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Electricity portfolio innovation for energy security: The case of carbon constrained China

Konstantinos J. Chalvatzis [a,b,*], Keagan Rubel [c]

[a] Norwich Business School, University of East Anglia, Norwich NR4 7TJ, UK
[b] Tyndall Centre for Climate Change Research, University of East Anglia, Norwich NR4 7TJ, UK
[c] Mr. & Mrs. S.H. Wong Center for the Study of Multinational Corporations, 1922 Tice Valley Blvd., #2460, Walnut Creek, CA 94595, United States

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ABSTRACT

China's energy sector is under pressure to achieve secure and affordable supply and a clear decarbonisation path. We examine the longitudinal trajectory of the Chinese electricity supply security and model the near future supply security based on the 12th 5 Year Plan. Our approach combines the Shannon–Wiener, Herfindahl–Hirschman and electricity import dependence indices for supply security appraisal. We find that electricity portfolio innovation allows China to provide secure energy supply despite increasing import dependence. It is argued that long-term aggressive deployment of renewable energy will unblock China's coal-biased technological lock-in and increase supply security in all fronts. However, reduced supply diversity in China during the 1990s will not recover until after 2020s due to the long-term coal lock-in that can threaten to hold China back from realising its full potential.

1. Introduction

1.1. Background on energy and electricity supply security

Access to energy is one of the most important aspects of modern and developed economies. Its importance extends wider than that of other commodities because without it they cannot be produced, delivered to the market, or used. Energy is used in all primary and secondary forms but during the last two decades the role of electricity has been rising (Armaroli and Balzani, 2011). This is not only a result of a proportional increase in energy consumption but also of a substitution of fuels with electricity. For example this is taking place in buildings as electricity increasingly substitutes oil and gas for temperature control and cooking. It is also evident in rail and road transport with urban and intercity trains as well as private vehicles becoming electrically powered. Finally in industrial processes electricity substitutes steam driven processes (Khatib, 1993; Balat, 2006; Kalkuhl et al., 2012; Turton and Moura, 2008; Shi and Lai, 2013).

Electricity is a flexible form of energy not only for consumers but also for producers. As a secondary energy carrier electricity can be generated with the use of primary fuels or renewable energy resources. Therefore producers do not have to rely solely on a certain fuel. When electricity is produced by renewable energy sources then it is the only form of energy with minimal environmental impact (Armaroli and Balzani, 2011; Blesl et al., 2010; Knapp, 1999).

Given the necessary role for energy and electricity in national security and economic development, it is not a surprise that securing their supplies is implicitly or explicitly amongst the top priorities of every country. Following the definition for energy supply security by Grubb et al. (2006) energy supply can be considered secure when its price does not disrupt the economy. This definition goes a step further than a simplified approach that is based on resource availability i.e. the resource supply is secure when it is available. The introduction of price puts forward the dimension of affordability which is paramount for energy supply security. Moreover, this price is not introduced at an absolute level but one that is relative to the capacity of a given economy to absorb it. At a national level, governments use a number of strategies to ensure supplies such as utilising indigenous resources, improving foreign relations with energy producing countries and facilitating efficient operation of energy markets (Flavin and Dunn, 1999; Energy Security in a Multipolar World (ESMW) Research Cluster, 2011; Nuttall and Manz, 2008). In this paper we examine the role of electricity portfolio innovation in combining seemingly conflicting targets i.e. electricity supply security and climate change mitigation. The approach adopted is focused on technology policy innovation in a way that differentiates it from a technology research approach.

Diversity of production methods is a major strength for electricity supply security (Stirling, 1994). However, most of the energy security literature refers to primary energy resources and electricity tends to be under-represented in energy security research. A main reason for

* Corresponding author at: Norwich Business School, University of East Anglia, Norwich NR4 7TJ, UK.
E-mail address: k.chalvatzis@uea.ac.uk (K.J. Chalvatzis).

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this is that electricity does not rely on a single resource for its production since it is produced in numerous ways; thus it requires a broader understanding of the energy context in order to encompass existing and alternative generation scenarios as they impact stability of supply and price dynamics. Furthermore, in contrast to most other commodities, electricity is not easily stored in a financially viable way. Therefore storage is a missing link in electricity's supply chain, although this excludes solutions that would suggest buffering (Makansi and Abboud, 2002; Zafirakis et al., 2013a; Poudineh and Jamasb, 2014). Whilst there is significant capacity for energy storage in China, this is an evolving issue both in means of policy (Zhanga et al., 2015) and development of technological solutions (Yang et al., 2015).

On top of the difficulties that concern securing electricity supply, the electricity sector is a leading source of greenhouse gases (GHGs) in many developed and emerging economies. It also is the most concentrated sector in terms of emissions per source, and accounts for more emissions than any other sector (Metz et al., 2007; Verbong and Geels, 2010; Kaldellis et al., 2004). At the same time potential reductions in the carbon intensity of the electricity sector can benefit other sectors, which can be partially electrified. For these reasons policies to reduce GHGs in most countries target primarily the electricity sector (Australian Government Productivity Commission, 2011; van den Bergh, 2013). Reducing the carbon intensity of the electricity sector may include policies such as increased use of renewable energy sources and nuclear energy, substitution of coal with natural gas where possible, introduction of carbon capture and storage (CCS) technologies as well as efficiency improvements in existing power stations. Arguably, several of these substitutions, change the electricity sector's fuel mix and as a result contribute to changes in the electricity supply security (Chalvatzis, 2012; Zha and Ding, 2014). By focusing on electricity portfolio innovation we model the impacts of these substitutions and offer a technology mix forecasting tool and analyse multiple levels of impacts including environmental, social and technological.

