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

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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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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 innovation system in which the main aim is to generate innovations that reduce pressures on the environment and global public goods (Stamm et al., 2009). SoIS is differentiated from other innovation systems based on a focus on sustainable innovation. At a conceptual level, SoIS was exemplified based on case studies in such areas as renewable energy (Stamm et al., 2009). Descriptive case studies from the BRICS countries (Brazil, Russia, India, China, and South Africa) were included based on achievements in renewable energy technologies (Stamm et al., 2009).

1.2.1. Opportunities for analytical methods

Analytical methods that are supported with data analysis have not been applied to analyze the priorities and/or performance of SoIS in any country, including the BRICS. SoIS can hold great importance especially for the BRICS as a means to pull the fast paced level of economic growth to a more sustainable direction. In addition, studies on the BRICS are limited and analyses of technological capability lack any thematic focus. Wong and Wang (2015) evaluated the growth trajectories of the BRICS based on paper and patent analyses in general and proposed an index that can be used to evaluate the process of catching-up to leader economies. Other analyses of the BRICS focused on aspects of renewable energy policy (Zhang et al., 2011), environmental efficiency of electric power industries (Xie et al., 2014), and technology foresight (Chan and Daim, 2012). Yet other studies included those on energy efficiency and the Kuznets curve (Chang, 2015) as well as Kyoto mechanisms (Freitas et al., 2012).

In further comparison, technology oriented studies that involved samples of firms from one of the BRICS countries lacked an innovation system focus. Cai and Zhou (2014) surveyed firms in China from different sectors of the economy to determine the role of technological and organizational capabilities in driving eco-innovation. Nagano et al. (2014) analyzed four Brazilian companies based on the influence of contextual factors on product development activities. Jabbour et al. (2015) analyzed 62 Brazilian companies to relate technical and organizational factors with practices that involved green product development. Jabbour (2015) found that environmental training in 95 companies in Brazil was correlated to environmental management maturity.

1.3. Aims of the research work

This research work aims to address the gap in the literature for analyzing the priorities and performances of specific kinds of innovation systems that are directed to sustainable R&D and innovation activities, namely SoIS. The research work focuses on SoIS at the country level of specific emerging and innovation based economies, including the BRICS. The aim is to advance the analytical approach towards SoIS based on an analysis of the priorities of the support mechanisms to promote environmentally-friendly R&D and innovation. The thematic priorities are compared to related data analyses of papers and patents. Papers and patents are defined as intermediate output measures of technological change (Kemp and Pearson, 2007). Such a scope provides a measurable boundary for SoIS performance. In contrast, the impacts of SoIS are expected to extend to improving resource efficiency, e.g. energy, material, water, and CO_2 intensities.

Section 2 of the paper describes the method that is developed for the analyses while Section 3 provides the results for the country sample. As a whole, the method provides useful insight on the level of alignment between the priorities of the SoIS and related performance in papers and patents to assess the prospects for more mature innovation systems for sustainability.

2. Method

Fig. 1 summarizes the four layers of analysis that are integrated in the research work to analyze the priorities and performance of the SoIS of a given country in the sample. The four layers represent aspects of system analysis (Section 2.2), knowledge production (Section 2.3), technological innovation (Section 2.4), and system efficiency (Section 2.5). The method of analysis in each of the four layers is made specific to a particular set of keywords that are related to patent codes. This aspect enables compatibility between layers and allows the analyses to be compared per keyword. The datasets that are obtained from the four layers of analysis are used to integrate qualitative and quantitative results. An index that represents the performance of SoIS based on aggregated values of all keywords is further developed.

2.1. Keyword clusters and keywords

Table 1 provides the set of 19 keywords that pertain to three thematic keyword clusters (*KC*) relating to renewable energy technologies, energy efficiency, and environmental management. The keywords are compiled based on the International Patent Classification (IPC) Green Patent Inventory (WIPO, 2015a). This is an inventory of keywords and matching patent codes that relate to environmentally sound technologies as listed within the United Nations Framework Convention on Climate Change (UNFCC) (WIPO, 2015a). Non-technology specific keywords, such as energy policy, are added from the keywords of the Sustainable Development of Energy, Water and Environment Systems Conferences in the field of sustainable development (SDEWES Centre, 2014). The grouping of the 19 keywords into 3 keyword clusters facilitates the thematic nature of analysis.

2.2. System analysis layer

In Fig. 1, the first layer constitutes system analysis in which the keyword clusters and/or keywords that receive priority in the support mechanisms of a given country *c* are identified. These inputs are matched to the functional dynamics of SoIS based on the scope of the support mechanisms in which the priorities are present. The first three functional dynamics are facilitation of experimentation and learning (F_1), knowledge development (F_2), and knowledge diffusion (F_3) (Bergek et al., 2008; Hekkert et al., 2007; OECD, 2014a). The last three functional dynamics are guidance of search and selection (F_4), market formation (F_5), and the development and mobilization of resources (F_6) (Bergek et al., 2008; Hekkert et al., 2007; OECD, 2014a). Table 2 summarizes the primary scope of the functional dynamics, F_x. Within the integrity of SoIS, these main activities are expected to be in systemic interaction (Kılkış, 2014).

In the systemic interactions of SoIS (see Fig. 1), F_4 is in a central position to effectively guide the SoIS in the direction of sustainable innovation. One such systemic interaction is based on the opening of thematic calls to stimulate collaborative R&D projects in the priorities of F_4 under the functional dynamics of F_2 and F_3. Based on the maturity of the SoIS, the priorities that are set in F_4 may further extend to other kinds of support mechanisms. For example, the priorities may be aligned with those for scholarships and fellowships (F_6) and/or support for physical research infrastructure (F_6). The priorities may be diffused to initiatives for public procurement and pilot demonstration initiatives (F_5). Entrepreneurial activities (F_1) may include thematic support for clean technology incubators and technology parks.

