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Technology learning in a small open economy—The systems, modelling and exploiting the learning effect

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ABSTRACT

This paper reviews the characteristics of technology learning and discusses its application in energy system modelling in a global–local perspective. Its influence on the *national* energy system, exemplified by Norway, is investigated using a global and national Markal model. The dynamic nature of the learning system boundary and coupling between the *national* energy system and the *global* development and manufacturing system is elaborated. Some criteria important for modelling of spillover[1] are suggested. Particularly, to ensure balance in global energy demand and supply and accurately reflect alternative global pathways spillover for all technologies as well as energy carrier cost/prices should be estimated under the same global scenario. The technology composition, CO_2 emissions and system cost in Norway up to 2050 exhibit sensitivity to spillover. Moreover, spillover may reduce both CO_2 emissions and total system cost. National energy system analysis of low carbon society should therefore consider technology development paths in global policy scenarios. Without the spillover from international deployment a domestic technology relies only on endogenous national learning. However, with high but realistic learning rates offshore floating wind may become cost-efficient even if initially deployed only in Norwegian niche markets.

1. Introduction

The development of the national energy system depends on a large number of factors external to the system but strongly influencing the choice of technology and energy carriers. A taxonomy of such factors used by Wene and Rydén (1988) is: the availability of domestic energy sources, cost of imported energy carriers, development of the energy technology, environmental constraints and energy demand. The taxonomy includes global, regional and national factors. A corresponding global–local perspective is thus called for national energy planning and analysis. For example, there may be a choice between local-renewable energy and fossil energy from the global market. While the price of fossil fuel is mainly determined by the balance of regional supply and demand, the exploitation of local renewable energy requires energy conversion technologies which costs and technical performances are largely determined in the global technology markets. From the national perspective the cost reductions of the nascent energy technologies are seen as spillover of technology learning from the global technology market.

Understanding the forces of technological change and incorporating them in energy–economic–environmental (EEE) models have received increasing attention during the last decade. Different global EEE models provide a variety in their results with respect to future technology composition and total system cost, but concur that experience fosters technology learning (TL) and is an important factor affecting the cost of the transition to a sustainable energy system (Edenhofer et al., 2006). The starting point of the analysis presented is the assumption that in a small open economy spillover from the global market will in most cases be more important for the price of new energy technologies than the experience gained in the national market. However, in the very early stages of technology development learning in the national market may dominate. While TL reduces costs, national circumstances may require adaptation of a technology and thereby increase in costs. In the long run, though, it is also a source of learning and thus indirectly contributes to cost reductions. The aim of this paper is to contribute to the understanding and modelling of the effect of technological change on the *national* energy system of a small open economy. It is exemplified by Norway.

In Norway, primary energy sources are abundant, particularly wind offshore and natural gas. There is also potential for storage of CO_2 underneath the sea bed. There is thus ample potential for electricity generation with low or zero CO_2 emissions.

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[1] Spillover in this paper includes the effect of technology learning embedded in the technologies purchased in the global technology market, i.e., cost reductions and efficiency improvements resulting from accumulated global production.

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The development of the Norwegian energy system towards low emissions of CO_2 may thus follow a variety of technology paths, depending on the cost development and performance of the nascent energy technologies available in the global market. Moreover, Norway's energy resources and engineering capacity offer possibilities as a cradle for offshore floating wind power, thus influencing the technology path through TL in a national niche market.

We ask three questions: (1) How should spillover be included when modelling the energy system of a small open economy? (2) What is the potential influence of spillover on the Norwegian energy system? (3) What is the sensitivity of the *national* system to spillover and will learning in the national market give a similar result? The elucidation of the application of spillover on the *national* energy system analysis in a globalised energy technology market is novel. It contributes to the stock of knowledge on modelling TL with a focus on the national energy system.

The first part of this paper reviews the properties of TL relevant to a small open economy and discusses it in a global–local perspective. From the discussion some criteria important for the parameterization and modelling are suggested. The criteria are subsequently applied to evaluate the influence of spillover on the Norwegian energy system up to 2050. Two national cases are analysed: (1) spillover of TL dominates and the local TL is assumed negligible, and (2) a special case where learning for offshore floating wind power (OFW) is dominated by the national niche market. While the other technologies benefit from spillover, TL for OFW is modelled endogenously and thus is dependent on national deployment only. The results presented focus on the overall system performance and technology composition of electricity conversion and light duty vehicle (LDV). Finally, some conclusions are drawn and suggestions for future work are offered.

