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Carbon capture and storage in South Africa: A technological innovation system with a political economy focus

Yu-Chia Ko, National Chengchi University
Krystin Zigan, University of Kent
Yu-Lun Liu (Corresponding author; y.l.liu@ntut.edu.tw), National Taipei University of Technology

Highlights

- This research analyses the South African carbon capture and storage (CCS) project using a technological innovation system (TIS) framework.
- It complements this approach with a political economy framework and explores the relevance of political dynamics related to the successful implementation of TIS.
- Through a systematic review of relevant contextual factors and the relationships between key actors, this study identifies important shortcomings in the management of the CCS project in an emerging market.

Abstract

This research investigates the technological innovation system (TIS) approach in emerging markets, focusing on South Africa's deployment of the carbon capture and storage (CCS) project and explaining its underlying structures and functions. In identifying the shortcomings of the TIS, this study further considers relevant contextual factors that affect the successful employment of the system, particularly the political economy of the energy sector. As a result, it develops an integrated framework that offers a more comprehensive understanding of the factors relevant to TIS implementation. Utilising a qualitative thematic analysis to analyse secondary data, the findings of our study reveal the pertinence of the power of incumbents and the lack of a legal framework. The results not only theoretically contribute to the innovation system field but also offer practical suggestions for the execution and management of technological projects in South Africa.

Keywords: Technological Innovation System, Carbon Capture and Storage, Political Economy, South Africa

1. Introduction

Emerging markets, also known as emerging economies, are nations that have numerous characteristics of a developed market but do not fully meet certain standards, such as the level of openness to foreign ownership, ease of capital movement and efficiency of market institutions (Amankwah-Amoah, 2016a). These countries are moving away from traditional economies that rely on agriculture and the export of raw materials; they are investing in more productive capacity and seeking to upgrade traditional industries (Amankwah-Amoah, 2016b). The rapid industrialisation among emerging markets has increased the need for power and electricity. In addition, it has led international organisations to request that emerging markets meet environmental protection standards and global sustainability goals (Edsand, 2019), including reducing the release of carbon dioxide and toxins into the atmosphere when firing coal for electricity generation.

South Africa is one of the largest emerging markets and part of the Brazil–Russia–India–China (BRICS) grouping. Although its tertiary service industries (e.g. finance, real estate and business services) have grown in significance, the primary and secondary sectors, including mining, manufacturing and transport, still contribute significantly to the national gross domestic product (Statistics South Africa, 2019). Compared with other BRICS countries, the economy of South Africa has relied heavily on coal for its energy supply. More than 80% of South Africa's electricity comes from coal, whilst renewables account for only 7% (African Development Bank Group, 2019). Even though international institutions have required the use of renewable energy and reductions in coal mining, replacing all the coal-fired power plants in South Africa is particularly challenging. Further, the evaluation of an alternative power source involves redefining energy policies based upon the existing geographical, economic, societal and environmental conditions (Pathak & Shah, 2019).

Therefore, in 2004, after an extensive assessment, South Africa agreed to implement carbon capture and storage (CCS), a technological system designed to remove CO_2 from flue gas and store it in an underground reservoir (Beck et al., 2013). South Africa received support from international institutions such as the World Bank for their CCS infrastructure development until alternatives such as wind power could be used to replace thermal power. However, although the CCS deployment should have begun in 2013, media outlets have reported that the implementation has not met the expected timeline; the unsatisfactory progress of CCS deployment in South Africa has also been indicated by the World Bank (2020a). Nevertheless, there is a significant lack of systematic reviews or analytical frameworks on the establishment and implementation problems of the CCS system in South Africa.

Previous research on CCS in South Africa has primarily studied geological storage (South Africa Coal Roadmap, 2011); however, Falcon (2016) argued that parts of South Africa have little suitable geology to undertake CO_2 storage. Recent research insights into the non-viability of CCS as a general technological innovation (Sanderson, 2019) might provide further explanations for the lack of progress made by South Africa's CCS project. Given its dominant position among African countries and its unique history and economic development, studying South Africa's CCS efforts can advance our understanding of the underlying contextual factors, including political dynamics, that influence the successful implementation of CCS.

By applying secondary data analysis, this study employs a technological innovation system (TIS) framework with a focus on the context of an emerging country. Furthermore, since a growing number of researchers (e.g. Dodgson, 2009) have argued that the quality of formal institutions such as regulations and government policies is vital for the effective implementation of TIS frameworks, we focus particularly on the political context. Building on Kern et al.'s (2016) and Jakob et al.'s (2020) analytical frameworks, this study aims to identify key actors and relevant contextual factors to develop a framework that integrates TIS and political economy approaches. The results will thereby not only improve our understanding of CCS in South Africa but also contribute to the innovation system literature and the policy research literature by emphasising the critical role of the political interests and decisions of key actors.

This paper is structured as follows. First, we review the existing CCS literature with a focus on emerging countries before introducing the South African context. We then introduce the TIS framework and focus on political economy in the energy sector. Next, we explain the research methods applied in the current study. In the results section, we present the relevant contextual factors in South Africa and develop an integrated TIS and political economy framework. The discussion of the findings is followed by concluding remarks, which include recommendations for researchers, industry members and government officials who continue to pursue CCS development in the country.