The output of the first layer is a matrix of the functional dynamics and keyword clusters and/or keywords that are found to exist in the support mechanisms per country *c*. The matrix is

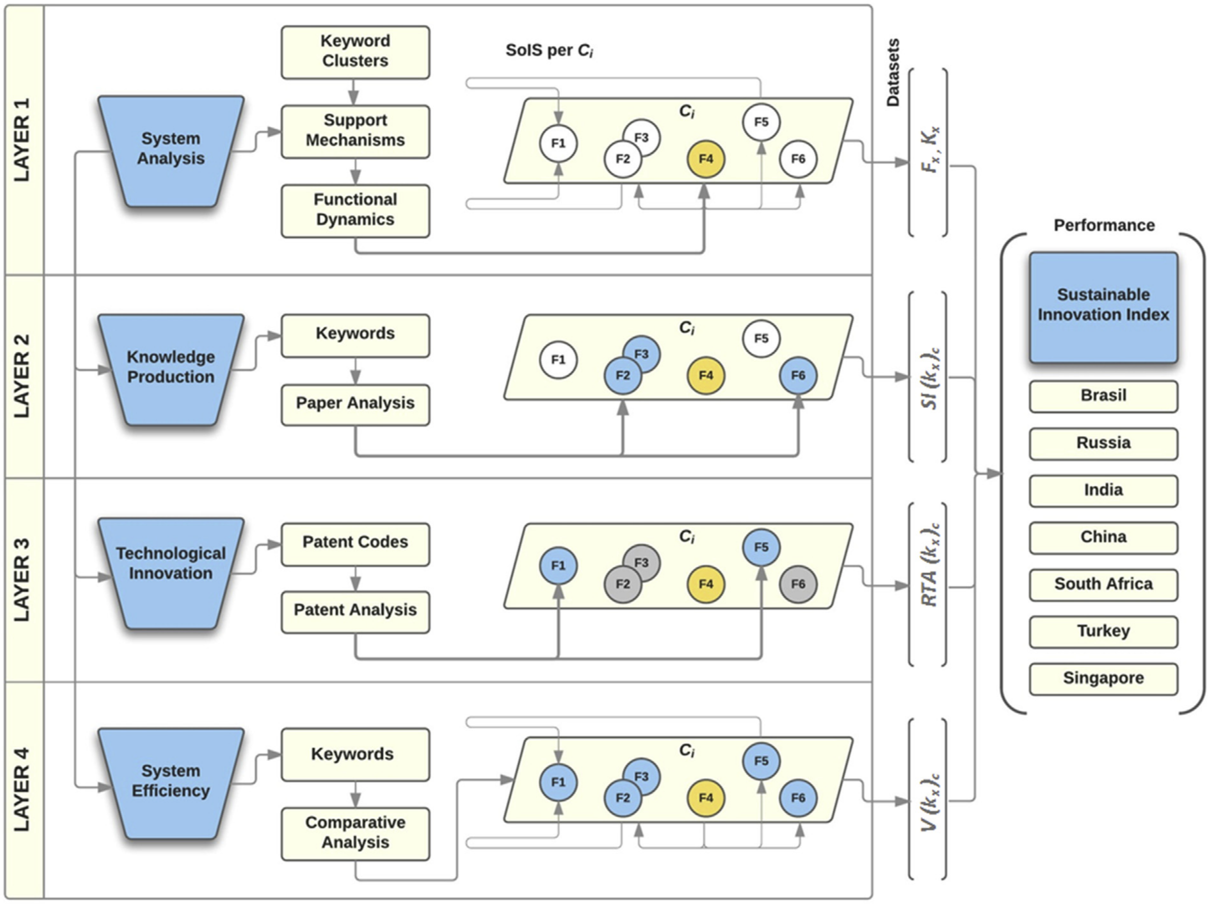

Fig. 1. Layers of analysis in the research method.

Table 1
Keyword clusters and keywords used in the analysis.

KC_x	Keyword cluster	Keywords	k_x
KC_1	Renewable, alternative energy technologies	Solar energy, photovoltaic(s), solar cells	k_1
		Wind energy, wind power, wind turbine	k_2
		Bioenergy, biofuels, biomass gasification, pyrolysis	k_3
		Geothermal energy, geothermal power	k_4
		Hydro energy/power, ocean energy, tide energy	k_5
		Fuel cell(s), hydrogen fuel cells, hydrogen energy	k_6
KC_2	Energy efficiency, technology and policy	Hybrid vehicles, electric vehicle(s)	k_7
		Energy storage	k_8
		Integrated gasification combined cycle, cogeneration, polygeneration, waste heat	k_9
		Energy efficient electric appliances	k_{10}
		Energy efficient buildings	k_{11}
		Smart grid(s), smart energy systems/networks, smart meters	k_{12}
		Energy policy, renewable energy policy	k_{13}
KC_3	Mitigation and environmental management	Pollution control, carbon capture and storage	k_{14}
		Waste disposal, waste management, material reuse	k_{15}
		Transport policy, traffic management, alternative fuels	k_{16}
		Sustainable development policy	k_{17}
		Water management, water policy, water technologies	k_{18}
		Environmental policy, ecological management	k_{19}

organized to represent the systemic interactions that are expected to take place within SoIS.

2.3. Knowledge production layer

The second layer of analysis for knowledge production is based on analyses of papers for each of the 19 keywords per country in the sample. Such an analysis pertains mostly to F_2 and F_3 for knowledge development and diffusion. F_6 for the development and mobilization of resources, including human resources and research infrastructure, is another functional dynamic that supports knowledge production. The output of this layer is the dataset for the share of a particular keyword in the subset of papers that relate to sustainable innovation.

Table 2
Identification of functional dynamics.

F_x	Functional dynamic	Primary scope
F_1	Facilitation of experimentation and learning	• Entrepreneurship, seed capital
F_2/F_3	Knowledge development and diffusion	• R&D projects, collaborative networks
F_4	Guidance of search and selection	• Calls for R&D projects, key initiatives
F_5	Market formation	• Public procurement, pilot demonstration
F_6	Development and mobilization of resources	• Scholarships, fellowships, research infrastructure

2.3.1. SoIS performance based on clean technology papers

The source of the paper analysis is Scopus that is the largest bibliometric database of peer-reviewed literature (Scopus Database Advanced Search, 2015). The advanced search option of Scopus allows for the entry of string commands. The country of the publication and the 19 keywords are inserted into the string commands. The search results are limited to articles in peer-reviewed journals that were published between the years 2003 and 2014. In the method, 160 searches were conducted.

2.3.2. Specialization Index

The data inputs are analyzed based on the Specialization Index (EC Directorate-General for Research and Innovation, 2014), referred to as SI hereafter. SI is the quotient of two ratios both of which compare the share S of a country in the total number of papers. Equation (1) is specific to a particular keyword, k_x. Here, R represents the total number of papers for a particular keyword k_x for a given country c and the world, w. In Equation (2), R is taken for the total number of papers for c and w regardless of keywords. Equation (3) formulates SI based on these two shares. SI values greater than 1 indicate that the world share of a country in the total number of papers for k_x is greater than the world share of the same country in all papers. SI values less than 1 indicate no particular specialization. The results of Equation (3) indicate the keywords k_x in which a country can be more specialized.

$$S(R_{k_x})_c = (R_{k_x})_c \Big/ (R_{k_x})_w \tag{1}$$

$$S(R)_c = (R)_c/(R)_w \tag{2}$$

$$\mathrm{SI}\ (k_x)_c = S(R_{k_x})_c \Big/ S(R)_c \tag{3}$$

2.4. Technological innovation layer

The third layer represents technological innovation that is based on patent analysis using patent codes that relate to the specific keywords. Patenting is related directly to F_1 for entrepreneurial activities and F_5 for market formation. Within the systemic integrity of SoIS, however, patenting further receives significant support from the other functional dynamics, including F_2 and F_3, which are required for the basis of technology development. The output of this analysis layer is the performance of a country in patents based on specific keywords.

