DOI: 10.1515/ijme-2016-0014

International Journal of Management and Economics
No. 50, April–June 2016, pp. 100–112; http://www.sgh.waw.pl/ijme/

Honorata Nyga-Łukaszewska[1]
Institute of International Economics, Warsaw School of Economics, Poland

Selected Issues in Innovation in the Energy Industry. The Case of Poland

Abstract

Innovation determines the competitiveness of companies and countries. Innovative products and processes have revolutionized the world economy, and are particularly important in the energy industry. Demand for energy innovation originates from resource scarcity, a surge in energy consumption and stringent environmental regulations. The objective of this paper is to examine the application of selected energy-related innovations in Poland. The analysis is based on the database of the Organization for Economic Cooperation and Development (OECD). Our analysis covers the period 2009–2014, as extended by limited data availability. From it, we conclude that Poland performed well in selected energy-related innovations. This study extends knowledge concerning the link between energy efficiency/renewables and innovation.

Keywords: energy industry innovativeness, R&D in the energy industry
JEL: Q40, O32

Introduction

Contemporary social sciences devote much attention to innovation, which are critical for every nation regardless of geographical location or GDP. Countries seek innovation in all economic sectors/industries in the hope of gaining an edge over competitors.

In 2008, the energy industry accounted for nearly 10% of global revenue, and would approach 40% if industries that heavily rely on energy (e.g., transportation, logistics, construction, IT services, mechanical and plant engineering) were included [McKinsey& Company, 2008]. This significant share of energy and energy-related industries in global revenue underlines the fact that innovation in those activities impacts economic welfare.

The paper is organized as follows: part one introduces the innovation concept; part two elaborates on innovation theory in the energy industry, and part three quantitatively assesses selected innovations in the energy industry. The paper then presents conclusions suggested by the aforementioned analysis.

The Innovation Concept

Most works on the role of innovation in the economy present either an economics or management perspective. The former is based Schumpeter's work, and the latter on Kotler or Drucker. Schumpeter (Schumpeter, 1934), sometimes called a "prophet of innovation" [McCraw, 2007], distinguishes between five innovation types: introducing a new product; implementing a new production method; entering a new market; introducing a new way to sell products or buy raw materials; and implementing a new organizational structure. The Schumpeterian approach focuses on innovation as a response to problems of economic activity [Frankowski, Kubiak, 2012]. Schumpeter's concept echoes in the nomenclature of innovation prepared jointly by the OECD and Eurostat. Both organizations [the OECD and Eurostat, 2005] distinguish product, process, marketing, and organizational innovation.

A different line of reasoning is represented by Kotler or Drucker. The former, whose focus is product innovation, describes differences in their "innovative" nature. Kotler [1994] states that a new product might create a new market; represent a new line of goods, supplement existing product lines, embody upgraded characteristics, be repositioned, and reduce costs while meeting the same customer needs.

Drucker's taxonomy differentiates innovation on the basis of impact [Drucker, 2015]. In distinguishing incremental, additive, complementary and radical (breakthrough) innovation, Drucker combines Schumpeter and Kotler's approaches. Drucker's work pertains not only to product itself, but also to production and organizational processes.

The concept of breakthrough innovation resembles the so called "disruptive technology" coined in the late-nineties by Christensen [1997], which was initially criticized by business and academia [European Commission, 2012, pp. 26–32] but is now widely recognized, with its constraints[2] by the OECD and Eurostat [OECD and Eurostat, 2005].

Innovation can be also perceived as a process. Rotwell [1994] distinguishes five innovation models, by generation. The first group includes technology push models, which were popular from just after World War II up to mid-1960 s. This approach stemmed from the then favorable societal attitudes towards scientific advances and industrial innovation. In the mid-1960 s, companies began shifting towards demand-oriented innovation processes driven by market needs and, during the next decade (mid-1960 s-mid-1970 s), technology pull (or need) models gained importance. The oil crisis and resource constraints in the 1970 s proved, that push and pull models of innovations were extreme and atypical. Consequently new innovation processes were predicated on a stronger interaction between technological capabilities and market needs. This attitude led to the so called "coupling model of innovation". The emergence of Japan as an economic superpower in the mid-1980 s marked the fourth generation of innovation models, often called parallel/integrated models. This model assumed, on one hand, supplier integration into new product development and, on the other, the simultaneous work of different company departments on product development. At the end of the XX^{th} century the fifth generation of innovation emerged, during which entrepreneurs shifted from their innovation focus from a company-inside to a company-outside approach. In contrast to the fourth generation model, a company's ability to innovate was de-emphasized, in favor of the company's networking capacity and inclusion of customer feedback in the innovation process. This approach has continued to present.

