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RESEARCH ARTICLE

# Low-carbon Frontier: Renewable Energy and the New Resource Boom in Western China

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**Abstract**

China's west has long been framed as an undeveloped frontier, set apart by poverty and a resource-based economy. Since the 2000s, however, utility-scale renewable energy infrastructure has expanded rapidly in western China, promising local economic benefits tied to national low-carbon transition. This paper contends that these benefits have been precarious and unevenly distributed. I argue that utility-scale renewable energy has remade western China as a "low-carbon frontier," a resource-rich region that generates low-carbon value for the national green economy. I highlight three features of low-carbon frontiers: they are constructed as spaces of exploitable low-carbon resources, creating an investment boom; they are enclosed through new land arrangements and infrastructure construction, rapidly and with little coordination; and they are reliant on external markets and policy decisions, entrenching dependency. These conditions make it difficult for frontier regions to capture sustained economic development benefits from the boom in the absence of persistent central state supports. I analyse these features by comparing two sets of technologies with similar, but ultimately diverging, trajectories: small and large hydropower in China's south-west, and solar and wind in the north-west.

**摘要**

长期以来，中国西部一直被视为一个不发达的边疆，因贫困和资源型经济而与众不同。然而，自 2000 年代以来，公用事业规模的可再生能源基础设施在中国西部迅速扩张，有望实现与国家低碳转型相关的地方经济效益。本文认为，这些好处是不稳定的并且分布不均。我认为，公用事业规模的可再生能源已将中国西部重塑为低碳边疆，一个资源丰富的地区，为国家绿色经济创造低碳价值。我强调了低碳边疆的三个特征：它们被构建为可开发的低碳资源空间，创造了投资热潮；它们是通过新的土地安排和基础设施建设迅速和几乎没有协调的；并且他们依赖外部市场和政策决定，从而加深了依赖。这些条件使得边境地区在没有中央政府持续支持的情况下难以从繁荣中获得持续的经济发展利益。我通过比较两组具有相似但最终不同的轨迹的技术来分析这些特征：中国西南地区的小型和大型水电，以及西北地区的太阳能和风能。

**Keywords:** renewable energy; resources; frontier; infrastructure; China; solar; wind; hydropower

**关键词:** 可再生能源; 资源; 边疆; 基础设施; 中国; 太阳能; 风能; 水电

In the last decade, China constructed renewable energy infrastructure at a speed and scale matched nowhere else in the world. Between 2008 and 2021, installed solar photovoltaic (PV) and wind capacity leapt from 8 gigawatts (GW) to a staggering 635 GW,[1] accounting for 33.9 per cent of all

1 CEC 2022.

systems installed worldwide.[2] Installed capacity of hydropower – considered a "bedrock" renewable energy source – rose from 190 GW to 391 GW in the same period.[3] Such a rapid increase was achieved, in large part, through the construction of utility-scale installations, including the world's largest wind farm (Jiuquan Wind Power Base in Gansu) and hydropower plant (the Three Gorges Dam hydropower station in Hebei), and the world's second-largest Solar Park (Huanghe Hydropower Hainan Solar Park in Qinghai province) – not to mention many other plants comprised of hundreds of megawatts (MW) of generating equipment.

Where is this new infrastructure located? Unlike traditional coal-fired power plants in China, which are situated near urban and industrial load centres, utility-scale renewable energy installations are limited to places with high potential – even if they are thousands of kilometres from major cities. In China, this potential is concentrated in places like Gansu and Qinghai – provinces far from the populated east coast and its industries. Qinghai and Gansu are part of a loose grouping of provinces and autonomous regions known as "western China," which covers almost half of the national territory, but contains 10 per cent of the national population. Western China has long been viewed in Chinese society as a "frontier": a land of mountains and deserts, unruly ethnic minority groups and natural-resource wealth that lags behind the development of China's east.[4] Since the founding of the People's Republic of China (PRC), western China's economy has been based on resource extraction, with major state-led investment in infrastructure since the 2000s to both boost regional development and to facilitate the movement of people and goods between west and east. Renewable energy is a continuation of this investment, but one that is based on electricity transfers tied to national low-carbon transition.

Yet, while the rapid growth of renewable energy infrastructure is relatively new to western China, the technologies themselves are not. In the 1970s and 1980s, the central government provided subsidies for local officials to construct small hydropower plants for rural electrification, which is now considered China's first renewable energy programme.[5] Beginning in the 2000s, rural areas still disconnected from the power grid were offered financing assistance to install solar PV mini-grid systems, solar PV home systems and hybrid PV/wind home systems.[6] Such areas were, at the time, too far from the coal-dependent national power system to justify grid expansion, making renewable energy a poverty alleviation programme.[7] Indeed, in addition to state investment in infrastructure, western China has also been the site of rural development and "ecological construction" (*shengtai jianshe* 生态建设) initiatives aimed at alleviating poverty and protecting environmentally sensitive areas.[8] Renewable energy infrastructure, then, brings with it the promise of local economic development benefits – benefits that China's leaders believe will help bridge the gap between the country's west and east.

