Technological Change in Service of the Environment

BY JONAS GRAFSTRÖM

Introduction

There is an increasing interest in developing, integrating and managing a growing share of intermittent renewables from solar and wind into electricity generation for both existing and new geographical areas. Studying and promoting these developing and integrating processes are highly important because human economic activity, which historically has been highly dependent on fossil fuels, is dramatically increasing the atmospheric concentrations of CO_2, exceeding 400 parts per million (ppm) compared to an historical value around 250 ppm (EPA, 2016).

It has been established that the anthropogenic emissions of greenhouse gases (GHGs) have a distinct impact on the global climate (e.g., IPCC, 2007, 2013). Although CO_2 is a normal component in our atmosphere, and has made life on earth possible in the first place, the increased concentrations may change our climate in ways that present a critical mix of dangers (e.g., changed weather patterns with increased variability, rising sea levels and droughts, etc.) (e.g., Dietz and Maddison, 2009; Suganthi and Samuel, 2012). One way to protect the global climate and limit the concentrations of CO_2 is to develop and diffuse new carbon-free or low carbon technologies, not the least in the form of renewable energy sources (Stern, 2007).

However, a large body of literature has shown that the market can fail in a substantial way when it comes to providing the socially efficient amount of resources aimed at generating technological and scientific knowledge in the environmental field (e.g., Nelson, 1959; Arrow, 1962). The uncertainties about the future returns to environmental R&D investments are particularly high, e.g., because of policy inconsistencies (Jaffe et al., 2002; Grafström 2018).

Global energy demand has risen more quickly in the past decade than ever before, and energy demand is predicted to continue to rise with economic development and population growth in the developing world (Suganthi and Samuel, 2012). It is likely, therefore, that the emissions of GHGs will also increase - even if the production of goods and services becomes less emission-intensive.

If the absolute demand for energy cannot be decreased sufficiently, then a supply-side solution offers an alternative for addressing the need for GHG mitigation. The mounting concerns of climate change, caused by mankind's accelerating use of carbon intensive energy since the Industrial Revolution, have led policy makers to highlight technological development in the renewable energy sector as a crucial and achievable remedy for the emission problem.

Following the above, the overall purpose of this paper is to briefly outlay and analyze the fundamentals of technological change in the renewable energy sector. Considering the threat of severe consequences of global warming, and policymakers' desire to focus technological change in renewable energy as one of the solutions, the contribution of this paper lays in its attempt to promote understanding of the technological change process, i.e., the drivers behind it and the possible development patterns for different countries. Such knowledge should enable policy makers to make more efficient decisions.

JONAS GRAFSTRÖM is with The Ratio Institute and Luleå University of Technology, Stockholm, Sweden. He may be reached at jonas.grafstrom@ratio.se.
This article builds on ideas from a paper that was presented at the 41st IAEE International Conference in Groningen 2018. Responsibility for any remaining errors, however, resides solely with the author.

Technological Change in Service of the Environment

This paper draws on an intellectual foundation from seminal contributions by Schumpeter (1947). In Schumpeter's work ideas around an economy's creative response to changes in external conditions were offered. Furthermore, several analytical approaches have been applied historically to analyze the process of environmental technological change, and a lot of inspiration from past works has been drawn from the extensive literature on induced innovation (primarily originating from, for instance, Hicks, 1932, and Arrow, 1962), which later has come to play an important role for the analysis of technological development in the renewable energy sector (e.g., Ruttan, 2000).

The technological change approaches have drawn from general economic thinking and been applied as tools in the empirical context of renewable energy. For example, in their pioneering work Nelson and Winter (1982) emphasized the importance for a country to develop its own technological capabilities, i.e., the ability to produce an output (e.g., patents), this to be able to be a part of further technological development. Hence, improvements of technological capability contain a broad range of efforts that are needed to access, absorb, and assimilate knowledge (e.g., Rip and Kemp, 1998; Unruh, 2000; Grafström, 2017).

Technological change in general – and in the renewable energy sector in particular – has commonly been characterized and analyzed as a process encompassing three major development stages: invention, innovation and diffusion. Empirically these stages have typically been analyzed separately from each other. Such approaches, however, come with some drawbacks (Grafström and Lindman, 2017). The implicit assumption in the traditional stylized linear model of technological change is that technologies subsequently pass from one stage to another but with limited interactions between various stages, e.g., between diffusion and further inventions and innovations. In the systemic model, though, several feedback loops are suggested and these point at interactions between the different stages (Rip and Kemp, 1998). For instance, the diffusion of new technology will lead to further improvements in the performance of the technology, i.e., through learning-by-doing, and it may also affect the rate-of-return to additional R&D efforts.