2.4.1. SoIS performance based on clean technology patents

In the patent analysis, the advanced search option of the World Intellectual Property Organization (WIPO) PatentScope database (WIPO, 2015b; WIPO, 2015c) enables the search of international and national patent collections. String commands are written to search for a given country and more than one IPC code for a given keyword simultaneously. The string command includes entries for address country, publication date, and IPC patent codes. These codes are based on the IPC Green Patent Inventory that consists of 265 mutually exclusive patent codes (Kılkış, in press).

2.4.2. Revealed Technological Advantage

The data inputs in the third layer are analyzed based on Revealed Technological Advantage, hereafter expressed as RTA (EC Directorate-General for Research and Innovation, 2014). This indicator represents the relative advantage of a country in a specific technology field when compared to world patenting trends (Khramova et al., 2013). Equations (4) and (5) formulate the components of RTA. Here, P represents the total number of patents for a particular keyword k_x and/or a given country c and the world, w. Equation (6) gives RTA that compares the world share, S of a given country in the total number of patents for a specific keyword k_x over the share among all patents. Values of RTA greater than 1 indicate that the share in the total number of patents for a keyword k_x is greater than the share among all patents. The reverse is true when patents for keyword k_x do not represent a similar advantage.

$$S(P_{k_x})_c = (P_{k_x})_c \Big/ (P_{k_x})_w \tag{4}$$

$$S(P)_c = (P)_c/(P)_w \tag{5}$$

$$\mathrm{RTA}(k_x)_c = S(P_{k_x})_c \Big/ S(P)_c \tag{6}$$

In Table 1, four of the keywords are policy related in nature, namely k_{13}, k_{16}, k_{17}, and k_{19}, which make them valid for paper but not for patent analysis. As a result, the RTA values of these keywords are zero by default since the scope is not suitable for patenting activities.

2.5. System efficiency layer

The theme of system efficiency comprises the fourth layer. This theme is based on analyses of the previous two layers by comparing the datasets of SI and RTA per keyword, k_x and country c. In this process, the values in the two datasets are first normalized per k_x based on the Min–Max method (OECD-JRC, 2008) as given in Equation (7). Here, the value v for a given keyword k_x and country c is normalized into value V. The normalized value is based on the minimum (*min*) and maximum (*max*) values in the dataset for the same keyword k_x among all countries in the sample. In Equation (7), the values are taken from the datasets of SI and RTA per keyword k_x to form two new datasets with the normalized values. Accordingly, the datasets of SI and RTA per keyword k_x are normalized between 1 and 0 that correspond to the highest and lowest values in the dataset whichever country these values may belong. The results of the normalized values for all keywords k_x are then compared in radar charts per country, c.

$$V(k_x)_c = \left(v\ (k_x)_c - v\ (k_x)_{\max}\right) / \left(v\ (k_x)_{\min}\right) - \left(v\ (k_x)_{\max}\right) \tag{7}$$

The radar charts are useful to compare the level of alignment between performances in SI and RTA for a specific keyword k_x in a given country. Any strength in both SI and RTA are compared to the keywords that received priority in the functional dynamics matrix. In the context of system priorities, the analysis is pertinent to compare the system efficiency of transforming knowledge based on papers into technological innovation based on patents. The fourth analysis is also useful to assess the maturity of the SoIS in being able to align priorities and outputs, thereby allowing the system to have coherency in approach and performance.

2.6. Sustainable Innovation Index

In addition, a Sustainable Innovation Index (SUSIN) is developed to complement the keyword specific nature of the four analyses in the method. Sustainable innovation depends on competences in more than one keyword and in particular, interactions between multiple keywords within the integrity of SoIS. SUSIN aggregates the normalized values of SI and RTA for all keywords k_x for a particular country. Equation (8) formulates SUSIN that consists of the summation of the normalized values V of SI and RTA based on Equation (7) for all keywords k_x from $x = 1$ to $x = 19$ per country c. Countries that have the highest aggregated values indicate the presence of higher normalized scores in multiple keywords in SI and RTA. In addition to the total aggregated value, SUSIN is also presented by keyword cluster.

$$\text{SUSIN} = \sum_{x=1}^{19} V_{SI}(k_x)_c + \sum_{x=1}^{19} V_{RTA}(k_x)_c \tag{8}$$

2.7. Determination of the country sample

In this paper, the country sample is taken to be the countries in the BRICS group and two additional countries. One of these countries is Turkey that is starting to be added to the BRICS countries as BRICTS (Bildirici and Bakirtas, 2014). The other country is Singapore that is taken as a benchmark to represent an innovation-based economy (Schwab, 2014). Since the indicators of SI and RTA are indexed to the world share of the country, the aspect of country size is not an influencing factor in the analyses. In total, the country sample represents 7 countries. The BRICS group is also added to compare the performance of the BRICS as a whole.

3. Results and discussion

The application of the method in Fig. 1 to the BRICS countries as well as Turkey and Singapore provides the opportunity to analyze the priorities and performances of the SoIS of these countries based on the set of 19 keywords. Sections 3.1–3.5 provide the results of the multiple layers of analysis and their integration within the coherency of the method. The results are presented in a stepwise manner in the order of the analysis layers in Fig. 1. The results of the countries in the sample are further discussed individually and collectively.

3.1. Results of the keyword and functional dynamics matrix

In total, more than 250 support mechanisms from the BRICS countries as well as Turkey and Singapore are reviewed based on data mining and/or institutional visits. The range of support mechanisms in these countries support the definition of SoIS based on policy tools for each functional dynamic. The same support mechanisms are scanned for priorities that are related to the 19 keywords and/or 3 keyword clusters and distributed to the functional dynamics as appropriate. Table 3 provides the results of these priorities that are arranged in matrix format. The priorities of support mechanisms that involve thematic calls for collaborative R&D projects are marked under the column that involves the interaction ($\leftrightarrow$) of F_2/F_3 and F_4. The priorities of the other support mechanisms, such as those for market formation (F_5) and the development and mobilization of resources (F_6), are marked in the other columns. Table 3 is useful to determine the penetration of the priorities in the various systemic interactions of SoIS.