This paper argues that these local benefits of renewable energy infrastructure are precarious and unevenly distributed. Instead, utility-scale hydropower, solar and wind have remade western China into a "low-carbon frontier," a resource-rich region that produces low-carbon value for the national green economy. This new frontier has three main characteristics: it is constructed as a space of exploitable low-carbon resources, creating an investment boom; it is enclosed through land reallocation and infrastructure construction, rapidly and with little coordination; and it is dependent on external markets and policy decisions, entrenching economic dependency. Local production areas benefit initially from payments for land and water use rights and increased tax revenues, but these decline if demand falls and central state policy supports are removed.

2 "Renewable capacity highlights," International Renewable Energy Agency, 31 March 2021, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_-RE_Capacity_Highlights_2021.pdf. Accessed 3 March 2022.
3 CEC 2022.
4 Rippa 2020, 23–24.
5 HRC 2009.
6 Byrne et al. 2007; Li-qun Liu et al. 2010.
7 Yang 2003.
8 Chen, Zinda and Yeh 2017.

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Moreover, some projects – notably but not exclusively hydropower projects – have negative impacts on local communities and environments.[9] This paper thus argues that renewable energy infrastructure is not inherently beneficial – or politically neutral – but is wrapped up in socio-spatial processes of development in China.

To make this argument, I compare two sets of renewable energy technologies over two overlapping time periods with similar, but ultimately diverging, trajectories. The first set – comprising small hydropower (SHP) and large hydropower (LHP) – began booming in south-west China in the late 1990s following central government policies encouraging west-to-east electricity transmission, and later renewable energy generation. SHP plants were built by private companies and overseen by local governments with the stated purpose of contributing to local development; LHP was constructed by state-owned enterprises (SOEs) with priority financing and dedicated transmission lines to eastern China. Since 2016, however, SHP operators in western China have been forced to scale back generation and profits due to overcapacity and a preference in eastern China for other sources; indeed, new SHP construction in south-west China has mostly halted, and local revenues have plummeted. In contrast, LHP dams continue to be constructed and operated by SOEs, but with major social and environmental impacts.

The second set of newer technologies – wind and solar PV – expanded rapidly in north-west China since the late 2000s, with year-on-year installed capacity increases surpassing hydropower at peak deployment. Local governments in western China introduced preferential tax and land acquisition policies to attract investment in solar and wind infrastructure which, combined with central government subsidies, set off a construction bonanza and local economic boom. Yet, major subsidy reductions and a temporary ban on new installations in western China in the late 2010s forced many small firms to exit the sector (or go bankrupt) and prompted economic volatility in local production areas. Rapid construction has since resumed, however, and is rapidly increasing further due to institutional and regulatory reforms and new transmission infrastructure. This recent shift may potentially (but not necessarily) herald more lasting local economic benefits than those provided by SHP, without the significant negative impacts of LHP.

This study builds on long-standing scholarship on Chinese state-led development, resource extraction and infrastructure investment in western China. Research on rural development and ecological construction programmes[10] analyses local dependence and uneven outcomes of central government initiatives and fiscal transfers in western China. Analysis of China's Great Western Development Strategy (GWDS; aka the Open Up the West Campaign)[11] highlights the rapid growth in infrastructure investments oriented towards connecting the resource-rich west to the urbanized east – a trend that has continued despite some diversification due to industries seeking out lower wages and new logistics projects associated with the Belt and Road Initiative (BRI).[12] Yet while studies examine west-to-east hydropower transfers[13] and more recent solar and wind transfers,[14] little research analyses the local dynamics of hydropower, solar or wind industries in western China. This is the gap that this article aims to fill.

Data for this article were collected using three methods: more than 50 interviews with industry experts, renewable energy firm representatives and local government officials from production areas conducted from 2015 to 2019; participation in four hydropower, wind and solar energy conferences in China in 2015, 2016 and 2019; and ongoing analysis of Chinese policies, news articles and reports. Due to my status as a foreign researcher, I could not access data (such as land leases

9 Tilt and Gerkey 2016; Avila 2018; Harlan, Xu and He 2021.
10 Rogers 2014; Yeh 2013a.
11 Oakes 2004; Goodman 2004.
12 Su 2014; Zhu and Pickles 2014.
13 Chen, Li and Wu 2010; Magee 2006.
14 Cai and Aoyama 2018; Zifa Liu et al. 2015; Tang et al. 2018.

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and tax receipts) that would allow me to quantify local tax revenues; instead, I draw on qualitative interview data describing these benefits and how they changed over time.

