in, institutions are designed and adjusted. In short, many processes unfold that, positively or negatively, will influence technology diffusion. The build-up, or breakdown, of these processes is conceptualised as the fulfilment of a set of system functions. Examples are the emergence of Entrepreneurial Activities, Knowledge Development and Resource Mobilisation [16]; a complete overview will be given in the next section. The system functions combined foster the emerging technology. In the ideal case, the TIS will develop and expand its influence, thereby propelling the emerging technology towards a stage of market diffusion. Based on this idea, the system functions will serve as evaluation criteria. With the aid of the TIS framework we will be able to particularly pay attention to the dynamic nature of technology development.

We will analyse 17 years of biofuel innovation system dynamics. The focus on the Dutch situation has theoretical and practical reasons: (i) technology dynamics are largely country-specific [5] and (ii) the analysis requires direct access to the empirical field. The research question to be addressed is:

What strategies were followed with respect to the support of 1G and 2G biofuel technologies by decision makers in the Dutch biofuels innovation system, and how did these choices affect the development of system functions in the last 15 years?

Based on the analysis of system functions we indicate to what extent decision makers have been effective in supporting TIS development. From the results we draw lessons of relevance for scholars, policy makers and entrepreneurs who aspire to understand and influence emerging energy technologies.

The structure of the paper is as follows. In Section 2 the research design, including theory and method, is revealed. Section 3 provides the case study on the Dutch biofuels developments. In Section 4 we evaluate and discuss our results. Section 5 concludes by summarising the most important issues.

2. Research design

Our theoretical approach is based on the work by Carlsson and Stankiewicz [9], Bergek [17], Jacobsson and Bergek [15] and Hekkert et al. [16]. The method we use is derived from Abell [18] and Poole et al. [19], and thoroughly illustrated by Hekkert et al. [16], Suurs and Hekkert [20] and Negro et al. [21]. Since there is already a lot of literature on this approach, both from a theoretical and a methodical perspective, we limit ourselves to a condensed account.

2.1. Theory

The TIS approach is part of a wider theoretical school, called the Innovation Systems (IS) approach [5,9–11]. The central idea behind the IS approach is that determinants of technological change are not (only) to be found in individual firms or in R&D networks, but also in a broader social structure in which the firm as well as R&D networks are embedded. Since the 1980s, IS studies have pointed out the great influence of this social structure on technological change and economic performance within nations, sectors or technological fields. The structure of an IS consists of actors, institutions and the network of relations through which these are connected [22]. The TIS approach focuses on particularly that structure that surrounds a specific technology. We follow this idea in defining the Dutch Biofuels TIS (BIS) as the network of actors and institutions that directly support (or reject) the development and (eventually) the diffusion of biofuels, in the Netherlands.

The TIS framework matches our conceptual focus on a specific technological field. It has also proven its heuristic value for the evaluation of public and private intervention in relation to complex innovation processes [23]. However, a weakness of past innovation system studies is that they fail to address historical features in dynamic terms [16,20]. Recent TIS literature suggests that dynamics can be captured by pointing out positive (and negative) interactions between system functions [15–17,20]. These system functions are processes that foster the shaping