Journal of Cleaner Production 130 (2016) 235–247

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Sustainability-oriented innovation system analyses of Brazil, Russia, India, China, South Africa, Turkey and Singapore

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ARTICLE INFO

Article history:
Received 25 April 2015
Received in revised form
12 March 2016
Accepted 14 March 2016
Available online 8 April 2016

Keywords:
Innovation system
Functional dynamics
Sustainable development
Emerging economy

ABSTRACT

The coherency of research, development, and innovation processes are vital in promoting a more resource efficient society. Sustainability-oriented innovation systems define specific kinds of innovation systems, i.e. those that are directed to the aims of sustainable development. This paper develops an integrated method with four layers of analysis to evaluate the priorities and performances of such systems. The method is applied to a sample of emerging and innovation based economies, namely Brazil, Russia, India, China, South Africa, Turkey, and Singapore. The analyses consider the 6 main activities or functional dynamics of innovation systems and a set of 19 keywords. The keywords relate to the thematic clusters of renewable energy technologies, energy efficiency, and environmental management. The priorities of the countries in each main interaction of the system are classified accordingly. The priorities are compared to the existing level of specialization in the keywords based on the intermediate outputs of the system. The analyses cover 153,838 papers and 15,138 patents between the years 2003 and 2014. A Sustainable Innovation Index is developed to aggregate the normalized values of country performance across all keywords. Singapore receives the highest value (21.17) and the average of Brazil, Russia, India, China, and South Africa is 14.91. The results determine the ability of countries to align priorities and performance towards more mature innovation systems for sustainable development.

1. Introduction

Research, development, and innovation can promote a transition to more sustainable societies that are able to decouple economic growth from environmental pressure (Working Group on Decoupling, 2011). In this context, an essential component of resource efficient societies involves effective innovation systems. Innovation systems define the complex system of actors that transform research activities into useful processes, products, and services (Lundvall, 1992). The presence of a synergistic mix of policy instruments can further increase the chances of success for sustainable innovations (Foxon and Pearson, 2008). The outputs of the system, such as technological innovation, can enable increases in resource productivity (Cropper, 2008). Better insight on the systemic nature of sustainable innovation is important to support the means of activating innovation systems to promote sustainable development.

1.1. Overview of the literature

In the literature, sustainable innovation is defined as innovation towards more sustainable processes in which resource use and waste production remain within proper environmental limits (Foxon and Pearson, 2008). Several studies have analyzed sustainable innovation at the level of small and medium-sized enterprises (SMEs). Other studies evaluated cases for sustainable innovation at the sectoral or country level. The literature review as presented in the sections below exemplifies the respective studies at the various levels. It further includes studies that provided an outlook for sustainable innovation.

1.1.1. Sustainable innovation in SMEs

Among the studies at the firm level, Klewitz and Hansen (2014) conducted a review of the types of sustainability-oriented innovations (SOI) in SMEs. In such studies, SOI were found to give direction to integrating economic, social, and ecological aspects in innovation activities (Hansen et al., 2009). Other authors analyzed SMEs that applied business models based on the triple bottom line. Such SMEs proved to have greater ability in spreading SOI in niche

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http://dx.doi.org/10.1016/j.jclepro.2016.03.138
0959-6526/

Nomenclature

F_1	facilitation of experimentation and learning
F_2	knowledge development
F_3	knowledge diffusion
F_4	guidance of search and selection
F_5	market formation
F_6	development and mobilization of resources
KC	keyword cluster
k	keyword in the cluster
max	maximum value in Equation (7)
min	minimum value in Equation (7)
P	WIPO PatentScope patents in Equations (4)–(6), dimensionless
R	Scopus papers in Equations (1)–(3), dimensionless
S	share of papers or patents in Equations (1)–(6), dimensionless
V	normalized value in Equation (7)
v	data entry value in Equation (7)

Subscripts

c	country in the sample
w	world total or share
x	number of relevant entries, dimensionless