## China's Low-carbon Frontier

### *Interrogating the western China "frontier"*

The notion of the "frontier" has powerful connotations in China. For centuries, the frontier meant those places at the edge of state control, associated with "barbarian" indigenous groups beyond the Great Wall and the western mountains and deserts.[15] As the Qing state consolidated its territorial control in the early 20th century, the frontier came to be understood as set apart from the political and cultural "core" that needed to be disciplined and integrated into a homogenous (Han Chinese) national community.[16] Today, the frontier is still popularly viewed as borderland region of ethnic minorities who have been offered the "gift" of modernization by the Chinese state,[17] but who are also prone to unrest and separatism.[18] Relatedly, the frontier is also seen as a region that culturally and economically lags behind the Han Chinese heartland, which needs to be rectified through state investment in infrastructure, poverty alleviation and ecological construction.[19]

At the same time, the frontier in Chinese state discourse is a region of tremendous natural resource endowments that are essential to the national economy. The vast majority of China's oil and natural gas reserves are found in western China; so too are concentrations of nonferrous metals, mineral ores and rare earth resources.[20] Industrial crops such as rubber[21] and cotton[22] are also largely grown in western China. The state has emphasized the need to extract and produce these resources since the 1950s, particularly following China's transition to a net oil importer in 1994 that prompted major concerns about energy security. More recently, the discourse has shifted to framing western China as a source of resource inputs and as a strategic location along BRI infrastructure corridors – as an encouragement for Chinese industries to move west.[23] In these framings, the frontier is an indispensable natural resource base for the nation, but one that offers opportunities for major profits for pioneering enterprises.

A number of scholars have analysed the material effects of the frontier discourse in western China, especially since the launch of the GWDS in 2000.[24] One focus of this strategy was investment in poverty alleviation programmes targeting ethnic minority, borderland and ecologically degraded areas of the west – several of them later classified as "contiguous poor areas with particular difficulties."[25] The central state ramped up transfers to local governments for infrastructure and agricultural modernization, such as for roads, irrigation, schools and electricity grids.[26] China's leaders also inaugurated a suite of ecological construction programmes to force peasants to abandon farming and herding in environmentally sensitive frontier regions and pay them to plant trees or sow grass instead.[27] In many mountainous villages, peasants were completely resettled to another location due to stated concerns about sloping land degradation and the risk of natural disasters.[28] Yet,

15 Barfield 1992.
16 Leibold 2007.
17 Yeh 2013.
18 Hillman and Tuttle 2016.
19 Lai 2002; Yeung and Shen 2004.
20 Klinger 2018; Woodworth 2017.
21 Sturgeon and Menzies 2006.
22 Cliff 2016.
23 Klinger 2019; Ma and Summers 2009.
24 Becquelin 2004; Economy 2002; Goodman 2004; Magee 2006; Oakes 2004; Su 2014; Woodworth 2017; Yeh 2013.
25 Yansui Liu, Jilai Liu and Zhou 2017.
26 Fan, Zhang and Zhang 2002; Peng and Pan 2006.
27 Economy 2002; König et al. 2014; Yeh 2009.
28 Wei Liu, Xu and Li 2018.

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while aggregate incomes in China's west have increased since 2000, these gains are unevenly distributed between rural and urban regions, where many villagers have migrated.[29] Yeh argues that rural poverty alleviation and ecological construction programmes like "converting pastures to grasslands" are chiefly about internal territorialization,[30] drawing the frontier and its resources further under state control.

The major economic focus of the GWDS, meanwhile, has been state investment in resource extraction and energy production on the frontier. According to Xinhua,[31] from 2000 to 2016, the central government invested 6.35 trillion yuan in 300 major projects in western China, mostly in infrastructure and energy. Woodworth,[32] citing Zeng,[33] notes that the largest component of this investment went towards electricity generation, transmission lines and grid improvements, designed for a five-fold increase in capacity by 2020 to "send western electricity east" (*xi dian dong song* 西电东送). Similarly, the "west–east gas delivery" and "west–east oil delivery" networks involved the construction of national pipeline networks linking resources in the west to consumers in the east. Such investments in delivery infrastructure coincided with new oil and gas plays in the north-west and rapid growth in hydropower plants in the south-west.[34] As Cliff details,[35]large-scale infrastructure investments and policy encouragement incentivized hundreds of thousands of Han Chinese to migrate to the frontier, creating an ethnic division of labour in cities where migrants are given priority in employment over ethnic minorities.[36] This evidence suggests that state control over resources and supply networks is a chief driver of new infrastructure on the frontier.