2. Literature review

2.1 CCS in emerging economies

CCS is an energy-related technology that has gained significant attention in recent years, as it captures up to 90% of the carbon dioxide emissions produced from the use of fossil fuels in electricity generation and industrial processes. It involves the transport of carbon dioxide to a storage location for long-term isolation from the atmosphere (Intergovernmental Panel on Climate Change [IPCC], 2005). Several studies that focus on emerging markets propose that CCS has the potential to benefit energy and technology development. A few of these studies also indicate that, even though CCS is recognised as a solution that reduces CO_2 emissions, it is not prioritised. These existing studies (see Table 1 for an overview) offer useful insights regarding CCS development in emerging countries, including the levels of public awareness. Support from stakeholders such as national governments are issues that need to be strategically evaluated and managed. Beck et al. (2017) review the current status of CCS in South Africa and, in line with Roman (2011), argue that the government plays an important role in steering the country's CCS programme. Previously, Beck et al. (2013) have reviewed the roadmap for CCS in South Africa, including an overview of the key stakeholders. However, there are some theoretical weaknesses within the existing studies, as they lack reviews on the challenges of CCS deployment through the application of a systematic framework with a political economy perspective, especially in those countries where politics and economy are expected to influence the process greatly.

Table 1
Existing CCS management-related academic studies

Author(s)	Country(ies)	Content
Shin et al. (2016)	South Korea	This study forecasts the demand for CCS technology using an integrated logistic model. The results indicate that the number of patent applications for CCS technology is expected increase to 16,156 worldwide and to 4,790 in Korea by 2025. With the development and application of CCS technology, CO_2 emissions are expected to decrease significantly by 2040 if these technologies can be adopted in Korea from 2020.
Lai et al. (2012)	China	Adopting a TIS perspective, this study evaluates CCS development in China. The results indicate that China's CCS innovation system has a strong functional capacity for knowledge and technology development. In contrast, the innovative functions of knowledge diffusion, market formation and facilitating entrepreneurs and new entrants into the CCS market are considered weak.
Roman (2011)	Brazil, South Africa, India	This study discusses the conditions for a large-scale application of CCS technology in developing countries. Current CCS-related activities and policies in Brazil, India and South Africa are compared. The results show that there are considerable hitherto-unknown incentives for applying CCS and that, in some cases, structural and political obstacles also create significant barriers.
Iglesias et al. (2015)	Brazil	Although it is not a highly carbon-intensive energy-use country, with most of its power generated from hydroelectricity, this paper summarises and describes the recent activities undertaken to promote CCS in Brazil.
Ağralı et al. (2018)	Turkey	Using data from Turkey, this study proposes a general algebraic modelling system (GAMS) approach that aims to minimise the net present value of the sum of the costs associated with the installation and operation of CCS technology.
Ha-Duong et al. (2017)	Vietnam	As Vietnam has plans to develop new coal-fired power generation units, this study indicates that CCS has technical potential in the country; two scenarios for 2050 are proposed, evaluated and examined.
Setiawan and Cuppen (2013)	Indonesia	This paper investigates stakeholder perspectives on CCS in Indonesia. Four perspectives are proposed: (1) CO_2 emissions reduction through clean energy sources rather than CCS, (2) CCS as one of the options in the transition to a sustainable energy system, (3) CCS as the only optimal solution to reduce CO_2 emissions and (4) CCS as a diversionary tactic to keep burning coal forever.

Beck et al. (2013)	South Africa	This study provides a review of the fundamental roadmap and planned timeframe for the deployment of CCS in South Africa, starting in 2004 and looking forward to its expected progress by 2025.
Beck et al. (2017)	South Africa	The World Bank Group CCS Trust Fund was established in 2009 to support CCS projects in developing countries, including South Africa. This study explores the World Bank CCS Trust Fund plans and provides an overview of the key stakeholders involved in CCS in South Africa.

2.2 CCS in South Africa

South Africa is a signatory to both the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, which form the roots of its climate policy. The country thus has a general commitment to reduce greenhouse gas emissions within certain targets (Mwakasonda & Winkler, 2005). The CCS project is under the authority of the Clean Energy Division. CCS was acknowledged as a clean development mechanism (CDM) under the Kyoto Protocol, through which a number of countries pledged financial support for CCS projects in developing economies such as South Africa (DoE, 2011).

As early as 2004, the South African government started investigating CCS as a technological project to complement initiatives engaged in reducing CO_2 emissions from coal-fired power stations. Numerous projects were implemented early on with support from international funders and local organisations. In 2009, the South African Centre for Carbon Capture and Storage (SACCCS) was established, and the development of a South African CO_2 Geological Storage Atlas was completed the following year. In 2011, an inter-departmental CCS task team was formed to facilitate CCS activities. From 2012 to 2017, Eskom and EcoMetrix Africa joined as partners of the Optimisation of CO_2 Capture Technology Allowing Verification and Implementation at Utility Scale (OCTAVIUS) project, part of the 7th Framework Programme of the European Commission. In 2019, SANEDI joined the Global CCS Institute, and South Africa’s carbon tax regulation went into effect on 1 June (Beck et al. 2013; DEA, 2012; EC CORDIS, 2014; Global CCS Institute, 2019; Department of Energy (DoE), 2019).

However, challenges to CCS development in South Africa include the slow progress of the development of CCS CDM (DoE, 2011), delays in implementing the CCS Roadmap (Global CCS Institute, 2019) and the unsatisfactory progress of the Technical Assistance Project for the Development of CCS in South Africa (World Bank, 2020a). This research investigates these problems with a holistic system approach and suggests further improvements.

2.3 Technological innovation system

2.3.1 Structure of TIS

Researchers (e.g. Carlsson & Stankiewicz, 1991) propose that as a dynamic approach, the TIS system involves several agents interacting in a specific economic and industrial environment and operating in a distinct institutional infrastructure. Further, they are engaged in the development, dissemination and utilisation of technology. Proponents of the TIS approach argue that technology-determining factors relate to individual firms and research institutes and to wider societal structures in which organisations are embedded. The TIS approach emphasises the need to develop and actively recombine knowledge to create new business opportunities. It has been widely applied to assess an innovation system's performance, *structurally* and *functionally*, at a certain stage and to identify the system's development problems.