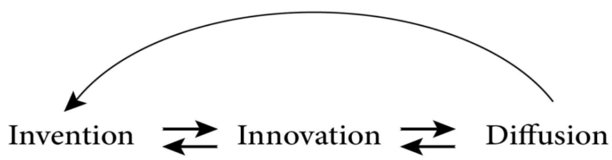

Figure 1: The integrated technological development approach.

Technological change is almost uniformly considered a necessary, although not a sufficient, condition for a transition to a sustainable energy system (Reichardt and Rogge, 2014). Since the global climate issue is transcending national borders, global solutions are required to reduce GHG emissions. Economic analyses of ways to reduce environmental harmful actions through better technologies are based on the idea that the potentially harmful consequences of economic activities on the environment constitute an externality. An externality is a significant effect of one activity, where the consequences are borne (at least to some extent) by someone other than the externality-generating actor.

Technology can affect emission levels and change the number of units of goods created with the same amount of inputs. Hence, an improved technology can either allow us to emit a smaller amount of GHGs than before without reducing our current consumption level or it can enable us to consume more with the same level of GHG emissions (Del Río, 2004). A simplistic way to show the human impact on the environment is to apply the following three-factor equation:

$$I = P + A + T \qquad (1)$$

where I represent the environmental impact variable. It is a product of P, the population, A, the wealth (often proxied by GDP per capita) and T, the technology used in production. A decrease in T would indicate a gain in efficiency making the impact on I less profound. Hence, if the production technology becomes less polluting we can either have more people, P, consuming a good without an increased environmental degradation or the same amount of people can have a higher wealth, A, without any change in the overall environmental impacts.

In the context of equation (1) it is useful to consider two facts. First, the current population (P) of the world is estimated to be 7.5 billion (in 2017) and it is expected to reach 9 billion by the year 2038 (United Nations Department of Economic and Social Affairs, 2017). Second, the global wealth (A) is expected to rise; the GDP of the world is, according to the World Bank (2016), expected to grow by about 2.7 percent in 2017, and most of authoritative projections suggest continued global economic growth during the coming decades. Considering these two facts together, the aggregate environmental impacts are likely to be significant unless technological change can help reduce them.

Technological change in the renewable energy sector is developing fast. Figure 2 displays the development of total renewable energy patent applications in 13 EU Member States by country (the number of granted patents are lower). It shows that Germany and Denmark are the two countries with the most significant patent outputs. Moreover, the number of patent applications filed for renewable energy technology at the European Patent Office (EPO) has increased by more than 20 percent annually in recent years (as a reference, the average annual increase for all patent applications was around 6 percent EPO, 2016).

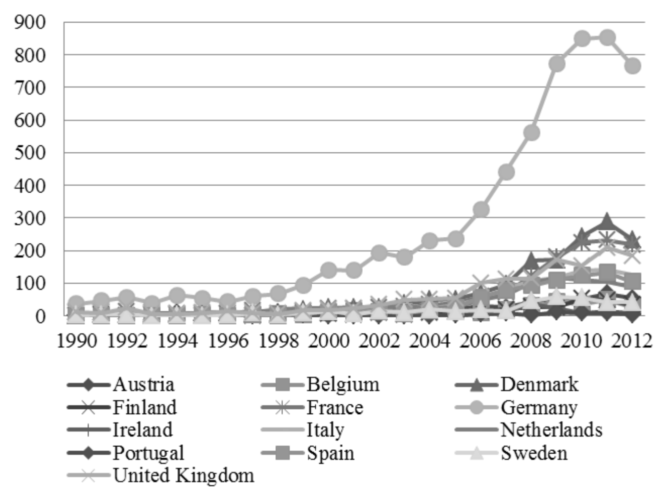

Figure 2: Total number of renewable energy patent applications in 13 EU Member States by country, 1990-2012. Source: OECD (2014).

Figure 3 displays the number of renewable energy patent applications in the same 13 Member States by technology. During the last ten years there has been a fast growth in wind and solar energy inventions while the other renewable energy sources also seem to have gained some momentum during the last decade.