Innovations in the Energy Industry

Innovation in the energy industry is part of the broader industrial innovation concept. Mesoeconomic analysis focuses on the innovation connected with an industry branch (sector) or region. According to Malerba "*The agents composing the sectoral system are individuals and organizations. These organizations may be firms (such as users, producers and input suppliers) and non-firm organizations (such as universities, financial institutions, government agencies and so on), as well as organizations at lower or higher levels of aggregation (such as consumers, R-D departments or industry associations)*" [1999, p. 4]. Agents may cooperate or compete in product development. Once cooperation within the industry focuses on technological assistance, agents (mainly companies) share infrastructure, knowledge and competencies [Carlsson, Stankiewicz, 1991]. According to Przychodzien [2015], one of the most comprehensive innovation notions in the sectoral system is the "Large Technical Systems" idea described by Hughes in 1980's. Sectoral system innovations include: artefacts (e.g. transmission lines); organizations (e.g. investment banks); natural resources (e.g. coalmine); university teaching/research programs; and regulatory law [Hughes, 2012]. With mesoeonomic level analysis comes cluster examination. Poland offers a prime example of energy clusters in the Silesia region (Śląski Klaster Czystych Technologii Węglowych).

In industrial innovation a key component is technology driven innovation. Freeman and Soete [1997], specializing in the economics of industrial innovation, devote much attention to analyzing oil sector innovations in the XX^{th} century. Energy technology innovation systems [Grubler, 1998] are a recent topic described through a Schumpeterian approach. Sagar considers energy technology innovation as "*research and development of emerging alternative energy technology as well as the improvement of existing energy technology*" [cited by Guo et al., 2016, p. 2]. He classifies energy technology innovation using four categories: innovation policy; innovation input; innovation process; and innovation organization. Sagar confirmed the results reached by Gallagher [ibidem] that energy technology innovation is a process reflected in market share and other factors related to new energy technology diffusion. This process starts with technological invention and ends with technological diffusion. Lefevre [1984] argues that innovation diffusion in the energy industry refers to demonstration projects that play a vital role in energy innovation commercialization process.

Investigating the theoretical underpinnings of the energy technology innovations requires additional clarification regarding the dual nature of energy technology innovations. As Margolis highlights [ibidem, p. 2], energy technology innovation is bidirectional because energy is both a determinant and a subject of the innovation process. In this first role, energy technology innovation appeared in the works of Hicks [1932] as "induced innovation," which Hicks claimed occurs from changes in the prices of production factors. This approach is followed in studies by Popp [2001], Doms and Dunne [1995] and Pizer et al. [2002], who assess the impact of increases energy prices on innovation and technology choices. Energy technology innovation steps are more often analyzed as a part of the innovation process that take different forms then, for instance, energy efficiency [Cagno, Ramirez-Portilla, Trianni, 2015] or, more generally, disruptive innovation [Govindarajan, Kopalle, 2006].

TABLE 1. McKinsey 10 "disruptive energy technologies"

McKinsey 10 "disruptive energy technologies"	
Unconventional gas	Market impact visible in 2015
Electric vehicles	
Advanced fuel efficiency standards,	
LED lighting	
Solar photovoltaics	
Biofuels and electrofuels	Market impact visible in 2020
Clean coal	
Digital power conversions	
Compressor-less air-conditioning with electrochromic windows	
Grid-scale energy storage	

Source: Own elaboration based on McKinsey, 2012.