Structurally, the *components* of the TIS dynamics include actors, networks and institutions (Carlsson & Stankiewicz, 1991; Hekkert et al., 2007; Bergek et al., 2008), as listed in Table 2. The actors comprise government bodies, industry, academic organisations, market players and non-governmental organisations (NGOs), whilst the interactions amongst the actors form the networks that together contribute to knowledge development, diffusion and utilisation of the focal technology. The institutions include formal institutions, such as legislation, regulation and industry standards, and informal institutions, such as norms, routines and shared practices.

Table 2
Structural components of TIS

Structural Components	Description
Actors	• Are essential elements for sustaining the system's structure. • Deliver functional performance that affects the system's development. • Differ for each TIS and context. • Emerge and are involved in different stages of system development.
Networks	• Are groups of actors with common or similar interests in an innovation system. • Are formed by actors who connect and interact to make collective impacts on or contributions to system development.
Institutions	• Serve as a formal directive or informal guidance for actors and networks to comply or follow in an innovation system. • Formal institutions legally govern actors, their actions and interactions. • Informal institutions provide connective functions to strengthen networks in the system, shape the interactions among actors and lead to a development path.

Sources: Carlsson & Stankiewicz (1991); Edquist & Johnson (1997); Hekkert et al. (2007); Bergek et al. (2008)

2.3.2 Functions of TIS

Researchers (e.g. Hekkert et al., 2007; Bergek et al., 2008; Markard & Truffer, 2008) propose major functions (see Table 3) that capture the performance-related contribution of a component or set of components that interact with each other (functions), resulting in virtuous cycles that transform an innovation system (Hekkert & Negro, 2009).

Table 3
System functions of TIS

System Functions	Description
F1: Entrepreneurial Activities	• Entrepreneurs include new entrants who envision business opportunities in new markets and incumbent companies diversifying their business strategy to take advantage of new developments. • Activities engaging in new technologies and applications can reduce the uncertainties impeding the development of a TIS.
F2: Knowledge Development	• Knowledge created through mechanisms of learning, including 'learning by searching' and 'learning by doing'. • Types of knowledge range from scientific, technological, production and market to design knowledge, whilst the sources of knowledge include R&D, learning from new production techniques or applications and imitation.
F3: Knowledge Diffusion	• Actors exchange information and scientific, technological or design knowledge that can facilitate the R&D of a TIS. • Knowledge exchanged through academic, industrial and government entities can bring policy and regulation-making in line with the latest technological insights.
F4: Guidance of the Search	• Incentives or pressures for firms and other organisations to enter a TIS and take part in its development, including beliefs and expectations in growth potential, policy and regulations, assessments of technological opportunities, technical bottlenecks and crises in current businesses. • The process of technological selection, allocation and the distribution of resources that can be fulfilled by the industry, the government or the market.
F5: Market Formation	• The creation of markets for the new technology, as markets are usually immature or do not yet exist for a developing TIS. • Creating a protected space is essential for a new technology/TIS to grow, including the establishment of temporary niche markets and the creation of temporary competitive advantages.
F6: Resource Mobilisation	• Financial and physical resources as well as human capital to be mobilised for all activities within the TIS where it evolves. • Financial resources comprise funding for R&D projects and capital investment for demonstration and commercialisation projects, whilst human resources are mobilised mostly through education and training.
F7: Legitimacy Creation	• The creation of legitimacy can help a TIS evolve in terms of public and social acceptance and compliance with the overthrow of relevant institutions. • The parties with vested interests generally resist the change required by an emerging TIS, whilst advocacy coalitions can create legitimacy by initiating the development of a new technology, putting it on the agenda, mobilising resources and lobbying for favourable policies and regulations.

Sources: Kemp et al. (1998); Bergek et al. (2008); Hekkert & Negro (2009); Hekkert et al. (2011)

The structural analysis of TIS identifies key actors, networks and rules that govern and maintain the system, whilst the functional analysis evaluates its state and performance. With the dual analytical frameworks, the TIS approach not only assesses the development of a specific technology but also analyses the systemic problems that hamper innovation so that further improvements can be made.

2.3.3 TIS with a political economy perspective

The TIS approach has been used to study various emerging technologies (e.g. Wieczorek et al., 2015). However, although the TIS framework is considered a comprehensive approach that demonstrates the relationships between the components involved in technological programmes (Bergek et al., 2015), it has been criticised for paying insufficient attention to contextual factors (Atteridge & Weitz, 2017). For instance, with a focus on developing countries, Edsand (2019) finds that issues such as corruption and informal and formal lobbying (e.g. from non-governmental organisations) significantly affect the work of formal institutions. Therefore, Edsand (2019) proposes an analysis of contextual factors such as economic growth, environmental awareness, climate change, armed conflict and unequal access to higher education.

For the context of South Africa, Business Monitor International (BMI) (2014) describes the country as one of the most advanced business environments in sub-Saharan Africa, being built on strong government institutions that provide relative political and economic stability and attract foreign investors. Amankwah-Amoah (2016b) indicates that historical contingencies play a significant role in both government policies and technological change. Power et al. (2016) argue that South Africa's energy sector and the political decisions related to it are heavily shaped by the nation's current social, political and economic context. Therefore, for understanding CCS in South Africa, we advance the TIS approach by focusing explicitly on political-institutional systems and government-driven objectives, frameworks and measures related to the energy sector as well as project characteristics that also influence the outcome of TIS implementation.

The political economy perspective focuses on the relationships between key actors and how these relationships shape resource allocation and project outcomes (Gamble et al., 1996; Atteridge & Weitz, 2017). The political dimension of energy transitions is a greatly understudied area in emerging markets (e.g. Markard et al., 2015; Power et al., 2016), and we aim to shed light on the potential systemic weaknesses by analysing collective action and the conflict that may arise due to the unequal power distribution between actors in South Africa. These power differences derive from disparities in access to ideational (knowledge, political connections), institutional (power relations within and across government) and material (technology, finance, production) resources (Krammer & Jiménez, 2020).