3.1.1. Priorities of the SoIS of Brazil

Brazil prioritizes various aspects of the keyword clusters KC_1, KC_2, and KC_3 under thematic calls for collaborative R&D projects (see Table 3). The priorities are set as climate mitigation technologies, bioenergy, other renewable energy technologies, ecosystems and biodiversity, and sustainable cities (Ministry of Science and Technology and Innovation, 2011). The support mechanisms that are used to implement these priorities include Inova Energy (BNDES, 2014) and Inova Sustainability (FINEP, 2014). Both are administered by the Ministry of Science, Technology and Innovation and the Brazilian Innovation Agency. The Brazilian Development Bank provides a financing continuum for the results of R&D projects. One thematic program is PAISS that focuses on lignocellulosic ethanol (BNDES-FINEP, 2014). Hence, k_3 for bioenergy is marked in Table 3 under specific priorities for market formation (F_5). In addition, the program Science without Borders (Conselho Nacional de Desenvolvimento Cientifico e Tecnológico, 2014) provides an integrated approach to foster human resources, including in priorities that correspond to the keywords k_1, k_2, k_3, k_8 and k_{19}.

3.1.2. Priorities of the SoIS of Russia

As indicated in Table 3, Russia prioritizes the keyword clusters KC_1 and KC_2 as well as the keyword k_{14}. Critical technologies include sustainable energy sources, energy saving systems for energy transmission, distribution and use, as well as energy-efficient power generation technologies (Russian Federation, 2014). Technologies for monitoring the environment are also prioritized (Russian Federation, 2014). The Federal Targeted Program addresses these and other priorities by providing grants to pre-competitive and applied research (Ministry of Education and Science of the Russian Federation, 2014). In addition, the Skolkovo Innovation Center is launched as a pilot site to stimulate market formation, including for green building technologies (Russian Venture Company, 2014). Entities such as the Russian Venture Company (RVC) provide

Table 3
Keyword and functional dynamics matrix for SoIS.

Country	F1 ↔ F4	F2/F3 ↔ F4	F5 ↔ F4	F6 ↔ F4
Brazil	✓	✓KC_1, KC_2, KC_3	✓k_3	✓k_1, k_2, k_3, k_8, k_{19}
Russia	✓	✓KC_1, KC_2, k_{14}	✓k_1, k_7, k_{10}, k_{11}	✓
India	✓	✓KC_1, KC_2, KC_3	✓k_1, k_7, k_{18}	✓k_3, k_{13}
China	✓	✓k_1, k_6, k_7, k_9, k_{12}, k_{16}, k_{18}, k_{19}	✓k_7, k_{12}	✓
South Africa	✓	✓KC_1, k_8, k_9, k_{18}, k_{19}	✓k_3	✓k_{19}
Turkey	✓	✓KC_1, KC_2, KC_3	✓k_1, k_2, k_5, k_7, k_9	✓KC_1, KC_2, KC_3
Singapore	✓KC_1, KC_2	✓KC_1, KC_2	✓KC_1, KC_2	✓KC_1, KC_2, KC_3

support to bring the results of R&D into the market, including thin film solar cells and electric vehicles (RVC, 2013). The related keywords of k_1, k_7, k_{10} and k_{11} are marked in Table 3 as priorities for market formation.

3.1.3. Priorities of the SoIS of India

India presents a comprehensive coverage of the keyword clusters KC_1, KC_2, and KC_3 based on the priorities of national R&D policy (Department of Science and Technology, 2013) and foresight (TIFAC, 2015). As indicated in Table 3, the priorities in energy, water management, and climate change penetrate into call-based priorities for R&D projects. The priorities that extend to market formation are based on the priorities of broader initiatives, such as the Solar Energy Research Initiative (SERI) (DST, 2014a) for k_1 and the Water Technology Initiative (WTI) for k_{18} (DST, 2014b). These initiatives cover aspects of pilot demonstration that is vital for market formation (F_5). In addition, the Technology Development Board provides support at more mature technology readiness levels (Department of Science and Technology, 2014), including electric vehicles as k_7. Table 3 further indicates that India prioritizes k_3 and k_{13} in developing human resources (F_6). These priorities are included in those of the Nehru and Swarnajayanti Fellowships that are designed to support advanced, frontier researchers (DST, 2015).

3.1.4. Priorities of the SoIS in China

As presented in Table 3, the priorities of China exhibit a specific focus on the keywords k_1, k_6, k_7, k_9, k_{12}, k_{16}, k_{18}, and k_{19}. These priorities are based on the targeted frontier technologies and basic research areas of national plans (State Council of the People's Republic of China, 2006). Priorities that take place in this plan form the basis of the call-based National High-Tech R&D Program, known as 863 (Ministry of Science and Technology of the People's Republic of China, 2014). Beyond collaborative R&D activities (F_2/F_3), the priorities for market formation (F_5) are based on those of the National S&T Major (Mega) Projects Initiative that also includes specific production targets (Ministry of Science and Technology, 2014). One of the Mega Projects is next generation mobile communication networks that benefits smart grids (k_{12}). Other initiatives that enable a financing continuum for research results are those on electric vehicles (k_7). Under the Ten Cities, Thousand Vehicles Initiative, local authorities are expected to implement public procurement to achieve targets for electric vehicles. The initiative has since spanned targets for 25 pilot cities (Marquis et al., 2013).

3.1.5. Priorities of the SoIS in South Africa

In South Africa, the priorities for knowledge development and diffusion are based on the keyword cluster of KC_1 and the keywords k_8, k_9, k_{18}, and k_{19}. The national innovation plan includes a focus on energy security, including integrated gasification combined cycle (IGCC), renewable energy, and the hydrogen economy. The Plan also designates global climate change science as one of the five "grand challenges" (Department of Science and Technology, 2008). The Technology Mission on smart materials, including materials for energy storage (Department of Science and Technology, 2008), and the Water Sustainability Flagship (Council for Scientific and Industrial Research, 2015) further involve keywords k_8 and k_{18}. For market formation (F_5), the Biofuels Technology Demonstration Program that is implemented by the Technology Innovation Agency (Technology Innovation Agency, 2015) sets a clear priority for k_3. The Centers of Excellence Initiative (National Research Foundation, 2015) that supports research infrastructure includes a priority for keyword k_{19} under the functional dynamic F_6.