In 2012 McKinsey [McKinsey, 2012] identified 10 "disruptive energy technologies" with great innovative potential. They were divided into technologies with market impact visible in either 2015 or 2020. The former included: unconventional gas, electric vehicles, advanced fuel efficiency standards, LED lighting and solar photovoltaics and we can now see that all of them impacted global markets. LED bulbs, solar panels for individual customers, further constraints on fuel efficiency and shale gas fever – have become a reality (though the prospects of expensive electric vehicles remain unclear). In the second group are: biofuel and electrofuels, clean coal, digital power conversions, compressor-less air-conditioning with electrochromic windows and grid-scale storage. However, their market impact is too preliminary to justify assumed market influence.

One of the most visible innovation inputs in the energy sector is R&D activity, which costs less in this sector as compared to the industries. The reasons why include the large scale of innovation projects, a strong preference for incremental innovations and the continued dominance of existing technologies [Costa Campi, 2015]. Effects of R&D activities in the energy sector have had great intensity, both negative and positive. On one hand, R&D activities are connected with greater market failures (such as indivisibility and uncertainty) [Jamasb, Pollitt, 2008] relative to other sectors. On the other, they generate great positive externalities [Costa Campi, 2015]. The role of R&D activities in the energy sector is also discussed in the context of liberalization. Among others, such researchers as Jamasb and Pollitt [2008], Markard and Truffer [2006] have looked at how the liberalization process affects R&D activities in the energy sector.

Within energy technology innovation is the discrete subtopic of eco-innovations. This issue gained much attention as it focuses on links between energy and environment. Definitions of eco-innovations are always founded on technological aspects. More broadly, they also refer to how a company is managed, the type of products/services developed, or how they are marketed and distributed. Przychodzien [2015]. Among eco-innovations we can distinguish eco-innovative products and eco-innovative processes. Eco-innovative products result from market and customer expectations, while eco-innovative processes are response to changes in a regulatory framework [ibidem].

Eco-innovations in the energy sector seek to reduce negative industry impact on the ecosystem. Generally, these innovation efforts stem from greenhouse gas (GHG) mitigation efforts, increased energy-prices and energy resources scarcity. The International Energy Agency (IEA) puts energy innovation at the heart of meeting climate change mitigation goals. IEA [IEA, 2015] believes that global decarbonization is possible only through incremental, radical innovation in the energy industry.

TABLE 2. Examples of eco-innovations in the energy sector

Eco-innovations in the energy sector	
Energy efficiency	Demand side measures
Energy demand reduction (e.g. energy-saving bulbs)	
Re-using lost energy (e.g. cogeneration)	
Renewable/alternative energy sources	Supply side measures
Clean fossil fuels (e.g. clean coal)	

Source: own elaboration based on Przychodzien, 2015.

Eco-innovations can be divided into two groups. Demand-side measures reduce energy use and supply-side measures increase the quantity of energy supply. In this paper, an example of each type eco-innovations will be described.

A key eco-innovation on the demand-side is energy efficiency, which is gradually growing in importance due to supply constraints and volatile energy prices. Among the first works on energy efficiency and innovation were those of Lutzenhiser [1994] and Geels [2002]. Most of the literature devoted to innovation and energy efficiency tests the relationship between these two phenomena. For instance, Cagno, Ramirez-Portilla and Trianni [2015], using a multiple case study of 30 Northern Italy foundries, examined the relationship between innovation and energy efficiency[3], finding that more innovative firms are more energy efficient. Costa-Campi, García-Quevedo and Segarra [2015], sampling Spanish manufacturing firms, (surprisingly) proved that energy efficiency innovations were not a direct effect of R&D activities. Using panel data from the Community Innovation Survey for the period 2008–2011, these scholars discovered that the decision to introduce energy efficiency innovations in Spain's manufacturing industry was instead determined by company size and profile, investments in tangible assets such as machinery, export orientation and organizational innovations. McMichael and Shipworth [2013] investigated the role of social networks in energy efficiency in UK between 2007 and 2009, conducting a case study of three British communities, and finding that mobilization of social capital could promote energy efficiency innovation. In that study, some respondents introduced energy efficiency innovations more eagerly after talking to people they knew instead of relying on conventional campaign information. Similar research on energy efficiency determinants conducted by Hrovatin, Dolsak and Zoric [2016] at the company level (using 848 Slovenian manufacturing firms during the 2005–2001 period) applied probit and bivariate probit models on a panel data set to prove that Slovenian firms behavior pattern followed the Hicks approach [1932], i.e., high energy costs induced energy efficiency innovations.