3. Methodology

A systematic analysis of secondary qualitative data has been undertaken. As Elahi (2008) argues, sources for primary data collection in developing countries are often restricted to state institutions. These state-based departments might face internal problems such as poor institutional setup and weak infrastructure as well as external issues such as low literacy rates and a lack of awareness regarding data collection. Riedel (2000) indicates that a secondary data analysis allows researchers to evaluate the functioning of various agencies. Thus, this method is appropriate for analysing the various roles that different stakeholders play in this project. We are fully aware that the use of secondary data elicits the central challenge that the researcher is removed from the data and the contexts in which they were generated; however, we also see this as advantageous, as our distance from the data allows us to be reflexive and critical and to challenge existing explanations (Irwin, 2013).

The analysis began by identifying the structural TIS components of the system (actors, networks and institutions). Subsequently, the TIS functions were evaluated and the mechanisms that either drove or blocked the development into the expected functional pattern could be identified with key policy and economic factors and issues.

3.1 Data collection

To collect data, we systematically searched and cross-reviewed the data and documents available from the start of the project in 2004 until mid-2020 to understand the CCS development and the underlying political and economic dynamics. The majority of the data sources used were official websites of the South African government, annual reports, consultancy reports and international conference presentations published by international energy and CCS-related institutes (e.g. the Global CCS Institute). Peer-reviewed journals (e.g. *Energy Policy* and the *Journal of Environmental Management*) and news articles from global-scale publishers were analysed (e.g. the *Financial Times*) for triangulation verification purposes (O’Donoghue & Punch, 2003).

3.2 Data analysis

For data analysis, we applied Hekkert et al.’s (2011) framework and evaluated the data in relation to the seven functions of TIS introduced above (entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilisation and legitimacy creation). We also identified key stakeholders (such as local and national governments, private organisations and media outlets) and their roles in this project. Based on Braun and Clarke

(2006), we used the thematic analysis approach to code the documents using the seven functions mentioned above as themes, with subsequent cross-checking to ensure accuracy and consistency. The key activities were then sorted chronologically to identify potential gaps or delays.

4. Results

4.1 TIS structural analysis for CCS in South Africa

The structure of a technological innovation system is essential for the steady growth of a system and particularly its technological development. Embedding the TIS approach in the wider political economy (PE) framework allowed us to identify the importance of adequate policy and regulatory frameworks as well as point to the significance of an effective balance between government-funded organisations and private companies in order to provide the needed efficiency and know-how. For the structural analysis of CCS TIS in South Africa, this research identified the key actors, networks and institutions that were involved in or established for system development.

The key actors in the South African CCS context comprise government bodies, industry, academic organisations, market players and NGOs, whilst the interactions among them form the networks that contribute to knowledge development, diffusion and the utilisation of the focal technology. Key actors are summarised in Table 4, before their different objectives and power relations are presented.

Table 4
Overview of key actors in South Africa's CCS project

International Support Organisations	• **World Bank:** invested 1.35 million USD for Pilot CO_2 Storage Project in SA, and 27.4 million USD in 2014 to support the feasibility assessment, the building of expertise and a review of the legal and regulatory framework • **EU, UK, Norwegian and German governments:** supported CCS with financial resources and technological R&D collaborations
South African Government	• **Department of Mineral Resources and Energy (DMRE):** responsible for the energy security of the country, with a primary focus on integrated energy planning, regulating the energy industry and promoting electric power investment • Former **Department of Energy:** main authority in CCS project, overseeing CCS policy, the legal regime and regulatory frameworks • **Department of Environmental Affairs (DEA):** regulation of existing and new coal-fired power plants to retrofit the carbon capture technology in their infrastructure • **National Treasury (NT):** Carbon Tax Bill (2019) • **Department of Water Affairs (DWA):** addresses environmental issues associated with CCS-related activities and regulations • **Inter-departmental task team:** DoE, DMR, DEA, DWA, NT, the Department of Science and Technology and the Department of Trade and Industry
CCS-related Public Sector Organisations	• **Council for Scientific and Industrial Research (CSIR):** investigates the potential for CCS in South Africa • **SANEDI:** main government agency responsible for energy-related R&D and technology innovation promotion; established SACCCS in 2009, which assessed the technical feasibility of CCS and produced the CCS Roadmap • **Council for Geoscience:** investigated potential storage locations and, in 2010, produced the Atlas
Domestic Energy Suppliers	• **Eskom:** state-owned electricity supplier in a monopolistic position with severe financial difficulties • **South Africa Synthetic Oil Liquid Limited (Sasol):** energy and chemical company • **Petroleum Oil and Gas Corporation of South Africa (PetroSA):** state-owned company that supports SACCCS and co-developed the Atlas on the Geological Storage of Carbon Dioxide in South Africa • **Anglo American:** private mining company that supports SACCCS and the Clean Coal Centre of the IEA
External Consultancies and Advisors	• **Environmental Resources Management (ERM) South Africa:** appointed by the World Bank; responsible for assessing the legal and regulatory framework • **Parsons Brinckerhoff consultancy:** technical and economic review of CO_2 sources and potential storage locations; supported the Council for Geoscience in the creation of Atlas and also provided services for SANEDI, Eskom and Sasol • **SRK Consulting South Africa:** supports the development of national and local stakeholder engagement plans
Non-governmental Organisations	• **Batelle:** provides technical advisory services with the goal of 'ensur[ing] that South African organisations will be able to plan, construct and operate future carbon capture and storage projects on their own' (Batelle, 2017) • **Greenpeace Africa:** opposes CCS • **WWF South Africa:** opposes CCS
Research and Educational Institutes	• **University of Pretoria (UP):** Carbon Storage Working Group organised in 2012 to research geological approaches to storing CO_2 • **University of Witwatersrand (UW):** Clean Coal Technology Research group that pushes CCS in research and education • **University of Western Cape:** hosted CCS Workshop 2019, funded by the UK's Royal Academy of Engineering

