Renewable and Sustainable Energy Reviews 94 (2018) 682–693

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

# Reform and renewables in China: The architecture of Yunnan's hydropower dominated electricity market

Chuntian Cheng[a,c,*,1], Fu Chen[b,1], Gang Li[a,c], Bora Ristić[d], Ali Mirchi[e,g], Tu Qiyu[f], Kaveh Madani[d,g]

[a] Institute of Hydropower & Hydroinformatics, Dalian University of Technology, Dalian 116024, Liaoning Province, China
[b] Global Energy Interconnection Development and Cooperation Organization, Beijing, 100031 Beijing, China
[c] Key Laboratory of Ocean Energy Utilization and Energy Conservation of Ministry of Education, Dalian University of Technology, Dalian 116024, China
[d] Center for Environmental Policy, Imperial College London, London, United Kingdom
[e] Department of Civil Engineering and Center for Environmental Resource Management, University of Texas at El Paso, USA
[f] Yunnan Power Exchange, Kunming 650000, Yunnan Province, China
[g] Department of Physical Geography, Stockholm University, Stockholm, Sweden

ARTICLE INFO

*Keywords:*
Electricity market
Hydropower
Power industry reform
Renewable energy

ABSTRACT

Reforms currently under way in China's electricity markets bear important implications for its decarbonization objectives. The southwestern province of Yunnan is among the provinces piloting the current iteration of power market reforms. As such, lessons from Yunnan will inform future market reform and renewable energy policies in China and potentially elsewhere. The dominance of hydropower in Yunnan's energy portfolio and the particular transmission constraints it faces, offer an interesting case study of the challenges of decarbonization. We report on market architecture reforms and aggregate market data collected from the Yunnan Power Exchange. We review four elements in the reformed market architecture. Market pricing rules, transitional quantity controls, the generation rights market, and inter-provincial trade. The specifics of market reform reflect a compromise between decarbonization, inter-provincial competition, grid security and development objectives and contribute to understanding of how the dual transitions of hydropower decarbonization and market liberalization interact. We conclude on six insights regarding the role of the grid operator, security checks on trade, integration of cascade hydropower, the inclusion of renewables in the generation rights market, price controls, and market participant price uncertainty.

## 1. Introduction

Energy conservation and emissions reduction in China is both a domestic need as well as part of the country's commitment to the international community [1]. This is particularly important in the Chinese power industry. Since the economic reforms of the 1980's, China has enjoyed rapid economic growth, urbanization, and poverty alleviation. These transformations have been supported by rapid growth in electricity generation and consumption [2]. The cumulative installed power generation capacity of China reached 1.519 Terawatts by the end of 2015, ranking it number one globally and accounting for about 23% of the world's total installed capacity [3]. Coal-based thermal power accounts for nearly 65.9% of China's installed power generation capacity. The power industry is responsible for 57.9% of total carbon emissions and 34.6% of total sulfur emissions [4]. As a result, seven of the 10 most polluted cities in the world are in China [5].

In order to move to a low carbon economy, development of clean and renewable energy has become part of national policy. The country boasts the largest installed renewables capacity and has taken a leading role in international climate negotiations [6–8]. In the last two decades, China saw rapid development of its hydropower capacity, rising from 20 GW in 1980 to 330 GW in 2016. An increase of more than 16 fold. Hydropower is the largest source of renewable energy in China, accounting for 20.9% of China's installed capacity [9].

Deploying renewable energy has a set of generic issues; intermittency, interconnection, energy storage, peaking capacity, and

*Abbreviations:* OECD, Organization for Economic Cooperation and Development; TWh, Terawatt Hours; GWh, Gigawatt Hours; SPCC, State Power Corporation of China; SGCC, State Grid Corporation of China; CSG, China Southern Power Grid; NDRC, National Development and Reform Commission; SERC, State Electricity Regulatory Commission; YNPX, Yunnan Power Exchange; YNPG, Yunnan Power Grid; RMB, *Renminbi* (Yuan) Official Currency of the PRC; PRC, People's Republic of China; EOEC, Ex-ante Obligatory-use Electricity Contract; MTQ, Minimum Trade Quantity; UHV, Ultra-High Voltage; DOP, Difference of Prices

* Corresponding author at: Institute of Hydropower & Hydroinformatics, Dalian University of Technology, Dalian 116024, Liaoning Province, China.
[1] Chuntian Cheng and Fu Chen contributed equally to this work.

https://doi.org/10.1016/j.rser.2018.06.033
Received 26 December 2017; Received in revised form 14 June 2018; Accepted 14 June 2018

stranded assets amongst others [10–12]. Although renewables deployment is happening rapidly, a key issue highlighted by the State Council in its 2015 *Opinions on Further Deepening the Reform of the Electric Power Systems: Document No. 9* is that the usage of that renewable capacity is not keeping up [13]. In northern China, rapid wind capacity deployment meant that at one point, as much as one third of wind capacity was not connected to the grid and that the capacity factor for China's wind power in 2006 and 2007 was 0.16 (compared to OECD members achieving 0.2–0.3) [14,15]. Inefficiencies also occurred in the rapid deployment of hydropower. Due to poor energy planning, lagging power grid construction, falling demand, and gaming between different interests, hydropower generation in southwest China was curtailed by more than 25 TWh in 2015 [16]. In 2016, 28.7 TWh of hydropower was wasted in Sichuan alone [17]. Officially published values for abandoned water and energy spillage exceed 60 TWh [18]. In Yunnan, it has been reported that wasted hydropower grew from 5 TWh in 2013 to 31 TWh in 2016 [19]. Wasted clean and renewable energy is a serious problem for China's hydropower, one which partly motivates electricity market reform, namely promoting hydropower consumption via the establishment of intra- and inter-provincial markets.