One of the most important supply-side eco-innovation measures are renewable energy sources (RES) [Przychodzien, 2015]. Introducing RES into the primary energy balance became necessity for many countries. Irandoust [2016] tested the relation between technological innovation and renewables in four Nordic countries (Sweden, Finland, Denmark and Norway) during the period 1975–2012. He discovered unidirectional Granger causality running from technological innovation to renewable energy. But according to the literature, the source of innovation in the renewables' sector is ambiguous. Rexhauser and Loschel [2015] claim that studies confirming the regulation-driven nature of innovation in renewables are scarce. However, Johnstone, Hascic and Popp [2010] argue, that regulation, not prices, drive renewable innovations. This line of reasoning supports work by Huang et.al. [2012], who analyzed China's energy policy through 2008, showing that national science and technology programs were the main source of innovations and R&D funding in the Chinese RES industry. Even though public funding in RES was meager (when compared to total domestic R&D), it crowded out private R&D investments in renewable in China. Dalton and Gallachoir [2010] go further, claiming that government policies not only support innovation in the renewables industry but are a primary determinant of the RES industry's creation. Using Irish and Danish energy policies, the authors conclude that without prudent government policy successful wind energy industry in Denmark would have never been established. The role of government policies in RES innovation has also been investigated on the company level. Noailly and Smeets [2015] analyzed 5,471 European electricity sector firms during the 1978–2006 period. Using heterogeneous (in terms of size) companies, the authors tested differences between investments in renewables and fossil fuel technologies. Their analysis indicated that in the case of small companies, innovation in renewables can be supported in the long-run only by specific policies. On the contrary, Przychodzien [2015] finds, that introducing innovations in the German renewables industry required no technological, market or social support. However, German society is one of the most environmentally-conscious in the world, which may explain why no additional stimulus was needed in this respect. In the long-term more stringent climate policy goals will intensify supply side eco-innovations [ibidem].

Innovations in the Energy Industry in Poland

Measuring innovation relies on different indicators. In the 1950 s and 60 s outlays on education or R&D[4] and the number of the research personnel were pivotal. In the 1970 s and 80 s attention shifted towards the number of patents, scientific publications, new products and processes (or even to trade volume in high-tech goods). In the late XXth century innovations were captured by surveys that permit innovation rankings later used for international comparison [Rószkiewicz, 2015].

No single measure fully captures innovations in the energy industry. There are several different measures showing innovation input, output and outcome. One energy-input metric is R&D outlays on energy related activities. Output measures include technologies that result from research and development, such as energy efficiency or RES. The metric depicting innovation outcomes in the energy industry includes energy intensity measures – often given in relation to GDP [Global Energy Assessment, 2012].

In this section, we will depict energy innovations in Poland in the broader perspective of eco-innovations and on the basis of R&D outlays in the energy industry in Poland (innovation input) and two of the aforementioned energy-related innovations: RES and energy efficiency (innovation output).

According to the Eco-innovation Scoreboard, Poland's performance was weak in 2013, ranking second to last in the EU. The country scored in the Eco-innovation index 42, while EU-28 was on average more than twice as high (100). This negative trend had remained stable for Poland since the first report's release in 2010, and Poland's weak performance stemmed from poor overall resource- and energy-management. Energy-related issues included low energy- and carbon-efficiency were driven by heavy reliance on coal-fired electricity generation (Eco-innovation Observatory).

A survey conducted in 2013 on eco-innovations in Poland showed that energy innovations accounted for the majority of eco-innovations in Poland. There, eco-innovation suppliers primarily sold renewable energy technologies (biomass, bio-fuels, biogas and PVs), energy saving technologies in manufacturing and energy efficient construction capabilities. On the demand side, eco-innovation buyers in Poland sought such energy innovations as renewable energy technologies (PVs, solar collectors and heat pumps), energy saving technologies in manufacturing, energy technologies in construction and energy storage. There were private (53) and state-owned (2) companies, R&D units (34) and municipalities (10) [Miedzinski, 2013] responding to the study.