Sources: Glazewski et al. (2012); Power et al. (2016); Batelle (2017); Beck et al. (2017); Global CCS Institute (2019); National Treasury South Africa (2019)

During the process of categorising key actors, the following findings were identified as direct and indirect barriers when implementing CCS in South Africa:

4.1.1 Powerful incumbents of the energy industry in South Africa

Although the South African government has faced massive pressure from international funders to restructure its energy sector, researchers highlight that the incumbents in the energy industry are very powerful and able to protect their interests (Baker et al., 2014; Rennkamp, 2019), as the South African economy is heavily dependent on traditional fossil-based energy suppliers. In emerging markets such as South Africa, green energy projects are substantially supported and influenced by international organisations and research institutes with the aim of mitigating the effects of climate change and encouraging developing countries to engage in related initiatives. They often encounter key stakeholders in the public sector, such as national and local governments, political parties, regulatory agents, research institutes, universities and industry associations with strong domestic interests and power relations, which might be in line with or in contradictory to international directives.

In terms of political economy, the energy sector is controlled by large incumbent companies that seek to influence policy. Politically, the private sector and civil society develop a strong interest in policy making as they are directly or indirectly affected by it (Jakob et al., 2020). South African energy firms such as Eskom lobby aggressively to protect their interests and are even more powerful than government departments, and there is evidence of strong resistance towards change (Baker et al., 2014; Rennkamp, 2019). Due to their accumulation of capital, their ability to control energy production and their significant contribution to the South African economy (Ashman, Fine & Newman, 2011), as well as their privileged access to various key ministries, the government cannot politically afford to offend these industries. This leads to a reciprocal relationship between energy provision and policy making that can influence the progress of energy transition programmes.

In South Africa, the strong dependence on fossil fuels and the advancement of existing technologies in coal mining make it all the more difficult for the national government to develop strong enough incentives to encourage local energy incumbents to support projects when their effectiveness is not yet proven. One example is South Africa Synthetic Oil Liquid Limited (Sasol); it has been a powerful actor in the energy sector and possesses significant financial and human resources. The firm has been instrumental in delaying the introduction of a carbon tax. Its links to the government are strong but often marked by conflicting interests. For example, in 2019, Sasol used its legal resources to sue the government over legislation related to air (Sguazzin, 2019). In terms of the

CCS project, it has actively participated in the investigation of potential storage capacities and supported the development of the CCS technology chain with its expertise and experience. Sasol's and Eskom's support for CCS is vital and would also send signals to other stakeholders as, together, they are 'responsible for more than half of the country's emissions, which altogether amount to more than 400 million tons of carbon dioxide a year' (Flak, 2009).

4.1.2 The importance of the current economic situation

The GDP of South Africa has not seen expected growth in recent years, and the South African government currently faces massive pressure to restructure its energy sector. This is, first, because its main supplier, Eskom, is struggling to service approximately 30 billion USD of debt, and it expects a roughly 20 billion USD loss in the current year. International banks have described Eskom as the biggest current threat to South Africa's economy. The government has agreed to support Eskom with about six billion USD over the next years in addition to 16 billion USD of bailout spread over the next decade, although it is not clear where it would find the required resources (BBC, 2019; Reuters, 2019). Second, PetroSA, the national oil and gas exploration and production company, has also been confronted with financial problems since 2014 due to serious maladministration and corruption, as well as its poor quality of diesel and gradual loss of clients (Skiti, 2018). This means that the two major industrial actors in South Africa have been in crisis with two serious problems: high operating costs and the inability to pay off debts (Crompton, 2019). These organisational inefficiencies and financial difficulties have affected the government's capability and resources to concentrate on CCS development, which points to the political-institutional factors. It can be assumed that these corporate failures contributed to the slow progress in developing CO_2 storage projects.

4.1.3 Government-internal power conflicts

Furthermore, severe power struggles and competition exist within the South African government and its different departments. Legislative power seems fragmented between key departments, for example, the National Treasury and the DEA, which have developed separate processes and lack support from the presidency and other government departments- and this seems to be one of the problems when implementing CCS (Rennkamp, 2019).

4.1.4 Opposing voices from environmental non-governmental organisations

Although CCS is recognised as one of the main options for effectively reducing CO_2 emissions from large point sources, environmental non-governmental organisations (ENGOs) such as Greenpeace Africa, one of the major ENGOs opposing CCS, argue that its adoption is merely an excuse to extend the use of fossil fuels for power generation (Greenpeace Africa, 2011). Greenpeace Africa maintains that CCS is a short-term approach to the immediate reduction of CO_2 emissions from existing fossil-fuelled power plants and that it could be a long-term mitigation option if it is combined with biomass energy generation (Viebahn et al., 2015). WWF South Africa has also criticised the South African government's recent policy and denied that the CCS solution would help reduce coal-fired power. The organisation expressed concern that the plan would not respond in good time to the climate crisis, as recently highlighted by the IPCC. The WWF thus urges that efforts and financial resources should be transferred from building new coal power plants with CCS infrastructure to further developing renewable energies (WWF South Africa, 2019). Figure 1 presents the results of the structural analysis with a PE focus.

Institutions – framework providers (norms and rules makers)

- Department of Environmental Affairs developed the ‘Carbon Capture Ready’ regulation which requires existing and new coal-fired power plants to retrofit the CCS technology on the plant infrastructure.
- Carbon Tax Bill (published by the Treasury).