## The frontier as heuristic

The frontier discourse and its effects offer one way to analyse the political economy of infrastructure in places like western China. Scholars have also employed the frontier as a heuristic to examine the contours of capitalism and its regional development dynamics. In political science, frontiers have been conceptualized as places subject to the "resource curse" of low growth and "boom and bust" cycles.[37] Alternatively, geographers and political ecologists in the Marxist tradition understand frontiers as the edge of capitalist expansion; in De Angelis's words, "a space of social life that is still relatively uncolonised by capitalist relations of production and modes of activity."[38] Frontiers tend to be rich in natural resources that "have not yet been enclosed, extracted, and incorporated into circuits of production and consumption."[39] As such, they are unregulated and interstitial zones ripe for "primitive accumulation"[40] and "frontier capitalism"[41] characterized by violent dispossession, super-profits and environmental degradation. Nonetheless, scholars also point to the many cases in which capital's enclosure of the frontier is frustrated and modified by networks of actors and particular political-economic and environmental contexts.[42]

29 Yansui Liu, Jilai Liu and Zhou 2017.
30 Yeh 2009; Vandergeest and Peluso 1995.
31 "New Five-Year Plan brings hope to China's west," *Xinhua*, 27 December 2016, http://english.www.gov.cn/premier/news/2016/12/27/content_281475526349906.htm. Accessed 3 March 2022.
32 Woodworth 2017.
33 Zeng 2010.
34 Becquelin 2004; Magee 2006.
35 Cliff 2016.
36 Pannell and Schmidt 2006.
37 Barbier 2005; Sachs and Warner 1995.
38 De Angelis 2004, 72.
39 Barney 2008, 146.
40 Glassman 2006.
41 Tsing 2005.
42 Li 2014; Peluso 2017.

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Building on this work, Barney suggests that the frontier be understood in a relational manner; one that recognizes that global capital continually seeks out new resource frontiers, but that frontier making is unevenly produced and composed of a heterogenous assemblage of actors.[43] Huber[44] takes this relational perspective further by applying it to resources themselves, which are not "naturally" resources[45] but are defined as such through social, political and cultural work. Seen in this way, resource making and frontier making go hand in hand, as natural objects (oil, gold, carbon) come to be seen as valuable due to their useful properties or value-generating potential,[46] creating an impetus for capital to expand to places rich in those objects. Yet as Klinger shows in her study of rare earth resources, the creation of new frontiers is inseparable from the state's desire to strengthen territorial claims – often in the guise of local development – and to isolate the negative externalities of extraction to areas outside the core.[47] Frontiers may thus be both made and remade as particular resource become valuable to locate, enclose and transfer.

Such processes, of course, require major investments in infrastructure. Energy and mining firms must construct fixed assets that enable local resource exploitation and linkages to the national transportation network. As demand for the resource grows, governments may choose to construct (or contract) roads, rail lines, electricity transmission and urban infrastructure to facilitate the transport of goods to consumers. As a result, the "frontier" becomes more than a place to extract a particular set of resources; it becomes a "spatial fix"[48] for capital to avoid falling profits associated with overproduction by investing in new spaces and/or new infrastructure. One need not look far for examples of such "infrastructure frontiers" – whether in nations only recently open to foreign direct investment,[49] in Arctic regions experiencing rapid warming,[50] or areas of the Himalayas undergoing "hyper-structure" road and rail construction[51] – all examples that are, incidentally, part of China's BRI.

Woodworth compellingly examines these developments in Ordos, a coal boom town region in Inner Mongolia.[52] He notes that energy resource production in western China was discursively "envisioned as a key strategy to spur industrial growth and ease regional development gaps" and made available for intense forms of "hyper-exploitation."[53] With this policy encouragement, local and regional authorities transformed the sector starting in the late 1990s by forcing the closure of many small, privately owned mines and scaling up and mechanizing production, which involved relocating nearly half a million people from their farmland.[54] State-led investment in transportation and energy generation infrastructure enabled ramped-up coal extraction to thrive. Yet Woodworth also notes that this extractive boom was built on the price of coal, which (for a time) was high enough to spark an intense bout of speculative urbanism.[55] Since the mid-2010s, however, growth in alternative energy and overproduction of coal have led to a bust on the Ordos frontier, taking a widespread social and economic toll and turning the boomtown into a "ghost city."[56]

43 Barney 2008.
44 Huber 2018.
45 Hudson 2005, 42.
46 Huber 2018, 553.
47 Klinger 2018.
48 Harvey 2001.
49 O'Connor 2011.
50 Bennett 2016.
51 Murton, Lord and Beazley 2016.
52 Woodworth 2017.
53 Ibid., 135–37.
54 Ibid., 137–38.
55 Ibid., 138.
56 Yin, Qian and Zhu 2017.

### *Low-carbon frontiers*

Renewable energy, in contrast, would seem to offer a different path for China's west, tied to a long-term commitment to national low-carbon transition and poverty alleviation. Yet while renewable energy infrastructure is far less environmentally destructive than mining or traditional electricity generation, it is incorporated into similar processes of frontier making as low-carbon value is constructed, enclosed and transferred – a kind of low-carbon frontier.