R&D expenditures in the energy industry serve as a proxy for innovation in this particular industry. OECD data includes in the energy budget R&D on production, storage, transport, distribution and rational use of energy (excluding prospecting and propulsion R&D) [OECD, 2015]. Poland, with its R&D energy budget accounting for 8% of the total R&D expenditures in the economy, ranked above the OECD (6%) and EU-28 (7%) average in 2014 [OECD, 2015]. This contrasts favorably with Poland's relatively low R&D budgets overall (2014 – ca. 0.9% GDP, EU-28 average: 2%) [Foy, 2015].

TABLE 3. Total R&D expenditures in Poland for energy-related activities between 2009–2014 in million USD (2014 prices and PPP)

Total R&D in million USD (2014 prices and PPP)						
Time	2009	2010	2011	2012	2013	2014
Total budget	219.5	305.5	350.2	232.6	243.4	218.9
Other cross-cutting research	1.6	2.2	2.1	2.6	2.4	3.2
Hydrogen and fuel cells	6.3	4.3	13.8	13.0	13.2	5.7
All fossil fuels	43.5	74.2	96.6	56.4	102.4	68.3
Oil and gas	10.6	26.4	11.0	8.9	31.8	32.7
Coal	28.1	40.5	71.1	45.5	40.3	17.4
Nuclear	6.2	11.0	13.1	15.6	14.6	8.8
Energy efficiency	82.3	118.7	113.3	77.5	53.5	47.8
RES	52.8	53.5	63.0	35.8	27.1	47.1

Notes:
Data range stems from the OECD database availability.
Numbers do not add up to the total R&D budget as they omit a category pertaining to power storage.
Source: own elaboration based on the OECD database.

Since Poland is a coal-abundant country most implemented, ongoing and planned R&D projects focus primarily on cleaner fossil fuels. Breaking fossil fuels category into subcategories yields surprising results. Hydrocarbons – not coal – attracted the most R&D attention in the respective period. In 2014 other beneficiaries of energy R&D in Poland were energy efficiency and RES. Those three categories, namely fossil fuels, RES and energy efficiency, with different intensities between 2009 and 2014, contributed most to the overall energy R&D budget. This composition of the energy-R&D budget led the IEA in 2011 to call for greater diversification of the portfolio of R&D projects in Poland [IEA, 2011]. A similar R&D structure was also found across the world in 2008 [Global Energy Assessment, 2012], with the exception of nuclear energy, which in 2008 attracted the greatest volumes of R&D worldwide (and is still in the introductory stage in Poland). All energy-related R&D activities in Poland between 2009 and 2014 were financed from public spending. The main funding sources for energy R&D and demonstration projects included the national budget, EU funds, and the National Fund for Environmental Protection and Water Management [IEA, 2011].

TABLE 4. Selected renewable production/use and energy intensity indicators for Poland in 2003–2013

Time	Share of renewables in electricity production (%)	Share of renewables in TPES (%)	Total production of renewables (Mtoe)	Energy intensity (TPES/GDP) (toe / thousand 2005 USD)
2003	1	5	4.15	0.32
2004	2	5	4.32	0.31
2005	2	5	4.55	0.30
2006	3	5	4.76	0.30
2007	3	5	4.85	0.28
2008	4	6	5.40	0.27
2009	6	7	6.03	0.25
2010	7	7	6.86	0.26
2011	8	8	7.45	0.25
2012	10	9	8.48	0.24
2013	10	9	8.51	0.23

Notes:
TPES – Total Primary Energy Supply
Mtoe – Million Tons of Oil Equivalent
Toe – Tons of Oil Equivalent
Source: own elaboration based on the IEA database.