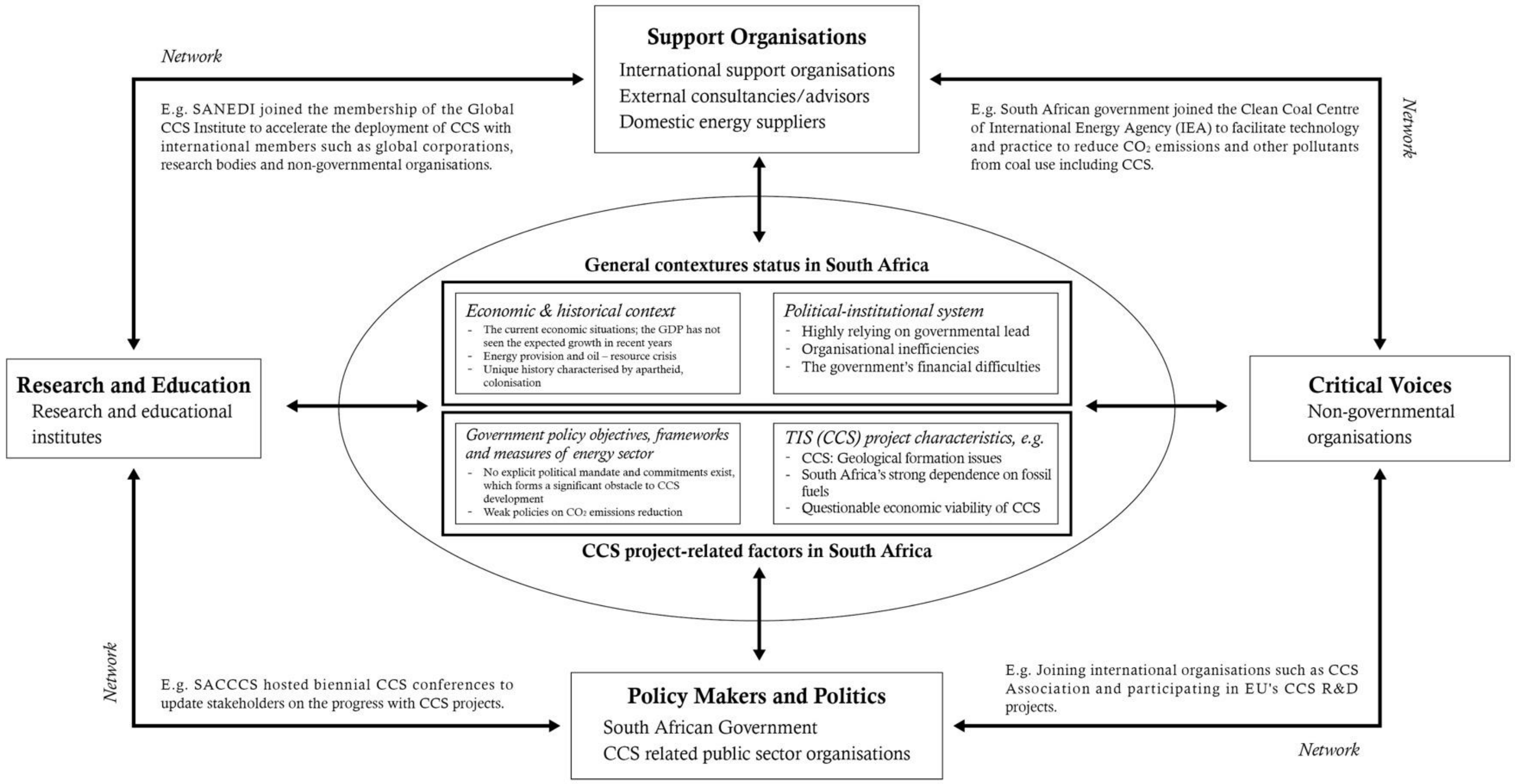

Fig. 1. Structural analysis of CCS in South Africa with a PE focus

4.2 TIS functional analysis for CCS in South Africa

4.2.1 Functional dynamics

The build-up of the technological innovation system of CCS in South Africa started in 2004 with the assessment of its countrywide potential, which was commissioned by the then Department of Minerals and Energy and completed by the Council for Scientific and Industrial Research (CSIR). The result of the assessment confirmed the potential for CCS, which not only generated knowledge (F2) but also provided guidance of the search (F4) for further development. The South African government then sought financial support (F6) to establish the South African Centre for Carbon Capture and Storage (SACCCS) in 2009, whilst the funding came from government, industry and international stakeholders, such as the World Bank.

Following the mandate for CCS development, SACCCS produced a CCS Roadmap comprising five stages, which strengthened the guidance of the search (F4), whilst the Roadmap was further endorsed by the South African Cabinet in 2012 (F7). CCS was recognised as one of the options for reducing CO_2 emissions in the government's long-term mitigation plan (Glazewski et al., 2012). After the first stage of the measurement, the Atlas on the Geological Storage of Carbon Dioxide in South Africa (Atlas) was produced by the Council for Geoscience and completed in 2010 (F2), whilst the Atlas project was funded by the South African National Energy Research Institute (SANERI) and industrial stakeholders (F6), including Eskom, PetroSA, Sasol and Anglo American (SA News, 2010). Atlas was recognised as an important milestone for identifying CO_2 storage sites in the country with 1.5 giga-tonnes of potential capacity, of which 98% would be located offshore (SA News, 2010; Global CCS Institute, 2019).