3.1.6. Priorities of the SoIS in Turkey

Turkey has an extensive call-based system for national R&D priorities (TÜBİTAK, 2015a) that covers the keyword clusters KC_1, KC_2, and KC_3. The calls are opened in programs that incentivize R&D collaboration in the priority areas based on milestones in technology roadmaps, which have been coordinated by the Scientific and Technological Research Council of Turkey (TÜBİTAK) (OECD, 2014b). In the aspect of market formation (F_5), landmark projects allow public authorities to be the lead users of newly developed technologies under the Public Institutions Research Funding Program (1007) of TÜBİTAK (TÜBİTAK, 2013). As given in Table 3, these landmark projects address keywords k_1, k_2, k_5, k_7, and k_9 based on national projects for solar energy systems, wind energy systems, hydropower, electric vehicles, and cogeneration (Supreme Council for Science and Technology, 2015). Another aspect of supporting priorities across the systemic whole of the SoIS is the provision of scholarships in priority areas, including energy and environmental technologies (TÜBİTAK, 2015b).

3.1.7. Priorities of the SoIS in Singapore

Singapore presents the most consistent penetration of priorities across each interaction in the SoIS, including entrepreneurship (F_1). This consistency has allowed Singapore to gain competences in intelligent energy systems, energy efficiency, as well as water and solar research (Research Innovation and Enterprise Secretariat, 2015). For example, the Energy National Innovation Challenge (Energy NIC) that is initiated by the National Research Foundation (NRF) provides a whole-of-government effort (NRF, 2015a). The CleanTech Park (JTC Corporation's CleanTech Park, 2015) is also launched as an entrepreneurial living laboratory for early clean technology and solutions, which facilitates the penetration of the priorities as set in F_4 to F_1 and F_5. Another initiative is the Urban Systems Initiative that focuses on urban challenges (A*STAR, 2015). In the aspect of infrastructure and human resources (F_6), the CREATE Program of NRF supports partnerships in the thematic priorities of human, energy, environmental, and urban systems (NRF, 2015b), including those on future cities, low-carbon energy, and electromobility (TUM Create, 2015).

3.2. Results of the Specialization Index

Table 4 provides the results of the second layer of analysis based on data gathering in the Scopus database per keyword k_x and country c. Table 4 puts forth the keywords in which countries are relatively more specialized based on values of SI using Equations (1)–(3). Table 4 represents 152 entries for SI as the product of 19 keywords for the 7 countries and the BRICS group. Among this total, 73 entries represent keywords in which countries are more specialized based on SI values greater than 1 (see entries with arrows). The highest levels of specialization are observed to be in Turkey for k_4 (5.74) and Singapore for k_8 (3.38) and k_1 (2.86). South Africa and China also have high levels of specialization in k_{17} (2.82) and k_5 (2.79), respectively. The lowest value of SI appears to be for k_7 in Russia (0.05). The total number of papers in the sub-set of all keywords $x = 1$ to $x = 19$ and other key variables in Equations (1)–(3) are provided in the last two rows or last column in Table 4. Between the years 2003 and 2014, the countries in the sample had 153,838 papers based on the given keywords.

3.3. Results of the Revealed Technological Advantage

Table 5 provides the results of the third layer of analysis based on data gathering in WIPO PatentScope per keyword k_x and country c. In this context, Table 5 indicates the keywords in which countries are relatively more specialized based on values of RTA. Overall,

Table 4
Specialization Index values and variables per keyword.

Keywords (k_x)		Brazil	Russia	India	China	S. Africa	BRICS	Turkey	Singapore	World
SI[a]	k_1	0.40	0.67	1.53 ↑	1.70 ↑	0.60	1.42 ↑	0.94	2.86 ↑	57,670
	k_2	0.39	0.25	1.05 ↑	1.90 ↑	0.58	1.42 ↑	1.15 ↑	0.75	21,124
	k_3	1.49 ↑	0.97	1.58 ↑	1.55 ↑	0.93	1.48 ↑	1.35 ↑	1.35 ↑	63,994
	k_4	0.16	1.00 ↑	0.66	0.79	0.45	0.72	5.74 ↑	0.55	2722
	k_5	1.16 ↑	0.36	1.19 ↑	2.79 ↑	0.60	2.07 ↑	1.31 ↑	0.69	7262
	k_6	0.64	0.62	1.18 ↑	1.80 ↑	0.79	1.44 ↑	0.98	2.66 ↑	49,322
	k_7	0.16	0.05	0.47	2.31 ↑	0.22	1.52 ↑	0.34	0.98	8830
	k_8	0.32	0.54	1.24 ↑	2.25 ↑	0.86	1.69 ↑	1.08 ↑	3.38 ↑	16,445
	k_9	0.88	1.42 ↑	1.15 ↑	1.51 ↑	0.52	1.35 ↑	1.37 ↑	1.40 ↑	8677
	k_{10}	0.29	0.72	0.47	1.27 ↑	0.47	0.97	0.25	1.57 ↑	740
	k_{11}	0.43	0.17	0.49	0.87	0.17	0.68	1.69 ↑	1.11 ↑	2091
	k_{12}	0.68	0.08	0.71	1.79 ↑	0.58	1.30 ↑	0.78	2.44 ↑	3885
	k_{13}	0.77	0.24	1.09 ↑	0.75	1.30 ↑	0.77	1.92 ↑	1.36 ↑	30,489
	k_{14}	0.64	0.24	1.57 ↑	1.64 ↑	1.01 ↑	1.38 ↑	0.86	1.00 ↑	21,905
	k_{15}	1.42 ↑	0.24	1.69 ↑	1.24 ↑	1.29 ↑	1.22 ↑	1.40 ↑	1.52 ↑	53,482
	k_{16}	0.54	0.23	1.41 ↑	0.84	0.99	0.85	1.57 ↑	1.57 ↑	8602
	k_{17}	1.14 ↑	0.41	0.90	0.96	2.82 ↑	0.96	0.92	0.76	37,100
	k_{18}	0.97	0.18	1.55 ↑	1.11 ↑	2.37 ↑	1.11 ↑	1.35 ↑	1.49 ↑	42,276
	k_{19}	0.81	0.36	0.98	0.77	1.04 ↑	0.78	0.90	0.60	53,592
Sub-total[b]		10,070	5269	23,977	97,152	3318	139,789	9387	4665	490,208
Total (%)[c]		2.56	1.40	3.82	4.08	3.42	3.60	3.47	4.62	2.92

[a] Based on Equation (3) except world values that represent the number of papers in keywords.
[b] Total papers in the clean technology keywords for the country, BRICS group or the world.
[c] Total share of clean technology papers in country, region or world total (%).

Table 5
Revealed Technological Advantage values and variables per keyword.