Energy-related innovations, like the energy R&D budget, present an optimistic landscape of Polish energy management. Renewables' production and use, demonstrated on the basis of their absolute production and share in electricity production/total primary energy supply, prove that their role is gradually rising. Between 2003 and 2013 production of renewables in Poland and their share in total primary energy supply doubled. Even better performance was observed in the case of renewable-based electricity generation, which increased tenfold during that period, driven by changes in regulations. A similar positive trend was observed in energy efficiency. As the OECD explained [OECD, 2014], energy efficiency is often measured by energy intensity and presented as the relationship of the total primary energy supply to the GDP. The lower the achieved energy-intensity result, the better performance the country exhibits. Again, Poland improved its energy intensity between 2003 and 2013, and changes were as intensive as with renewables. Worth mentioning is the fact, that with the economic transition of 1990 s, Poland had already exhausted the easiest ways of improving energy efficiency, such as reducing obsolete energy-intensive industries. Therefore, energy efficiency changes after the 1990 s, required greater engagement from industry and have been more difficult to achieve.

Conclusions

Theoretical analysis of innovation in the energy sector leads to the following conclusions. Firstly, energy is both the determinant and subject of the innovation process in the economy. Energy prices can induce innovative solutions and, at the same time, energy can be subjected to various forms of innovation. Additionally, many energy-related innovations follow the theoretical concept of "disruptive innovations". Secondly, energy industry innovations in large part constitute eco-innovations. The reason for that is a close relationship between energy use and environmental protection. A primary goal of energy-related innovation is to develop solutions that reduce external costs associated with energy use. Thirdly, aforementioned solutions depending on their influence on the energy market, can be divided into two groups – measures affecting demand and the supply side of energy management. Fourthly, energy-related innovations (especially in energy efficiency) follow the idea of the fifth-generation innovation models, in which social mobilization plays role.

Empirical analysis of energy-related innovation suggests that for both types of measures, Poland performed well in the analyzed period. Between 2003 and 2013, the country increased renewable use and energy efficiency. Origins of those changes included, respectively, conducive regulatory and market conditions. Energy efficiency and RES were also among the top three recipients of public R&D between 2009 and 2014. The greatest R&D support for fossil fuels reflects energy security concerns. It is clear, that the search for cleaner coal and quest for a reduced reliance on hydrocarbon imports stipulate the composition of the energy-R&D budgets.

Theoretical and empirical study results (referring to RES) bring similar conclusions as the work of Huang et al. [2012]. First, in both of the analyzed countries, the source of RES innovation constituted public R&D spending. Second, countries performed well in RES deployment. One reason behind the convergence in those cases may be similar energy-resource endowment situations, which are driving energy policy priorities.

This paper examined only selected energy-related innovations in Poland. A comprehensive theoretical analysis of the other innovations (e.g. energy demand reduction and re-using lost energy) would be an interesting next research step. A valuable empirical contribution may also be to test the conclusions of Huang et al. [2012] for Poland in an expanded statistical analysis.

Notes

[1] Author's e-mail address: hlukas@sgh.waw.pl.

[2] OECD and Eurostat recognize that might it not be apparent whether an innovation is disruptive until it has been introduced. That generates problems of data collection and, in turn, the phenomenon identification.

[3] Firms' innovativeness is measured by internal R&D and Open Innovation practices. Whereas energy efficiency is measured by energy consumption, the level of adoption of energy-efficient technologies and barriers to energy efficiency. The results show that those foundries combining internal R&D with inbound innovation practices can expect a higher level of energy efficiency, a higher level of adoption of available technologies, and a lower perception of barriers to efficiency improvements [Cagno, Ramirez-Portilla and Trianni, 2015].

[4] Sometimes R&D is given as the relation of R&D to GDP.

References

Cagno, E., Ramirez-Portilla A., Trianni, A. (2015), Linking energy efficiency and innovation practices: Empirical evidence from the foundry sector, *Energy Policy*, Vol. 83, pp. 240–256.

Carlsson, B., Stankiewicz, R. (1991), On the nature, function and composition of technological systems, *Journal of Evolutionary Economics*, Vol. 1, pp. 99–118.

Costa-Campi, M., García-Quevedo, J., Segarra, A. (2015), Energy efficiency determinants: An empirical analysis of Spanish innovative firms, *Energy Policy*, Vol. 83, pp. 229–239.

Costa Campi, M. (2015), Challenges for R&D and innovation in energy, *Energy Policy*, Vol. 83, pp. 193–196.