Acronyms

BRICS	Brazil, Russia, India, China, and South Africa
BRICTS	Brazil, Russia, India, China, Turkey, and South Africa
GDP	gross domestic product
IGCC	integrated gasification combined cycle
IPC	International Patent Classification
NIC	National Innovation Challenge
NRF	National Research Foundation
R&D	Research and development
RTA	Revealed Technological Advantage in Equation (6)
Scopus	Bibliometric database
SDEWES	Sustainable Development of Energy, Water and Environment Systems
SI	Specialization Index in Equation (3)
SME	small and medium-sized enterprises
SOI	sustainability-oriented innovation(s)
SoIS	sustainability-oriented innovation system(s)
SUSIN	Sustainable Innovation Index
TÜBİTAK	The Scientific and Technological Research Council of Turkey
UNFCCC	UN Framework Convention on Climate Change
WIPO	World Intellectual Property Organization

and mass markets (Schaltegger, 2002). SMEs were further able to create more sustainable production and consumption patterns (Schaltegger and Wagner, 2011).

1.1.2. Sustainable innovation at the sectoral level

At the sectoral level, studies on sustainable innovation analyzed aspects of technology clusters or industrial sites. For example, Zapata and Nieuwenhuis (2010) analyzed incremental and radical innovations based on case studies in ethanol, hybrid, and hydrogen fuel cell vehicles. Nilsson et al. (2012) compared the governance structures for biofuel and hybrid electric vehicle technologies in Sweden. Severo et al. (2015) analyzed the impact of cleaner production processes in an automotive cluster of metal and mechanic parts in Serra Gaúcha, Brazil. Bai et al. (2014) assessed the progress of the Eco-Industrial Parks (EIP) initiative in China based on interviews at 33 locations. Zhang et al. (2015) analyzed the efficiency of resource flows at an EIP in Shandong Province, China as one of the sites that implemented industrial ecology.

1.1.3. Sustainable innovation at the country level

At the country level, studies focused on key concerns to accelerate the pace of sustainable innovation. Suzuki (2015) reviewed the barriers for clean technology diffusion with a focus on developing countries. The most frequent barriers were found to be high capital costs and low priority in finance. Other barriers were the lack of an enabling environment based on capacity as well as research and development (R&D) activities (Suzuki, 2015). Vollenbroek (2002) underlined that existing technologies are not sufficient to meet environmental goals. A national program was analyzed as a tool for transition management, namely the Dutch Program for Sustainable Technology Development. The Program targeted a factor 20 increase in eco-efficiency (Vollenbroek, 2002).

1.1.4. Sustainable innovation at an analytical level

In an analytical approach, Medeiros et al. (2014) categorized the literature on environmentally sustainable product innovation into five categories. The categories involved factors that influenced the adoption of green innovation and the drivers behind green behavior. Other aspects involved methods to develop sustainable products, the effects of sustainable innovation on competitiveness, and collaboration in green technologies. The presence of a specific gap in empirical research for testing and validating critical success factors was identified, including those for cleaner technology research (Medeiros et al., 2014). Bossle et al. (2016) reviewed the methods that were used in 35 studies to assess aspects of eco-innovation. The methods involved mainly the use of surveys and case studies while only two involved patent analysis.

1.1.5. Outlook for sustainable innovation

Beyond specific case studies, Vezzoli et al. (2015) underlined the vitality of a Sustainable Product and Service System to provide alternatives to end-of-pipe solutions to pollution control, cleaner production, and eco-design. Hargroves and Smith (2005) indicated that the sixth wave of innovation will be on clean technologies that radically alter productivity while lightening the load of humanity on the planet. Clean technologies were given to include radical resource productivity, biomimicry, green chemistry, industrial ecology, and renewable energy (Hargroves and Smith, 2005). In an outlook for the future, Khalili et al. (2015) identified characteristics of training programs that are needed to further develop human capacity in support of sustainable development.

1.2. Sustainability-oriented innovation systems

Beyond studies at various levels, an innovation systems approach can be a valuable tool to assess sustainable innovation. The innovation systems approach includes concepts such as technological innovation systems (Carlsson and Stankiewicz, 1991) as well as sectoral systems of innovation (Malerba, 2002). More recently, the concept of a sustainability-oriented innovation system (SoIS) was proposed (Stamm et al., 2009). SoIS is a specific kind of