In the complex framework of China's power system and the specifics of Yunnan's oversupplied hydro-dominated electricity portfolio, the building of electricity market faces many challenges. The literature on China's policies promoting renewable energy is rich and lively. One area of interest is that of dispatch reform and its role in better utilization of renewable resources [20–23]. Other contributions have evaluated the effectiveness of feed-in-tariffs and renewable portfolio standards among other mechanisms implementing renewable energy legislation [24]. These are largely considered successful but not always well integrated with economic reforms in electricity [25,26]. Among very recent contributions, one investigated the effect market reform has on the utilization of distributed renewables and found institutional barriers exit to employing market flexibility potentially required for decarbonization and the adoption of intermittent generation [27].

This paper examines the effectiveness of power market reforms in China's Yunnan Province for efficient use of hydropower to facilitate the attainment of the country's decarbonization objectives. We begin with brief reviews of the theory of market reform and the history of China's electricity markets to highlight salient factors in market reform and then turn to examine Yunnan's electricity market architecture in detail. We report aggregate data from the first year of trading on the Yunnan Power Exchange (YNPX) trading platform [28] highlighting four salient reforms to market architecture: 1) Pricing mechanisms and controls; 2) Transitional quantity controls; 3). Tradable generation rights; and 4) Interprovincial trade. This paper illustrates how market reform interacts with decarbonization and other objectives in the case of the architecture employed in Yunnan's market reform trial. How quickly and efficiently renewables are adopted will depend on the specifics of market reforms and the mechanisms these employ to that end [27]. We show how Yunnan's market rules are locally adapted to suit Yunnan's particularities (hydro-dominated supply, oversupply, and stagnant consumption growth). Finally, we show how the choice of market rules involves a balancing of interests which does not always create the circumstances most suited to renewables deployment and conclude on six potential areas for further reform.

## 2. Theories of market reform and its architecture

To reflect on market reform in China generally, and in Yunnan specifically, it is worth reviewing theoretical and practical issues in electricity market reform. Free market advocates argue central planners lack information needed for efficient resource allocation [29]. Instead, the argument goes, market prices send appropriate signals about profitable investment which ultimately fulfil social needs efficiently. Proponents of central planning might respond that the market does not reflect all necessary information either. Commensuration of all values under a monetary unit of account results in strategic, social, or environmental needs remaining unaccounted for. Under central planning competing needs are considered in their own valuation (be it physical quantities or otherwise) and planners allocate resources to meet these needs as far as possible [30]. When markets fail, vertical integration, regulation or government control can be more appropriate [31,32].

The choice between markets and planning is one of deciding which transactions happen under which institutions [33]. Questioning the sources of transaction costs can inform this decision for any given transaction. The first question is whether investment is required in assets specific to the participants in the transaction. Given asset specificity, parties to the transaction become mutually dependent for the efficient use of this asset. This issue is related to market-failure under monopoly which emerges when consumers of a product or service do not have a substitute or alternative producer to switch to [34–36]. The monopolist can then use this power to push prices over costs and generate monopolistic profits. The incentive for abusing this dependence to extract additional rents from the counter-party generates a transaction cost and makes a spot market an inappropriate structure for the transaction. A second question is that of the social cost of a market approach. If substantial safeguards are deemed imperative for protecting against costly market adjustments, then regulation and control is required and neither a spot market nor long-term contracting are efficient [33].

A monopoly occurs in electric utilities where a single power distribution infrastructure is required (e.g., in a city or urban district) which makes competition impossible [37,38]. In the case of network-level electricity markets, trade in electricity does not require a specific investment as there are typically multiple buyers and sellers in the market. However, investment in a transmission network does. The grid cannot supply anyone other than the connected buyers and sellers. Likewise, generators and consumers are dependent on the grid operator for market access. Instead of spot markets, procurement of network infrastructure is done through long-term contracts, strict regulation, or direct ownership and control [39].

Transitions from planning to electricity markets suffer from issues of market power, particularly in regulating the transmission network [38,40–42]. A “textbook architecture” for competitive electricity markets recognizes competition will not be possible in transmission [38]. Firms owning transmission networks must therefore be separated (or “unbundled”) from generation and retail. If not, they could give preferential treatment to their generators or otherwise exploit their control over transmission. The architecture therefore envisages independent regulators mandated to set charges grid users pay to trade on the network which the grid operator receives. Regulators must pressure operators to offer an efficient service while being sufficiently capitalized for investments needed in grid expansion, improvement and maintenance [36,37,43]. The regulator must be independent so as to not be influenced by either consumers, producers, or the grid operator as each may seek to influence pricing and regulation in their favor.

## 3. History of electricity reform in China

Different eras have been identified in the history of China's power sector reforms. A recent study considers 6 periods since the founding of the People's Republic of China, identifying decarbonization as a contemporary strategic objective which does not sit comfortably alongside existing development and reform objectives [1]. Older reviews focused on the reforms after the initial market opening in the mid 1980's, and found another distinct period after the 2002 reforms [44–47]. The most recent reforms are marked by the 2015 issuance of Document 9 by the State Council [48]. Although the history of power market reform in China has already been covered in detail in these historical accounts, it is worth highlighting recurring themes relevant to Yunnan's efforts at market reform.

One issue is that of decentralization. During the 1980's central