Christensen, M. (1997), *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Dalton, G., Gallachoir, B. (2010), Building a wave energy policy focusing on innovation, manufacturing and deployment, *Energy Review*, Vol. 14, pp. 2339–2358.

Doms, E., Dunne, T. (1995), *Energy intensity, electricity consumption, and advanced manufacturing technology usage, Technological Forecasting and Social Change*, Vol. 49(3), pp. 297–310.

Drucker, P. (1992), *Innowacje i przedsiębiorczość. Praktyka i zasady,* PWE, Warszawa.

Drucker, P. (2015), *Innovation and Entrepreneurship*. *Practice and principles*, Routledge, New York.

Eco-innovation Observatory, available at http://www.eco-innovation.eu/index.php?option=com_content&view=article&id=481&Itemid=69, accessed: May 27, 2016.

European Commission (2012), *Disruptive Innovation: Implications for Competitiveness and Innovation Policy.* INNO-Grips Policy Brief No.4, prepared by empirica GmbH for DG Enterprise and Industry, as part of the INNO-Grips project. Bonn/Brussels.

Frankowski, P., Skubiak, B. (2012), *Innowacyjność w teorii ekonomii i praktyce gospodarczej*, Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania, No. 30, Wydawnictwo Naukowe Uniwersytetu Szczecińskiego, pp. 271–283.

Freeman, C., Soete, L. (1997), The Rise of Science-related technology, in: C. Freeman, L. Soete, (eds.), *The Economics of Industrial Innovation*, Routledge, Reprint 2005, pp. 85–106.

Foy, H. (2015), Polish companies warned about R&D neglect, *Financial Times*, 23 March 2015, available at http://www.ft.com/cms/s/0/6e3eeda2-c8b4-11e4-8617-00144feab7de.html#axzz49t4DZo1b, accessed: May 27, 2016.

Geels, W. (2002), Technological transitions as evolutionary reconfiguration processes: a multilevel perspective and a case-study, *Research Policy*, Vol. 31, pp. 1257–1274.

Global Energy Assessment (2012), *Towards Sustainable Future,* Cambridge University Press.

Govindarajan, V., Kopalle, P. (2006), Disruptiveness of Innovations: Measurement and an Assessment of Reliability and Validity, *Strategic Management Journal*, Vol. 27, No. 2, pp. 189–199.

Guo, P., Wang, T., Li D., Zhou, X. (2016), How energy technology innovation affects transition of coal resource-based economy in China, *Energy Policy*, Vol. 92, pp. 1–6.

Hicks, J. (1932),*The Theory of Wages*, London: Macmillan, Reprint 1963.

Hrovatin, N., Dolsak, N., Zoric, J. (2016), Factors impacting investments in energy efficiency and clean technologies: empirical evidence from Slovenian manufacturing firms, *Journal of Cleaner Production,* Vol. 127, pp. 475–486.

Huang, C., Su, J., Zhao, X., Sui, J., Ru, P., Zhang, H., Wang, X. (2012), Government funded renewable energy innovation in China, *Energy Policy*, Vol. 21, pp. 121–127.

Hughes, T. (2012),The Evolution of Large Technological Systems in: W. Bijker, T. Hughes, T. Pinch, (eds.), *The Social Construction of the Technological Systems. New Directions into the Sociology and History of Technology*, Cambridge: MIT Press, pp. 45–77.

IEA (2011), *Energy Policies of IEA Countries: Poland*, Paris, available athttp://www.iea.org/publications/freepublications/publication/Poland2011_web.pdf, accessed: May 27, 2016.

IEA (2015), *Energy Technology Perspectives 2015. Mobilizing Innovation to Accelerate Climate Action*, Paris, available at: https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2015ExecutiveSummaryEnglishversion.pdf, accessed: February 27, 2016.

Irandoust, M. (2016), The renewable energy-growth nexus with carbon emissions and technological innovation: Evidence from the Nordic countries, *Ecological Indicators,* Vol. 69, pp. 118–125.

Johnstone, N., Hascic, I., Popp, D. (2010), Renewable energy policies and technological innovation: evidence based on patent counts, *Environmental Resource Economics*, Vol. 45, pp. 133–155.