Let me describe this heuristic in more detail. The low-carbon frontier refers, first, to the discursive construction of spaces as untapped stores of low-carbon value. Farmland and grasslands, for example, become valuable for their wind or solar resources; rivers in high mountain areas for their hydropower generation potential; peatlands and plantation forests for their ability to sequester carbon; and deposits of silicon, nickel, lithium and rare earth resources for the essential functioning of renewable energy and alternative-energy vehicle technology. The discourse of low-carbon value – and its practices of identifying, measuring and mapping value – transform these spaces from marginal to "productive." Places rich in these resources may indeed be situated at the edge of capitalist relations and of state control, while others have already experienced frontier making and resource extraction. What such spaces share, though, is a discourse identifying them as underpopulated, backward and in need of development, with low-carbon resources able to provide the necessary economic boost.

Second, low-carbon frontiers involve the material enclosure of low-carbon value through reallocation of land rights and infrastructure construction. This process, in its early stages, is often rapid and impetuous, whether due to a lack of state capacity or the desire of state officials to profit from new projects. To achieve scale, project developers target large tracts of land that can be most easily assembled and leased at the cheapest price, which tend to be lands held in common or by the state (as is the case in China). State officials are incentivized to attract as many projects as possible by facilitating land transactions and providing tax reductions and holidays. Once land arrangements are in place, the region experiences a boom in infrastructure construction, attracting private and state-owned companies, financiers and speculators who seek to get in on the bonanza. As a result, planning and regulations are relaxed or ignored, resulting in a rapid and uncoordinated spread of infrastructure in newly enclosed areas.

Third, low-carbon frontiers are still resource frontiers, reliant on transferring much of the value of the resource to buyers elsewhere. As such, they are stuck in a relationship of dependency on external markets and policy decisions, with little autonomy to capture sustained local economic benefits and plan for volatility. In the initial stages of the boom, when a low-carbon resource quickly gains value, local governments benefit from land sales and tax revenues that can swell coffers and be spent on infrastructure and services. Local communities, meanwhile, may be subject to land enclosures, but might also gain employment in construction and ancillary services. Yet, booms are unpredictable, and benefits can disappear – owing to a loss of state policy supports, a drop in the price of the low-carbon resource (sometimes due to a lapse in subsidies) or better technologies that allow for more efficient production elsewhere. This precarity can lead to short-term economic pain and a large reduction in revenues in the absence of local foresight and persistent state support. Such dependence and its consequences are especially salient for local residents, who receive less direct benefits from the boom, but bear the negative consequences from certain types of large-scale infrastructure, like hydropower – the subject of the following section.

## Large and Small Hydropower, the "Old" Technologies

LHP has been a major strategic industry in China since the 1950s. Mao Zedong promoted dam construction mainly for flood protection and irrigation in 1960s and 1970s;[57] in the 1980s, Chinese

57 Several of these dams failed, the most severe being the Banqiao dam collapse (along with the collapse with 61 other dams) in Henan province in 1975.

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state energy sector reforms and loans extended by foreign creditors accelerated dam construction for hydroelectricity.[58] Hydropower entities that were formerly arms of government ministries were reorganized as professional corporations and allowed to establish subsidiaries, finance companies and research institutes – what Webber and Han call China's "water machine."[59] Indeed, five of the hundred or so enterprises directly situated under the powerful State-Owned Assets Supervision and Administration Commission are large hydro-engineering corporations, while others are owned by central or provincial governments. These SOEs are responsible for all LHP construction in China, and are contractors for more than 70 per cent of hydropower plants around the world.[60]

The GWDS was a boon for the LHP industry. The "best" hydropower resources in China are located in Yunnan and Sichuan, where rivers drop continuously in elevation in gorges suitable for dam construction. Chinese state discourse viewed LHP as a key energy source for national economic development and modernization, particularly for manufacturing industries in the Pearl River Delta.[61] In the process, China's leaders maintained, LHP would pull "backward" western regions forward through investment and industrial growth.[62] Preferential policies for LHP – including access to capital, state investment in grid infrastructure and guaranteed electricity uptake by the state grid – made Yunnan and Sichuan a major destination for SOEs developing new projects in the untapped Yangtze River and its watersheds.[63] As a result, China's installed LHP capacity more than tripled from 90 GW in 2000 to 305 GW in 2015, increasing its share in the national electricity mix from 8 per cent to 22 per cent.[64]

The characteristics of SHP in western China are somewhat different. SHP in China refers to plants with an installed capacity of less than 50 MW; internationally, the definition is generally set at less than 10 MW.[65] China's first hydropower plant began operating in Yunnan in 1911, and since then more than 47,000 have been constructed.[66] In the Mao Zedong era, SHP construction was encouraged by the central government in order to generate electricity for areas outside of the grid network; local governments and villagers responded by building micro (<100 kilowatts) and mini (<1 MW) plants out of local materials.[67] In the 1980s and 1990s, the State Council introduced and extended subsidies for SHP plants in hundreds of "rural electrification" counties, the majority of them in western China.[68] Hydropower industry reforms in the 1990s enabled the private sector to purchase local-government-owned SHP plants and construct new (and larger) plants in areas with a guaranteed grid connection. Indeed, compared to the SOE-dominated large hydropower industry, SHP is the domain of private enterprises that operate 80 per cent of all SHP assets.[69]