In addition, SACCCS took the lead in distributing and exchanging CCS knowledge (F3). The Centre also worked with representatives of academia and industry to hold CCS workshops and conferences to update the progress of CCS and exchange R&D knowledge amongst stakeholders, whilst international partners were invited to share their expertise and experience with the aim of establishing collaborations and transferring CCS competence to South Africa (F3). Moreover, the Centre conducted stakeholder engagement programmes to raise awareness of CCS for climate change mitigation whilst also taking part in developing the CCS legal and regulatory framework to increase legitimacy (F7), as well as providing guidance of the search for further development (F4). For education and training, the Centre also offered funding to support students working on CCS-related research through its bursary scheme (F6).

4.2.2 The blocking mechanisms

The development of functional dynamics in South Africa's CCS TIS to date shows that the inducement mechanisms were formed at an early stage by the government's actions on developing the CCS Roadmap with strong guidance (F4), supporting knowledge development through the CCS potential and Atlas studies (F2) and establishing SACCCS as a major coordinator and platform for knowledge exchange and diffusion (F3). However, the dynamics of the early stage have not gained enough momentum to further develop the next stage, resulting in a delay in commencing the Pilot Carbon Dioxide Storage Project, which was expected to begin in 2017 (Global CCS Institute, 2019). The functional analysis of this research identified several blocking mechanisms that impeded the system's growth and resulted in the delay.

Consultancy firms have assisted in developing a partially new regulatory framework (see Beck et al., 2017, for a detailed overview), although the final legislative power has remained exclusively in the hands of the government (Rennkamp, 2019). Despite these efforts, the IEA (2019) has suggested that South Africa does not have a functioning legal and regulatory framework dedicated to CCS, leaving uncertainties for stakeholders, in particular investors.

This delay in completing the legal and regulatory framework for CCS has been identified as one of the major obstacles to further development as it weakened the guidance of the search (-F4) and hurt its legitimacy (-F7), which signalled uncertainties to investors. A lack of entrepreneurial activities (-F1), whether by incumbents or start-ups, is another weakness that blocked system development, as there was no sufficient funding support (-F6) for new projects on CCS innovation (Beck et al., 2013). The current CCS R&D activities remain mostly in universities, but they are not yet ready for large-scale demonstration or commercialisation. The absence of successful full-chain CCS pilot or demonstration projects in South Africa (Global CCS Institute, 2019) results in lack of important technical knowledge for scale-up (-F2). As a result, the weaknesses mentioned blocked market formation due to insufficient supply and demand for CCS technology (-F5).

We have observed that no explicit political mandate and only limited commitment exist, presenting a significant obstacle to CCS development in South Africa (Ngwenya, 2019). This barrier is linked with the government policy issue. For example, former President Jacob Zuma, who was in office from 2009 to 2018, spoke up for action on climate change; however, his government was criticised for weak policies on CO_2 emissions reduction (Carbon Brief, 2018). Recent changes in the national government were identified as causing delays in pursuing the CCS project further (Aidstream, 2017).

Furthermore, the Carbon Tax Act of South Africa, first proposed in 2010 by the National Treasury, was identified as a least-cost market-based instrument to reduce greenhouse gas emissions (Glazewski et al., 2012). However, the carbon tax bill had been postponed several times due to opposition from energy-intensive industries, although it eventually came into effect on 1 June 2019 with the first-phase tax rate of 120 rand ($8.34) per tonne of carbon dioxide. The impact of the tax does not yet seem significant (-F5) and will be assessed before the second phase from 2023 to 2030, because opponents, such as Eskom, are concerned that it would increase electricity prices and erode profits (Toyana, 2019).

With a view to inducing or blocking policy mechanisms, MacDowall et al. (2013) argue that associated policies in the formative stage of an innovation system relate to raising awareness and enable the involvement of a wide range of stakeholders. Although we found evidence that the South African government aimed to involve a wide range of stakeholders in order to achieve acceptance among the population and knowledge advancements in schools and universities, these initiatives, compared with those in developed countries, were rather limited. As a second policy initiative, MacDowall et al. (2013) propose that the government support the establishment of new industries and, again, for the South African context, we found that because of the strong power of existing energy incumbents, new companies and even industries could have been supported more vigorously.

5. Discussion and conclusion

For this research, the TIS framework with further consideration of the relevant political-institutional context provided valuable insights into the dynamics relevant for the development, diffusion and adoption of new technology, i.e. CCS in South Africa (Atteridge & Weitz, 2017). Our analysis has revealed that energy industry incumbents, the South African government (mainly the DMRE) and international support organisations are the key actors that significantly impact the related functional dynamics of the CCS TIS in South Africa. The establishment of the South African Centre for CCS and the launch of the South African CCS Roadmap with support from those key actors were recognised as the major forces to drive the functional dynamics, including the significant guidance of the search and the network for knowledge development and diffusion. However, those dynamics have not led to sufficient momentum towards further growth of the TIS due to some weaknesses, in particular knowledge accumulation and technological absorptive capacity which have also been identified in other emerging countries (Edsand, 2019).

These project-specific findings might also help to explain the main issue identified in this research, which relates to a failure to meet the level of financial investment necessary to support the project over the long term. We found that the financial capital mainly comes from external funders, such as the World Bank, which might imply that the South African government cannot contribute sufficient financial resources. Other factors contributing to the lack of investment have been identified as the lack of trust in the South African government – mainly owing to the lack of a political mandate and a functioning legal framework, which would provide clarity and transparency (Ngwenya, 2019).

The introduction of CCS potentially meant that existing power structures and the financial situation of incumbents would be challenged. Owing to the historically evolved power of the coal industry and the strong dependence of the country on coal-based energy, these incumbents possess political connections (ideational power) and substantive material power in the form of production and financing. Incumbents might be resistant to change and hesitant to invest human and financial resources in the CCS project. Our findings indicate that the economic situation of two major industrial actors (Eskom and Sasol) seem to have influenced the CCS project significantly, as their organisational inefficiencies and financial difficulties have arguably affected the government's focus on the programme (as indicated in the lack of information about CCS in the Annual Report of the (DMRE), 2019). Due to their financial issues, these incumbents have not been in a position to adequately contribute resources. They have also already had to deal with the newly introduced carbon tax.