Jamasb, T., Pollitt, M. (2008), Liberalisation and R&D in network industries: the case of the electricity industry, *Research Policy*, Vol. 37, pp. 995–1008.

Kotler, Ph. (1994), *Marketing. Analiza, planowanie, wdrażanie i kontrola*, Wydawnictwo Gebethner i Ska, Warszawa.

Lefevre, S. (1984),Using Demonstration Projects to Advance Innovation in Energy, *Public Administration Review*, Vol. 44, No. 6, pp. 483–490.

Lutzenhiser, L. (1994), Innovation and organizational networks: barriers to energy efficiency in the US housing industry, *Energy Policy*, Vol. 22, pp. 867–876.

Malerba, F. (1999), *Sectoral Systems of Innovation and Production*, Paper for the DRUID Conference on: National Innovation Systems, Industrial Dynamics and Innovation Policy Rebuild, June 9–12, available at: http://www.druid.dk/uploads/tx_picturedb/ds1999–69.pdf, accessed: May 25, 2016.

Markard, J.,Truffer, B. (2006), Innovation processes in large technical systems: Market liberalization as a driver for radical change?, *Research Policy*, Vol. 35, pp. 609–625.

McCraw, T. (2007), *Prophet of Innovation: Joseph Schumpeter and Creative Destruction*, Cambridge: Harvard University Press.

McKinsey (2012), *Energy = innovation: 10 disruptive technologies*, available at: https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/Sustainability/PDFs/McK%20on%20SRP/SRP_02_Innovation.ashx, accessed: February 15, 2016.

McMichael, M., Shipworth, D. (2013), The value of social networks in the diffusion of energy-efficiency innovations in UK households, *Energy Policy*, Vol. 53, pp. 159–168.

Miedzinski, M. (2013), *Eco-Innovation Observatory Country Profile 2013: Poland,* available at: http://www.eco-innovation.eu/images/stories/Reports/EIO_Country_Brief_2013_Poland.pdf, accessed: May 27, 2016.

Noailly, J., Smeets, R. (2015), Directing technical change from fossil-fuel to renewable energy innovation: An application using firm-level patent data, *Journal of Environmental Economics and Management*, Vol. 72, pp. 15–37.

OECD and Eurostat (2005), *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. The Measurement of Scientific and Technological Activities,* OECD Publishing, Paris, pp. 45–56.

OECD (2011), *Towards green growth,* OECD Publishing, Paris.

OECD (2014), *OECD Factbook: economic, environmental and social statistics,* OECD Publishing Paris.

OECD (2015), *Science, Technology and Industry Scoreboard,* OECD Publishing, Paris, pp. 230–231.

Pizer, W., Harrington, W., Morgenstern, R., Shih, J. (2002), Technology adoption and aggregate energy efficiency, *Resources for the Future Discussion Paper*, No. 02–52.

Popp, D. (2001), The effect of new technology on energy consumption, *Resource and Energy Economics*, Vol. 23, No. 3, pp. 215–239.

Przychodzien, J. (2015), *Ekoinnowacje w przedsiębiorstwie. Zarządzanie, pomiar i wpływ na wyniki finansowe*, CeDeWu.pl, Warszawa.

Ramadani, V., Gurguri, S. (2011), Theoretical Framework of Innovation: Competitiveness and Innovation Program in Macedonia, *European Journal of Social Sciences*, Vol. 23, No. 2, available at: http://ssrn.com/abstract=1432139, accessed: February 12, 2016.

Rothwell, R. (1994), Towards the Fifth-Generation Innovation Process, *International Marketing Review*, Vol. 11, Issue 1, pp. 7–31.

Rószkiewicz, M. (2015), Wskaźniki innowacyjności gospodarek narodowych, in: A. Kałowski, J. Wysocki, (eds.)*, Innowacje – ocena w ujęciu mikro, mezo i makro*, Oficyna Wydawnicza SGH, Warszawa, pp. 205–246.

Schumpeter, J.A. (1934), *The Theory of Economic Development. An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*, New York, Oxford University Press, Reprint 1961.