Despite these differences, though, LHP and SHP followed similar boom trajectories in western China. In the early 2000s, after the announcement of the GWDS, the Ministry of Water Resources launched the Small Hydropower to Replace Fuelwood Programme (*xiao shuidian dai ranliao xiangmu* 小水电代燃料项目) that offered subsidies for some SHP plants in mountainous areas of the south-west. In 2002, the National Energy Administration (NEA) under the National

58 Kang 2015, 9.
59 Webber and Han 2017.
60 "Zhongguo shuidian qiye yi zhan haiwai 70% yishang shuidian jianshe shichang" (China's hydropower enterprises control more than 70 per cent of the overseas hydropower construction market), National Energy Administration of the PRC, 23 January 2019, http://www.nea.gov.cn/2019-01/23/c_137767698.htm. Accessed 3 March 2022.
61 Magee 2006.
62 Lee 2013.
63 Chuntian Cheng et al. 2018.
64 EPS China Data 2021.
65 UNIDO and ICSHP 2016.
66 Kong et al. 2015.
67 Peng and Pan 2006.
68 HRC 2009, 4–5.
69 Xialei Cheng 2015.

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Development and Reform Commission (NDRC) implemented energy sector reforms that centralized all grids under two state-owned grid enterprises and forced the connection of all power plants to the grid, including SHP plants.[70] Then, in 2006, the National People's Congress passed the Renewable Energy Law that required the two grid enterprises to purchase and prioritize electricity from renewable sources – effectively awarding SHP operators the grid uptake guarantee that LHP SOEs already enjoyed. Moreover, SHP was included in cadre promotion criteria for local governments in Yunnan and Sichuan, incentivizing them to increase approvals.[71] As a result, thousands of new SHP plants were constructed in a short time, tripling installed capacity from 31 GW in 2000 to 76 GW in 2015; 43 per cent of this capacity was built in western China, mainly Yunnan and Sichuan.[72]

How did hydropower in western China resemble a low-carbon frontier? The first aspect was the prevalence of a discourse of exploitable low-carbon value. In the 1980s and 1990s, when LHP plants were being constructed in western China, they were framed by the state as modern infrastructure that contributed to economic growth and energy security.[73] By the mid-2000s, the discourse had shifted: Lee notes that, after the 2004 United Nations Declaration on Hydropower and Sustainable Development, the NDRC referred to hydropower as a "clean" renewable energy – language included in the 11th (2006–2010), 12th (2011–2015) and 13th (2016–2020) Five-Year Plans.[74] SHP, in particular, was recognized as a model of "green development" and became the main technology to receive financing from the Clean Development Mechanism (CDM).[75] This discourse, in turn, represented Yunnan and Sichuan as stores of hydropower potential that had to be tapped to further national low-carbon transition[76] – especially since, in the mid-2000s, wind and solar were in their infancy in China.

Hydropower infrastructure, meanwhile, turned low-carbon value into a commodity that could be bought and sold in the form of electricity. In the case of LHP, the central government awarded SOEs river rights in particular basins and established a price at which the grid would purchase electricity from each plant.[77] For SHP, prefectural development and reform commissions (DRCs) were allowed to grant construction rights to operators for plants with a capacity of less than 50 MW and negotiate on-grid purchase prices directly.[78] Local officials in Yunnan and Sichuan offered high purchase prices, tax holidays and express approvals for SHP plants in their administrative districts.[79] SHP investors from Zhejiang, Fujian and Guangdong were able to obtain low-interest loans to from local banks to construct new plants; many also received financing from the CDM.[80] The pace of hydropower construction grew to a frenzy in the mid-to-late 2000s and early 2010s, with LHP projects catalysing investment in transmission infrastructure that SHP operators could use to access new sites in remote areas. Chinese state media would later characterize this period as a "disorderly, unregulated and environmentally destructive" period of SHP development[81] – a kind of frontier boom dynamic.

Much of the value of this new hydropower commodity was transferred to eastern China, even as local governments took in royalties. West-to-east transmission was always the stated purpose of most LHP projects, and was facilitated by dedicated high-voltage grid infrastructure

70 Jenn-Hwan Wang, Tseng and Zheng 2015.
71 Harlan 2018; Jenn-Hwan Wang, Tseng and Zheng 2015.
72 EPS China Data 2021.
73 Magee 2006, 26.
74 Lee 2013, 3; see also NDRC 2011; 2006; 2017.
75 Cui and Xu 2017; Harlan 2020.
76 Heng Liu and Hu 2010; People's Government of Yunnan Province 2003; Teng and Zhang 2010.
77 Ming et al. 2013, 457.
78 Hennig and Harlan 2018.
79 Harlan 2018; Jenn-Hwan Wang, Tseng and Zheng 2015.
80 Hennig and Harlan 2018.
81 Zhao 2016.