Keywords (k_x)		Brazil	Russia	India	China	S. Africa	BRICS	Turkey	Singapore	World
RTA[a]	k_1	0.67	1.46 ↑	0.56	1.14 ↑	1.15↑	1.07 ↑	1.31↑	2.29 ↑	258,400
	k_2	3.87↑	3.77 ↑	1.24 ↑	1.52 ↑	2.81↑	1.79 ↑	2.33↑	4.51 ↑	63,678
	k_3	2.69↑	1.70 ↑	1.88 ↑	1.08 ↑	2.63↑	1.35 ↑	0.45	1.92 ↑	384,558
	k_4	1.36↑	4.46 ↑	0.87	1.45 ↑	1.15	1.59 ↑	2.01↑	0.51	33,194
	k_5	5.88↑	4.96 ↑	3.07 ↑	1.51 ↑	5.76↑	2.28 ↑	6.07↑	3.65 ↑	23,625
	k_6	0.33	0.62	0.29	0.42	0.38	0.41	0.60	0.81	135,725
	k_7	0.60	1.43 ↑	0.79	0.72	0.37	0.77	1.16↑	0.17	57,888
	k_8	0.19	0.64	0.58	1.41 ↑	0.74	1.17 ↑	0.83	0.83	92,493
	k_9	0.73	1.56 ↑	0.84	1.09 ↑	1.66↑	1.10 ↑	1.00↑	1.44 ↑	33,333
	k_{10}	0.14	0.28	0.23	0.53	0.56	0.46	0.19	1.01 ↑	76,157
	k_{11}	1.00↑	1.38 ↑	0.18	0.65	0.86	0.67	0.60	1.05 ↑	79,528
	k_{12}	0.68	0.47	0.61	0.80	0.88	0.75	0.36	1.70 ↑	187,582
	k_{13}	–	–	–	–	–	–	–	–	–
	k_{14}	1.24↑	1.76 ↑	1.00 ↑	0.75	1.88↑	0.91	1.00↑	1.36 ↑	330,592
	k_{15}	2.86↑	2.82 ↑	1.43 ↑	0.87	2.78↑	1.23 ↑	0.81	0.57	105,749
	k_{16}	–	–	–	–	–	–	–	–	–
	k_{17}	–	–	–	–	–	–	–	–	–
	k_{18}[b]	8.67↑	5.60 ↑	0.00	0.49	5.31↑	1.30 ↑	0.00	1.99 ↑	2404
	k_{19}	–	–	–	–	–	–	–	–	–
Sub-total[c]		781	1522	1655	8875	720	13,553	350	1235	1,864,906
Total (%)[d]		12.72	13.71	8.64	8.16	14.37	9.02	7.84	13.87	8.74

[a] Based on Equation (6) except world values that represent the number of patents in keywords.
[b] Includes patent codes for removing pollutants from open water based on WIPO (2015a).
[c] Total patents in the clean technology keywords for the country, BRICS group or the world.
[d] Total share of clean technology patents in country, region or world total (%).

Table 5 has 120 entries that are calculated based on Equations (4)–(6) for the 15 keywords that are suitable for inclusion in the patent analysis. Among these entries, 65 entries represent keywords in which countries are relatively more specialized based on RTA values greater than 1.

The highest level of specialization is observed to be in Brazil for k_{18} (8.67) and k_5 (5.88) and k_5 for Turkey (6.07). Russia and South Africa are also specialized to a high extent in k_{18} with values of 5.60 and 5.31, respectively. The last two rows of Table 5 provide the total number of patents in the sub-set of keywords $x = 1$ to $x = 19$, excluding k_{13}, k_{16}, k_{17}, and k_{19}. The share of the patents in this sub-set in the total patents of the country is further given. The total number of patents in the world per k_x is included as a key variable in Equations (4)–(6). Between the years 2003 and 2014, the countries in the sample had 15,138 patents in the given keywords.

3.4. Comparison of paper and patent performance

Equation (7) is applied to the data entries in Tables 4 and 5 to obtain the normalized values of SI and RTA per keyword k_x. These normalized values are plotted onto the radar charts in Fig. 2 that have axes with origin of 0 and outer border of 1. The radar charts in Fig. 2 are given per country and the BRICS group starting at the top left corner with Brazil (a) and proceeding in order to Singapore (h) at the bottom right corner. The series with circular (blue, in the web version) and rectangular (red, in the web version) markers