1.2. China as a case study

China is currently managing the largest programme of low carbon technologies in the world (World Bank, 2012). This includes unprecedented investment in nuclear energy and renewables, particularly hydro and wind energy. This is not always incentivised by policies that could have wider social benefits (Zafirakis et al., 2013b) but rather is driven by a "dash for electricity generation". At the same time, the Chinese government's 2012 Energy Policy (Chinese Government, 2013) lists increased coal production amongst its top five key targets. This is not a surprise because the Chinese electricity sector relies heavily on coal. Until 2009 coal used for electricity came almost exclusively from indigenous resources in China. However, gradual ore depletion, increasing direct coal consumption and rapidly growing electricity demand led China to become the world's largest coal importer soon after it started importing (International Energy Agency (IEA), 2012). In parallel, the supply of nuclear fuel to China relies heavily on imports; it is forecast that by 2020, 2/3 of uranium sources will be imported, roughly half of all non-indigenous sources coming from foreign imports and half from Chinese overseas possessions (Xie et al., 2011; Guidolin and Guseo, 2012). The forecast increased energy demand (particularly fossil fuels) is one of the main reasons for which China has not subscribed to international agreements to control emissions of greenhouse gases.

With regard to nuclear power China is leading the world in the second phase of what is often called the "nuclear renaissance" (Grimes and Nuttall, 2010), referring to the post-Chernobyl and Three Mile Island rapid development of nuclear energy that takes place mainly in Asia. The IAEA suggests that 72% of the reactors currently under construction are found in five countries China (29 including 2 at Taiwan); India (6); South Korea (5); Pakistan (2); and Russia (10) (International Atomic Energy Agency (IAEA), 2014). However, recent studies cast doubt on the uranium supply over the forthcoming decades (Guidolin and Guseo, 2012; Dalla Valle and Furlan, 2014).

The aim of this paper is to introduce electricity portfolio innovation as an approach the can successfully deliver on conflicting targets. China provides for an excellent case study to demonstrate dominant paradigms of energy supply security in the past, present and future as they are reflected in energy policy transitions. Even though China has a rapidly developing economy, the legacy of its energy sector creates strong pathway dependencies that need to overcome. Methodologically, we contribute a multi-perspective technology planning tool that bridges strategic views of the past with those of the present and the future.

This manuscript continues with a brief description of the case study i.e. the Chinese electricity sector and its specific challenges. Following that, in the third section we describe the methodological approaches used for assessing electricity supply security. In this section there is explicit reference to the data that was used for this study. The fourth section presents and discusses our results and finally the paper concludes with the implications beyond China's borders of electricity security in China.

2. Electricity sector of China

2.1. Current situation

China's electricity sector is the largest in the world, and electricity consumption in the country reached 5322 TWh in 2013 (National Energy Administration, 2014), with generation expected to rise to 9845 TWh by 2020 (State Grid Energy Research Institute China, 2013) (Fig. 1). China is the world's largest consumer of coal and its electricity sector is the largest single source of coal demand, consuming approximately half of the country's coal.

Prior to economic liberalization in 1978, China's electricity sector was operated by the Vertically Integrated State Owned Utility (VISOU), which has undergone significant transformations and is now privatized and dismantled (Ma and He, 2008). The resulting competition increased the generation capacity that was needed to satisfy China's growing demand, which comes primarily from the industrial sector; from 1980 to 2012, electricity generation grew 16-fold and is projected to continue (Kahrl et al., 2011a; Wei et al., 2006). Energy security concerns dictate that China meet its electricity needs with domestic resources, resulting in a system heavily reliant on coal. Recent developments and national policy demonstrate China's will to diversify its primary fuel mix in electricity generation. However, exploitation of coal resources is the top national energy priority (China National Renewable Energy Centre, 2013).

Approximately 75% of China's electricity demand comes from continuous production industrial facilities, causing a relatively flat demand profile. This flat profile is conducive to China's predominately inflexible base-load generation, however leads to integration problems for

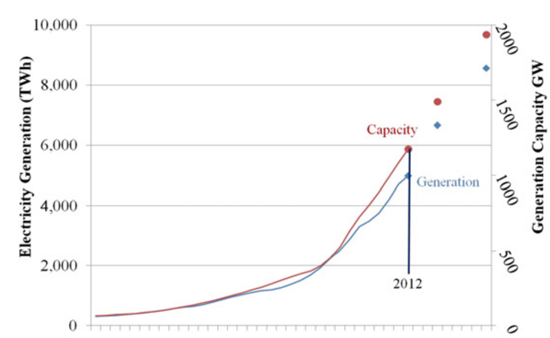

Fig. 1. Past and projected electricity generation and electricity generation capacity in China.