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that (for the largest dams) bypassed the local network.[82] SOE operators were required to pay royalties to the central and provincial governments,[83] generating consistent local revenues during the boom. SHP in western China also followed this model; in parts of Yunnan, for example, more than 80 per cent of SHP electricity was transmitted outside of the prefecture, much of it to Guangdong.[84] Still, local governments greatly expanded their budgets by collecting tax based on SHP power output, and by attracting mining and mineral processing industries to use hydroelectricity.[85] Nevertheless, infrastructure-adjacent communities experienced negative impacts of the boom: villagers near large dams were forced to resettle and shift their livelihoods from farming,[86] and some villages near SHP plants experienced reduced irrigation water access.[87]

Hydropower construction began to slow in the 2010s, and by mid-decade LHP and SHP plants faced significant curtailment, reaching a rate of 13.7 per cent in Yunnan in 2016.[88] The reasons for LHP curtailment were diverse, including an economic slowdown, inadequate transmission capacity, governance challenges, inflexible electricity markets and extreme seasonal and annual variability in precipitation.[89] New project approvals slowed as a result. SHP was much harder hit, primarily due to overcapacity problems and grid bottlenecks that prevented electricity from being "exported" outside of the local area. SHP operators were forced to curtail generation by up to 50 per cent in the wet season, doubling the amount of time to obtain a return on investment and vastly reducing local government tax revenues. In 2016, the Yunnan and Sichuan governments halted the ability of prefectural DRCs to approve plants,[90] followed by denunciations of SHP in state-run media.[91] An association of SHP operators in Yunnan complained to the Yunnan government and sought to negotiate a new on-grid purchase price, but to no avail. Some small SHP companies faced bankruptcy, while others managed to sell assets at a discount to SOEs. In 2018, provincial governments began demolishing plants they considered illegal; in 2019, new SHP construction was severely limited by the NEA.[92] Today, LHP curtailment rates have improved and new projects have somewhat rebounded – with significant new dams and pumped storage targeted in the 14th Five-Year Plan – but the SHP boom for local governments is over.

## Wind and Solar PV, the "New" Technologies

Wind and solar PV, like SHP, were first promoted in China for rural electrification and local development.[93] In 1996, as part of the Ninth Five-Year Plan (1996–2000), the NEA introduced a "new energy" development programme of grants and loans to local governments for wind and solar

82 Hennig et al. 2016.
83 Pineau, Tranchecoste and Vega-Cárdenas 2017, 5.
84 Hennig and Harlan 2018.
85 Ibid.
86 For an overview see Tilt 2014. The Three Gorges Dam is a particular case in point, which required resettling 1.35 million residents in Hubei and Chongqing to cities; see Wilmsen, Webber and Yuefang 2011; Li, Waley and Rees 2001.
87 Harlan, Xu and He 2021.
88 Benxi Liu et al. 2018, 701.
89 Ibid., 704–708.
90 People's Government of Yunnan Province 2016; David Stanway, "Dam nation: China crackdown spares big state hydropower projects," *South China Morning Post*, 4 September 2018, https://www.scmp.com/magazines/post-magazine/long-reads/article/2162523/dam-nation-china-crackdown-spares-big-state. Accessed 28 April 2022.
91 Shuang Guo 2016; Zhao 2016; Yu Wenjing, "Woguo xiao shuidian kaifa guodule ma? – Zhuanjia xiangjie xiao shuidian kaifa redian wenti" (Is small hydropower overdeveloped? Experts explain the main problems with small hydropower development)," *Xinhua*, 20 September 2015, http://news.xinhuanet.com/fortune/2015-09/20/c_1116618901.htm. Accessed 9 August 2021.
92 David Stanway, "China to impose new restrictions on small hydro plants," *New York Times*, 13 November 2019, https://www.nytimes.com/reuters/2019/11/13/world/asia/13reuters-china-hydropower.html. Accessed 25 April 2022.
93 Luo and Yi-wei Guo 2013.

energy infrastructure construction.[94] An additional 2.6 billion yuan was allocated for home and village wind/solar PV systems through the Brightness Programme (*guangming xiangcun xiangmu* 光明乡村项目) and Township Electrification Programme (*xiangzhen dianqihua xiangmu* 乡镇电气化项目) in the 10th Five-Year Plan (2001–2005), specifically targeting the north-western provinces of Gansu, Qinghai, Inner Mongolia, the Tibet Autonomous Region and Xinjiang as part of the GWDS.[95] For rural and remote communities in western China – especially the north-west – wind and solar systems were cheaper and easier to install than small-scale thermal plants or SHP.[96] Expenditures by the Ministry of Water Resources and grid enterprises on rural grid expansion and upgrades in the mid-to-late 2000s connected many off-grid villages to the electricity network and increased the stability of supply.[97]