2. Theory and application

Though stochastic at the micro-level, the influence on cost from learning may be approximated by a simple mathematical relation (Argote and Epple, 1990; Wright, 1936) using a systems approach.[2] The properties of this system are the initial cost C_0, the learning parameter E, the accumulated production and the resulting cost $C(X_{cum})$, see Eq. (1. Rather than using the learning parameter E directly, a progress rate (PR) or the learning rate (LR) is used. Its relationship to E is defined In Eq. (2). A technology learning curve is a graph of cost vs. accumulated production most often presented in a log–log diagram where it becomes a straight line. The relative cost reduction or percentage is thus constant for each doubling of production and equal to the learning rate:

$$C(X_{cum}) = C_0(X_{cum})^{-E} \tag{1}$$

$$LR = 1 - PR = 1\text{-}[C_0(2X_{cum})^{-E}/C_0(X_{cum})^{-E}] = 1 - 2^{-E} \tag{2}$$

Experience and learning curves provide a quantitative measure of TL, exhibiting a continuous reduction in cost with cumulative production of the technology. While the mathematical relationship is simple, sensible use of Eq. 1 requires careful evaluation of the system boundary (Schaeffer et al., 2004).[3] The choice of system boundary defines the technology with a cost C and thus what may contribute to cost reductions through learning. Moreover, only production within the system boundary may contribute to X_{cum}. Finally, the learning parameter E will vary depending on what learning processes are included within the system boundary. Each of these issues is elaborated further in Section 2.1. Another issue important for the inclusion of learning in *national* modelling is the non-linearity of Eq. (1). This causes path dependency enhancing the coupling between the global, regional and local energy systems and is discussed in Section 2.2.

2.1. The system boundary

The system boundary of learning by using (Arrow, 1962) was confined to the increased labour productivity in a production process while the term *experience* was introduced covering all aspects influencing the cost development of an industrial product (BCG et al., 1968). BCG et al. (1968) included more elements affecting the cost reduction within the system boundary and found the system characteristic valid, i.e., Eqs. (1) and (2). The importance of experience was generally accepted and the concept used, e.g., to assist investments decisions within corporations. Utilising this concept to determine cost development for an energy technology across producers expands the system boundary further. Following the IEA terminology, this paper uses the term *technology learning* to denote all those processes within a firm, group of firms or industries that lead to cost reductions in a *specific technology*, e.g., onshore wind power, as a result of actions in a competitive market (IEA, 2000).

A study comparing experience curves with technology bottom-up assessment finds support for treating wind turbines as a *specific technology* (Neij, 2008). While there may be more technological variety within other generic conversion technologies, e.g., solar PV, Neij (2008) concludes there is reasonable support in bottom-up technology analysis treating the major types of electricity generation technologies as specific technologies. The conclusion is useful with respect to modelling TL on a global scale. However, the approach may conceal the introduction of a new technology or the specialisation of an existing one until it should be viewed as a separate specific technology. This process typically takes place within a smaller system boundary, e.g., the national energy system. For example, offshore floating wind mills may initially use a turbine developed for onshore wind mills and thus be very similar but with a floating base. Because floating wind mills demand much lighter turbines the number of common parts and construction may diverge so much that the turbine for offshore floating wind should be considered a separate specific technology with a non-overlapping technology learning system with onshore wind. In general, the system boundary may change as the number of manufacturers increases and technology deployment spreads through the global energy system, see Fig. 1. Three stylistic views of the learning system boundary are extracted and described. They are marked A, B and C in Fig. 1. In A the learning system may initially have only one manufacturer and then expand to several manufacturers within a niche market. Because the same energy source, e.g., wind is available in many locations, technology development and manufacturing may initiate in completely separate niche market(s). The spillover between the niche markets 1 and 2 is negligible and the technologies are different specific technologies. They each have their learning system with a corresponding technology learning curve as indicated by the circle in view A in Fig. 1. Several niche markets with knowledge spillover and export/import of parts may follow. This is indicated by view B. For example, wind mills manufactured in Denmark and Spain may include the same parts, e.g., the gear box. The learning system boundaries are now overlapping while the technologies may be still viewed as separate specific technologies.

[2] A system is a set of elements connected together that form a whole, which shows properties of the whole rather than the properties of the individual parts (Checkland, 1981).

[3] Page 86.