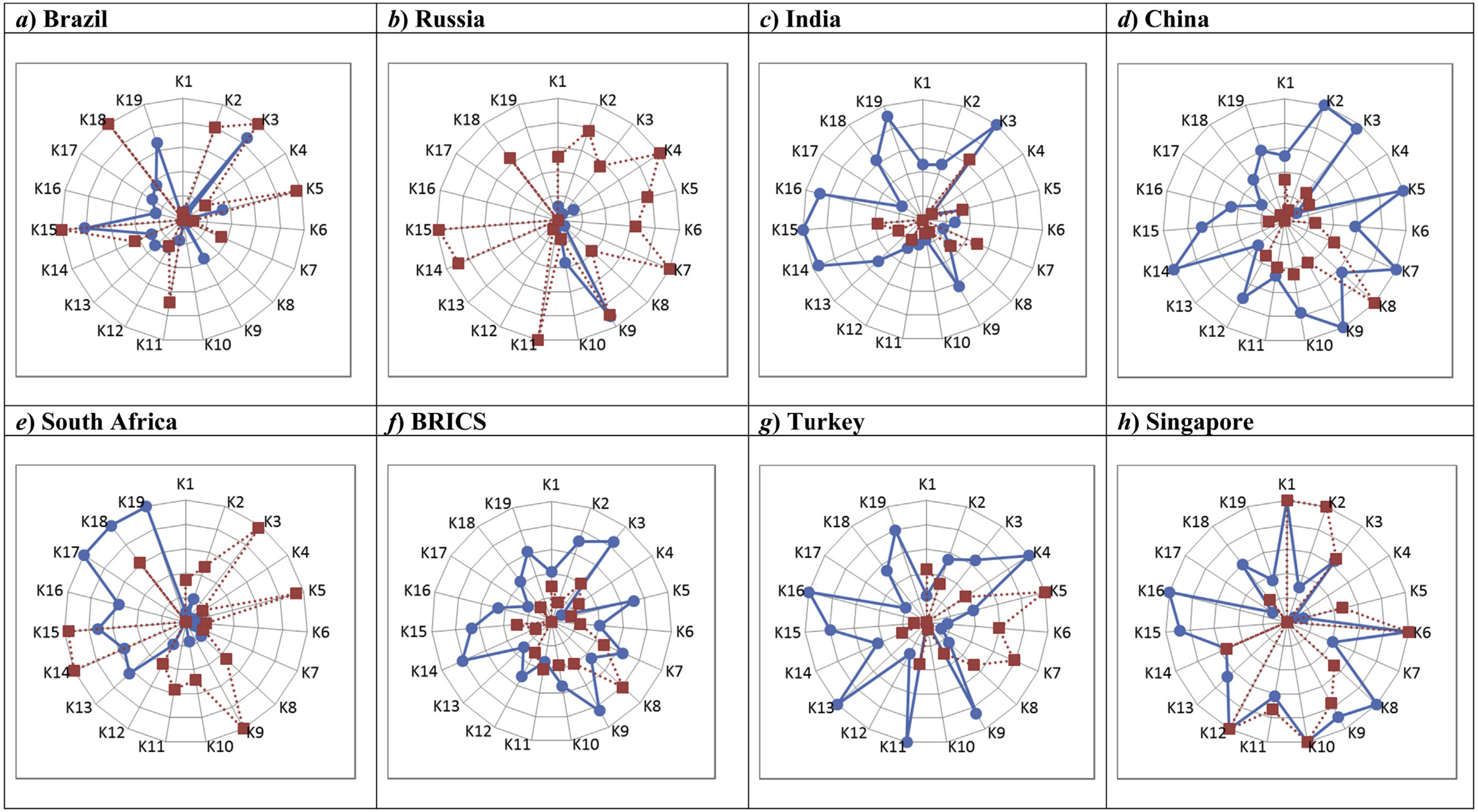

Fig. 2. Comparison of normalized SI and RTA values per keyword and country.

represent the normalized values of SI and RTA, respectively. The comparison of both markers per keyword k_x provides the relative level of alignment between the performance of a country in specializing in papers and patents at the same time.

3.4.1. Comparison of the SoIS performance of Brazil

In Fig. 2, the radar chart of Brazil (*a*) indicates that two keywords, namely k_3 and k_{15}, have a high level of performance based on the normalized values of SI and RTA. This indicates that Brazil is specialized in these keywords from the aspect of both paper and patent outputs. In other keywords, such as k_5, k_{11} and k_{18}, Brazil is specialized only from the aspect of patents and not papers. This indicates that Brazil is not specialized in all of the keywords that are prioritized based on the priorities in the support mechanisms and strategy documents. In contrast, k_3 comes across as a priority that is particularly emphasized under F_5, which could provide one reason for the relatively high level of performance in RTA in addition to SI.

3.4.2. Comparison of the SoIS performance of Russia

The radar chart of Russia (*b*) in Fig. 2 indicates that only keyword k_9 has a high level of specialization in both SI and RTA values. This keyword is covered by the priority on energy-efficient power generation technologies (Sokolov and Chulok, 2014). In the aspect of papers, Russia has the lowest level of specialization in the keywords among the countries in the sample. Relatively high levels of specialization are evident in patents in five other keywords, namely k_4, k_7, k_{11}, k_{14}, and k_{15}. Among these keywords, k_7 and k_{11} correspond to specific priorities that take place in F_5.

3.4.3. Comparison of the SoIS performance of India

Based on the normalized SI and RTA values in the radar chart of India (*c*) in Fig. 2, the country is more specialized in select keywords based on the performance in papers rather than in patents, particularly k_{14}, k_{15}, and k_{19}. The keyword in which India has a high level of specialization in both papers and patents is k_3. This keyword is one of the two keywords that are prioritized under both F_2/F_3 and F_6. This outcome exemplifies the possibility that the penetration of priorities across the SoIS can result in better performance in a given keyword.

3.4.4. Comparison of the SoIS performance of China

In Fig. 2, the radar chart of China (*d*) indicates that the SoIS of the country is relatively geared more towards a specialization in papers rather than in patents. In particular, China has the highest level of specialization in keywords k_2, k_3, k_5, k_7, k_9, and k_{14} in papers based on the normalized values of SI. In contrast, China has a similar level of performance in RTA values for patents only in k_8, which has some level of specialization based on papers. The priorities of the SoIS for k_7 and k_9 are represented only in the specialization of the country in papers.

3.4.5. Comparison of the SoIS performance of South Africa

In South Africa (see *e* in Fig. 2), the normalized RTA values of the keywords k_3, k_5, k_9, k_{14} and k_{15} are relatively high. Of these keywords, k_{14} and k_{15} have a related specialization based on papers. In contrast, k_{17}, k_{18} and k_{19} have the highest level of specialization among all countries in the sample based on SI values. In comparison to the first analysis layer, k_9, k_{18} and k_{19} take place among the keywords that receive specific priority under F_2/F_3. The other keywords that are prioritized in South Africa prove to be keywords in which the country has not attained a certain level of specialization but may be anticipated to do so in the future.

3.4.6. Comparison of the SoIS performance of BRICS

Based on Fig. 2, the BRICS as a group (*f*) specializes more distinctively in particular keywords based on the output of papers rather than the output in patents. The normalized values of the RTA are lower for all keywords except k_4, k_8, and k_{11}. Within BRICS, the strength in these keywords is driven by those of Russia and/or China. At the same time, k_7 was found to be one of the most commonly prioritized keywords in Table 3. The countries that specialize in this keyword, however, are more limited. This outcome places a role on the effective design of support mechanisms for system efficiency and maturity of the SoIS.

3.4.7. Comparison of the SoIS performance of Turkey

The results for Turkey (see *g* in Fig. 2) indicate that specialization in specific keywords are evident based on SI values and the performance of RTA in patents. Turkey appears to specialize in k_4, k_9, k_{11}, k_{13} and k_{16} based on paper outputs and has relatively high normalized values of RTA in k_5 and k_7 in patents. This outcome indicates that there is a varying level of match between the keywords that receive prominence in papers and patents. The keywords that receive a higher normalized value of RTA more closely resemble the R&D and innovation initiatives that are launched in the system, such as those on electric vehicles (k_7).

3.4.8. Comparison of the SoIS performance of Singapore

In Singapore (*h* in Fig. 2), there is better alignment between strengths in papers and patents in specific keywords that indicates a certain level of maturity in the SoIS. Singapore has the highest level of specialization in both SI and RTA among the countries in the