We further find that the South African government is in a difficult position due to being obliged to fulfil the conditions linked to the financial support of international funders and having to deal with powerful incumbents of the affected domestic energy-related industries. Along the same lines, Rennkamp (2019) finds that current changes in South Africa's climate policy are precarious as the government has limited power and capacity to initiate effective change, and the current industry incumbents are too powerful in protecting the status quo.

5.1 Implications of findings

This research has shown that the current TIS approach neglects the explicit focus on political and institutional dynamics needed to support the effective implementation of new technologies in emerging economies (as identified by Power et al., 2016). It adopted a deeper analysis of the political, economic and social actors, their interests and objectives, as well as relevant contextual factors, in order to better understand the struggles in implementing TIS. The study therefore contributes to the innovation system literature and the policy research literature by emphasising the important role of political decisions and the interests of key actors. From the practice perspective, as contexts in other emerging markets are expected to be similar, we argue that other countries can benefit from our findings. For example, the difficult position of the national government to deal with powerful key stakeholders and their conflicting interests is expected to be evident in other emerging countries (Edsand, 2019).

Some of the most important policy conclusions of this research are that a clear political mandate and legal framework must be established in South Africa to manage incumbents' interests and objectives and provide confidence to investors. Market structures, as well as institutional and system structures, need to function well to avoid failure when introducing new technology innovation. In South Africa, international investment and experience are still vital due to its current economic slowdown and the severe financial struggles of existing energy companies.

Based on the findings, we can provide the following recommendations: First, the legitimisation of CCS needs to be enhanced further with the support of international policy mechanisms and by international experience (MacDowall et al., 2013). To address the lack of a legal and regulatory framework for CCS (Function 4 of the TIS), South Africa could adopt the essence of other countries' related regulatory frameworks that were considered sophisticated and granted high scores by the 2018 CCS Legal and Regulatory Indicator Report (Global CCS Institute, 2019).

Second, in line with Amankwah-Amoah (2016b), we found that government policies and resource allocation must be strongly aligned to promote the successful implementation of innovation systems. More specifically, policies are needed to facilitate private sector investments, with incentives for local and international investors that support the project in the long term. The government could develop a public funding scheme that supports existing large companies to focus their internal R&D projects on CCS. As the CCS project evolves, more key actors will emerge for further reinforcement of the system structure. In response to the limited number of international R&D collaborations (Function 3 of the TIS), the actors should seek further international expertise through more frequent international collaborations in CCS R&D so that more advanced knowledge can be developed in South Africa whilst building domestic capabilities.

Our review has revealed that the current system still appears to lack domestic technology suppliers, either incumbents or start-ups, for CCS innovations and the integrated CCS chain (World Bank, 2016, 2020a, 2020b). Therefore, robust policy support from the South African government is needed to support related domestic industries that might then enhance investor confidence. This process seems to be influenced, however, by the power of the existing industry players, in this case, fossil-fuel electricity generation, oil and gas production, and coal mining and processing industries. Due to the significant power imbalances identified in this study, we recommend that, to improve the creation of legitimacy for CCS (Function 7 of the TIS), supportive organisations in South Africa form CCS associations or alliances to lobby for progress with more favourable conditions for the industry. The establishment of common goals and targets regarding the sustainable development of CCS, based on appropriate incentives, could help align the varying objectives and interests of the stakeholders involved, as identified in this study.

5.2 Limitations and suggestions for future studies

We suggest that future studies consider a longitudinal approach for tracking the effects of particular activities such as changes in actors' roles and functions on CCS practice over time. They could also investigate how the project may reference CCS implementation experience from developed countries and learn from successful and unsuccessful cases. A systematic comparison of the different energy transition initiatives in other emerging countries might further be useful to identify common systemic problems, which could then be addressed by researchers and funders.

Although the secondary data helped to identify the progress and problems of CCS development in South Africa, future researchers are encouraged to collect primary data and take more specific views on CCS issues. For instance, they are advised to look into CCS-related policy making and political cultures in South Africa, governmental leadership in this area, the technological infrastructure and the management of industry–academia cooperation. This might also reveal more relevant contextual factors that have not been considered in this research. We also acknowledge that the numerous actors involved have different interests (Markard et al., 2015). As a result, we suggest that future researchers investigate the micro-level dynamics between the actors involved as well as consider the role of any new actors as the project evolves.

Awareness of the related contextual factors and the political economy perspective can enable effective decision making when planning and executing TIS projects. However, we acknowledge that each country has a unique political economy based on its particular historical, economic and political contexts (Bergek et al., 2015; Amankwah-Amoah, 2017). We hope this study will attract further attention from researchers and practitioners to study the interplay between technology innovation systems and the political structure of emerging economies.

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Dr Yu-Chia Ko is Assistant Professor in innovation management and policy at National Chengchi University. He holds a PhD in Business and Management, a Master of Public Affairs in Environmental Policy, and an MBA in Technology Management. His-research interests focus on sustainable innovation management and policy.

Dr Krystin Zigan is Assistant Professor (lecturer) in strategic management at Kent Business School, University of Kent. Her research interests are in political economy, leadership and the impact of social media activities on business performance. She has published her work in journals such as Tourism Management, Journal of Business Ethics and Journal of Travel Research.

Dr Yu-Lun Liu is Assistant Professor in marketing at National Taipei University of Technology. He holds a PhD in Business and Management, and an MBA in Commerce Automation and Management. Yu-Lun obtained years of work experience in an IT company as a software engineer. He has a particular interest in information systems and technology management. He also has interest in online consumer psychology and consumer behaviour.