Still, while renewable energy technologies have developed over time and improved their performance in terms of lower generation costs, this does not automatically imply that these technologies will be adopted in all countries (Grafström, 2017). One reason for this may be that countries with little of their own development activities find it difficult (or costly) to

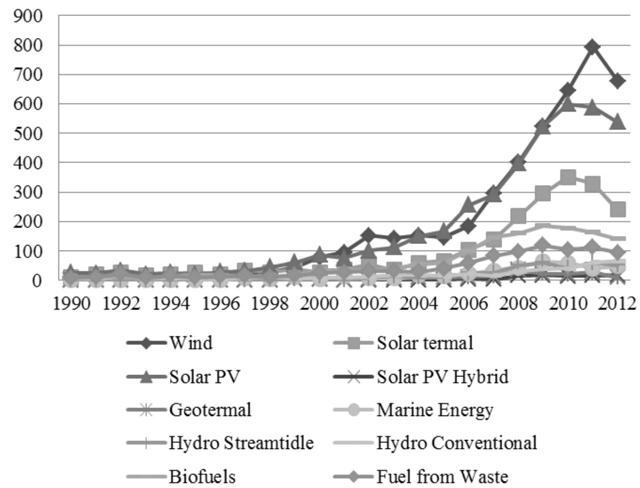

Figure 3: Renewable energy patent applications in 13 Member States by technology, 1990-2012. Source: OECD (2014).

make use – and implement – the knowledge generated in the leading countries.

In general, the speed of innovation will be higher if more countries are engaged in R&D (Nelson and Phelps, 1966; Baumol, 2002; Stöllinger, 2013). The same holds for the renewable energy sector (e.g., Costantini and Crespi, 2013; Costantini et al., 2015). The speed of innovation is of essence given the urgency of addressing the accumulation of GHGs in the atmosphere (GHGs accumulate over time and will stay for a long time). Hence, there exists a value in developing low-cost carbon-free technologies relatively quickly.

Concluding Remarks

This paper deals with the economics of renewable energy and technological change. The contribution of the paper lays in its attempts to provide a deeper understanding of technological change in the renewable energy sector, the drivers behind technological change and the development patterns that single countries will choose. Such knowledge enables policy makers (e.g., at the EU level) to make better and more informed decisions, e.g., on how to encourage an efficient and fair allocation of public R&D efforts across countries.

A major lesson is in line with Kirzner's (1985) observation; if one only looks at a specific part of the technological change chain one might miss "light-bulb-moments" that could have made a significant difference. It is perfectly fine to study the different steps (invention, innovation and diffusion) separately, but there is interconnection between different stages in technological development that policy makers need to be aware of. An increase in the diffusion rate may, for example, affect invention and innovation rates. At the same time, too little effort in terms of one of the development stages might lead to reduced effects of policies that are designed to influence the other stages.

Hence, technological development should be viewed as a system of interdependent parts. Policies aimed at reducing GHG emissions or increasing the share of renewable energy sources, may have limited effect at some stages at the technological development process, but could have important effects on other stages. Depending on what effects a policy maker wants, it is important for him/her to know where the effect will be and consider that there might be positive and negative unintended consequences. Thus, an important lesson for policy makers is that when designing policies in the renewable energy technology field, one must consider how different policy instruments interact since they can affect different parts of the technological change process.

Naturally, since this paper only attempts to provide answers to questions concerning a limited part of the entire technological development process, the field for future research should be wide. If we want to predict and understand how the new renewable energy technologies develop over time and what policy makers can do to stimulate this development, it is essential to continue to improve our understanding of the subject.

References

Arrow, K. J. (1962). "The Economic Implications of Learning by Doing", *The Review of Economic Studies*, Vol. 29 (3), 155–173.

Barro, R. J. (2015). "Convergence and Modernization", *The Economic Journal*, Vol. 125 (June): 911–942.

Costantini, V., F. Crespi, C. Martini, and L. Pennacchio, (2015). "Demand-Pull and Technology-Push Public Support for Eco-Innovation: The Case of the Biofuels Sector", *Research Policy*, Vol. 44 (3): 577-595.

Costantini, V., and F. Crespi (2013). "Public Policies for a Sustainable Energy Sector: Regulation, Diversity and Fostering of Innovation", *Journal of Evolutionary Economics*, Vol. 23 (2): 401-429.

Del Río, P. (2004.) Public policy and clean technology promotion. The synergy between environmental economics and evolutionary economics of technological change. *International Journal of Sustainable Development*, Vol. 7 (2): 200–216.

Dietz, S., and D. S. Maddison (2009). "New Frontiers in the Economics of Climate Change", *Environmental Research Economics*, Vol. (43): 295–306.

EPA (2016). https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases.