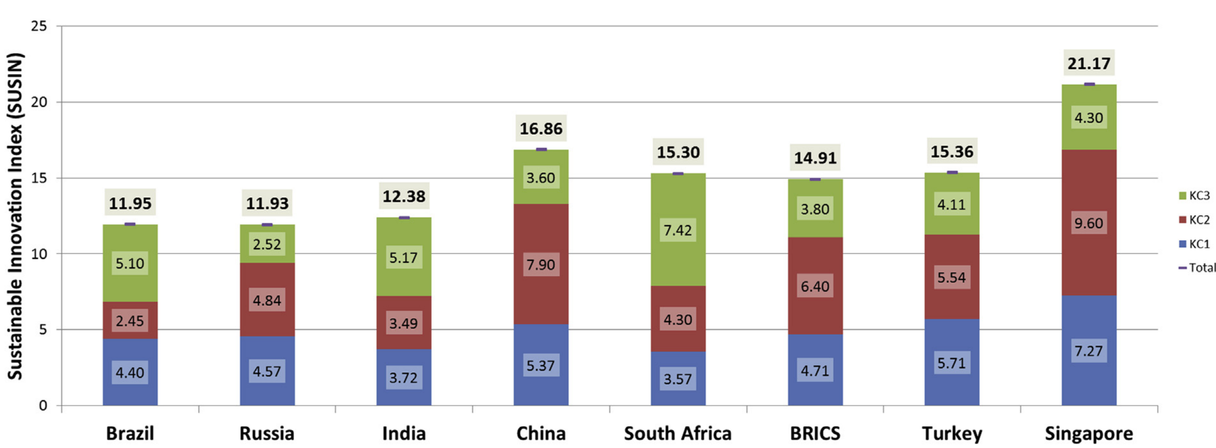

Fig. 3. Sustainable Innovation Index and keyword clusters sub-scores.

sample in k_1, k_6, k_{10} and k_{12}, which represent solar energy, fuel cells, energy efficient electric appliances, and smart grid technologies, respectively. There is also a high level of performance in keywords k_9 and k_{11} in both papers and patents. Such an alignment fits well with the priorities of the country that extends to multiple functional dynamics consistently for most priorities.

3.5. Results of the Sustainable Innovation Index

The stacked bar chart of Fig. 3 provides the results of the SUSIN index for the 7 countries in the sample and the BRICS group as a whole. Based on Equation (8), the normalized values of SI and RTA are aggregated per country for all relevant keywords. The compositions of aggregated values of the SUSIN are also given based on the totals of the keyword clusters.

In Fig. 3, Singapore has the highest value of SUSIN at 21.17. This indicates that the SoIS specializes in more keywords than other countries in the sample with favorable outcomes in papers and/or patents. The composition of the stacked bar for Singapore further indicates that keyword cluster KC_2 contributes the most to this outcome (9.60). This performance is consistent with the results of the multiple layers of analysis. Singapore is better aligned in specializing in both papers and patents in the same keywords. In addition, the priorities of the SoIS in each systemic interaction are more consistent when compared to other countries in the sample.

Such a performance of Singapore is followed by China with a SUSIN value of 16.86. China does not have a comparable level of alignment in keyword performance as Singapore. Within SoIS, however, China does have the next best coverage of multiple keywords with notable values of SI and/or RTA. The average value for SUSIN for the BRICS is found to be 14.91. Turkey (15.36) and South Africa (15.30) also perform above the BRICS average. Both countries had multiple keywords that received some of the highest normalized values for SI and/or RTA. In contrast, based on SUSIN values, India (12.38), Brazil (11.95), and Russia (11.93) perform below the BRICS average. While these countries, too, specialized in specific keywords, the performance is not as high or widespread as the other countries in the sample. In this respect, despite the presence of related priorities and initiatives that are set to guide the system, these countries may need to further boost the efficiency of SoIS performance.

4. Conclusions

The ability to activate SoIS will be a key strategy in enabling countries to direct R&D and innovation efforts towards the aim of sustainable development. The integrated method in Fig. 1 that was developed in this research work was instrumental in assessing the level of match between the priorities and performances of the SoIS in the country sample. In total, a set of 19 keywords were used in analyses for the BRICS countries, Turkey, and Singapore. The first layer as the system analysis layer evaluated the priorities across the various interactions in the functional dynamics. This analysis was crucial for determining the penetration of the priorities across the different systemic interactions of the SoIS.

The next two analyses provided a critical assessment of the related functions of the SoIS based on the intermediate output of papers and patents. The level of specialization in papers in the aspect of knowledge production was analyzed based on SI. Accordingly, SI values were highest in Turkey for k_4 at 5.74 and lowest in Russia for k_7 at 0.05, which relate to geothermal energy and electric vehicles, respectively. Technological innovation was analyzed based on outputs in patents. RTA was highest in Brazil for k_{18} at 8.67, which represented water technologies.

In the fourth analysis, values of SI and RTA were normalized and compared per keyword, including the BRICS group. The comparison enabled a qualitative assessment of system efficiency based on the level of alignment between performances in both SI and RTA for a given keyword. Singapore was found to have the best alignment in performance, which further corresponded to the specific priorities that were set to guide the activities of the SoIS.

The comparison of the results from more than one layer of analysis indicates that there are variances in the level of alignment between the priorities and performance of the SoIS. At present, countries do not specialize in every keyword that is prioritized across the various functional dynamics in the SoIS. Some priorities have been set as a commitment to increase the level of specialization in the future. In addition, countries do not have a consistent level of performance in both SI and RTA for each priority that is set for the SoIS. The results indicate that the countries in the sample are at various maturity levels in being able to align priorities with performance based on the best measurable outputs available, namely papers and patents.

The research work further developed SUSIN to provide insight into the performance of a country across multiple keywords simultaneously. SUSIN for the BRICS was 14.91 while Singapore had the highest value at 21.17. Hence, SUSIN was useful to assess the ability of a country to specialize in multiple keywords in either patents and/or patents. Since sustainable development depends on competences in more than one keyword, SUSIN is deemed to be vital in comparing the overall level of performance of the SoIS across all keywords. As a whole, the research work presents novelty in constructing an integrated method across multiple layers of analysis to assess the priorities and performance of the SoIS.

One limitation of the research work is that the assessment of SI and RTA are based on total values of papers and patents between the years 2003 and 2014. This situation represents the total stock of knowledge production and technological innovation in the specific timeframe. In contrast, it is not able to represent any increasing or decreasing trends in annual growth rate between the years. A temporal dimension on an annual basis may be undertaken in future work, which may provide further insight into an improvement in SoIS performance over time, if any. More effective SoIS can also take a role in realizing aspects of the 2030 Agenda.

Currently, a goal of the 2030 Agenda emphasizes the need to foster innovation and promote inclusive and sustainable industrialization (United Nations, 2015). The same goal includes the target of supporting domestic technology development as well as research and innovation in developing countries (United Nations, 2015). These aspirations may refer to the need of activating SoIS to enable a paradigm shift in producing assets to contribute to the diffusion of more sustainable practices. The related indicator that is proposed within the monitoring framework for the 2030 Agenda (Expert Group on Sustainable Development Goal Indicators, 2015), however, is not specific to measuring sustainable R&D and innovation activities. The method of the present paper can be used by interested countries to analyze the performance of SoIS towards activating sustainable R&D and innovation. In turn, more effective innovation systems can support the transition to more sustainable societies.

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