EPO (2016). European Patent Office receives record number of patent filings. https://www.epo.org/news-issues/news/2015/20150226.html

Grafström, J., and Å. Lindman. 2017. "Invention, Innovation and Diffusion in the European Wind Power Sector." *Technological Forecasting and Social Change,* 114: 179–191.

Grafström, J. 2017. "International Knowledge Spillovers in the Wind Power Industry: Evidence from the European Union." *Economics of Innovation and New Technology*, 1-20.

Grafström, J. (2018). Divergence of renewable energy invention efforts in Europe: an econometric analysis based on patent counts. *Environmental Economics and Policy Studies*, 1-31.

Hicks, J. R. (1932). *The Theory of Wages*. Macmillan, London.

Intergovernmental Panel on Climate Change (IPCC) (2007). *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment*, Report of the Inter- governmental Panel on

Climate Change, Geneva.

Intergovernmental Panel on Climate Change (IPCC) (2013). *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment*, Report of the Inter-governmental Panel on Climate Change, Geneva.

Jaffe, A. B., R. G. Newell, and R. N. Stavins (2002). "Environmental Policy and Technological Change", *Environmental & Resource Economics,* 22: 41–69.

Kirzner, I. M. (1985). Discovery and the capitalist process. University of Chicago Press, Chicago.

Nelson, R. (1959). "The Simple Economics of Basic Scientific Research", *Journal of Political Economy*. 67, 297–306.

Nelson, R., and Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA: Harvard University Press.

OECD.Stat (2014) data extracted on 20 May 2014 13:23 UTC (GMT) from OECD.Stat.

Rip, A., and Kemp, R. (1998). Technological change. In: Rayner, S., and Malone, E. (Eds.). *Human Choice and Climate Change. An International Assessment, vol. 2*. Batelle Press, Washington.

Reichardt, K., and Rogge, K. (2014). How the policy mix and its consistency impact innovation. Findings from company case studies on offshore wind in Germany. *Working Paper Sustainability and Innovation No. S7/2014*. Fraunhofer-Institut für System- und Innovationsforschung (ISI), Karlsruhe.

Ruttan, V. (2002). Sources of technical change: induced innovation, evolutionary theory and path dependence. In: Grubler, A., Nakicenovic, N., Nordhaus,W. (Eds.), *Technological Change and the Environment*. Resources for the Future Press,Washington, DC.

Suganthi, L., and A. Samuel (2012). "Energy Models for Demand Forecasting: A Review", *Renewable and Sustainable Energy Reviews*, Vol. 16 (2): 1223–1240.

Schumpeter, J. A. (1947). "The Creative Responses in Economic History", *Journal of Economic History*, Vol. 7 (2): 149–159.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge University Press, New York.

Stöllinger, R. (2013). "International Spillovers in a World of Technology Clubs", *Structural Change and Economic Dynamics*, Vol. 27, December 2013, pp.19-35.

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, Vol. 28:817–830.

United Nations Department of Economic and Social Affairs, 2015 revised, (2015). http://www.un.org/en/development/desa/news/population/2015-report.html

World Bank (2016). http://www.worldbank.org/en/publication/global-economic-prospects (accessed 2017 02 06).

Chen-Hao Tsai et al: *Renewable Integration Impact Assessment: The MISO Experience.* Continued from page 36

results of frequency response for loss of a 1,120 MW generator in MISO. Key system performance indices are found to be within the acceptable criterion.

Conclusion and Next Steps

Though still ongoing, the RIIA study has thus far been successful in meeting our goal to enhance better understanding on the impacts of renewable energy growth in MISO over the long term. The technically rigorous analysis hasprovided concrete examples of potential integration issues and has explored possible mitigation solutions. The assessment is giving MISO and our stakeholers specific areas on which to focus our efforts, including: the potential changes in MISO's loss of load risk profile; expansion of transmission and non-transmission-alternatives; and the need for operational flexibility. Finally, given the expected changes to the footprint's resource-mix, the assessment has offered an important forum through which MISO and our various stakeholders are discussing the future composition, structure, and operation of the grid.

Footnotes

1 Projects with active generation interconnection status as of Q2, 2018.

2 Per NERC Standard BAL-502-RF-03, the Resource Adequacy analysis shall "[C]alculate a planning reserve margin that will result in the sum of the probabilities for loss of Load for the integrated peak hour for all days of each planning year analyzed being equal to 0.1." This is comparable to a "one day in 10 year" criterion.

3 Heath, B. and Figueroa-Acevedo, A. L., "Potential Contribution of Wind and Solar Generation in MISO System," in IEEE International Conference on Probabilistic Methods Applied to Power Systems, Boise, ID, 2018.