These rural renewable energy programmes also helped foster the development of China's wind turbine and solar PV technology manufacturing industries. In 1996, the NDRC announced the Riding the Wind Programme (*chengfeng jihua* 乘风计划), which encouraged R&D for domestic wind turbines; preferential policies that followed slashed taxes on turbine imports, allowing domestic wind enterprises to learn from foreign technologies.[98] State-owned power engineering and construction firms established wind turbine manufacturing arms to compete with a burgeoning private market. The central government extended similar policies to the solar industry in the early 2000s to both fulfil domestic needs and to stake a position in the global market for PV cells.[99] Solar production capacity quickly ramped up in the mid-2000s, led by private corporations with aggressive policy support from local governments.[100] In 2010, after the 2007–2008 Great Financial Crisis (GFC), solar PV was highlighted in the State Council's list of strategic emerging industries, and the China Development Bank extended 500 billion yuan in credit lines to the solar PV technology manufacturers.[101]

Investments in the production of components set the stage for a western China wind and solar infrastructure boom. In 2003, the NDRC began a wind concession pilot project that granted 20-year operational concessions for large-scale wind farms through a competitive bidding process.[102] The Renewable Energy Law in 2006 required grid operators to purchase all generated wind energy and established a national fund to award subsidies for wind and solar construction, adding to a 2001 policy that cut the value-added tax (VAT) for wind projects in half (to 8.5 per cent). To speed up approvals, the NDRC empowered provincial DRCs to approve wind farms of up to 50 MW installed capacity.[103] A domestic feed-in tariff (FiT) for wind energy was introduced by the NDRC in 2009 based on wind resource potential – western China was given the lowest tariff, but continued to attract the most investment.[104] The 11th Five-Year Plan,[105] the 11th Five-Year Energy Development Plan (2006–2010)[106] and the Medium- and Long-term Development Plan for Renewable Energy (*kezaisheng nengyuan zhongchangqi fazhan guihua* 可再生能源中长期发

94 Zheng, Yang and Zhen 2002, 6.
95 Huang 2009; Sufang Zhang, Andrews-Speed and Ji 2014, 905.
96 Gang Liu, Lucas and Shen 2008, 1896.
97 Peng and Pan 2006.
98 Ru et al. 2012, 64; Yuan et al. 2015, 1236.
99 Sufang Zhang, Andrews-Speed and Ji 2014, 906.
100 Chen 2013; Li-qun Liu et al. 2010.
101 State Council 2010; Sufang Zhang, Andrews-Speed and Ji 2014, 908.
102 Changliang Xia and Song 2009, 1969.
103 "Decision of the State Council on reform of the investment system," National Development and Reform Commission of the PRC, 7 February 2004, https://en.ndrc.gov.cn/policyrelease_8233/200602/t20060207_1193914.html. Accessed 20 December 2021.
104 NDRC 2009.
105 NDRC 2006.
106 NEA 2007.

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展规划)[107] set ambitious targets for installed wind capacity. By the late 2000s, wind farm construction in western China had proceeded so rapidly that the NDRC decided to shift approvals from for plants of less than 50 GW capacity from the provincial back to the central level (though this policy was again reversed in 2013).[108] Installed wind capacity leapt from just 2 GW in 2006 to 186 GW in 2013, 49 per cent of which was situated in western China.[109]

The solar boom in western China began a few years later than wind, as manufacturers had previously only targeted export markets and were faced with a huge glut of panels after the 2007–2008 GFC.[110] In 2009, the Ministry of Science and Technology and the NEA launched the Golden Sun Programme (*jin taiyang xiangmu* 金太阳项目) that provided a 50 per cent up-front subsidy for grid-connected systems, setting a max of 20 MW installed capacity for each province – an approach that led to extensive subsidy fraud as developers engaged in false bidding and used low-quality products.[111] That same year, the NEA led (as it did with wind) a concession programme for large-scale solar PV, with 20-year operational leases and competitive bidding, with all 290 MW of new capacity installed in north-west China.[112] After lobbying from the industry and provincial governments,[113] the NDRC established a nationwide solar FiT in 2011 based on power output.[114] Like FiT for wind generation, the solar FiT was set at different levels based on "zones" of solar potential, but which still made the solar-rich western provinces hugely attractive to developers. The provinces of Gansu, Qinghai and Ningxia submitted more than 3 GW of solar projects for NDRC approval in early 2011 so as to obtain a higher FiT rate for projects initiated before July of that year.[115] This FiT policy catalysed the solar energy boom that grew from a mere 2 GW in 2011 to 39 GW in 2015;, 44 per cent of which was situated in western China.[116]

How do wind and solar in western China resemble a low-carbon frontier? Discursively, the region was framed as a huge store of exploitable potential in state media: an area near Urumqi in Xinjiang was called China's "Wind Valley";[117] a large wind project in Inner Mongolia was hailed as the "Grassland Three Gorges";[118] and a high-altitude region of Qinghai was described as a "Solar Plateau."[119] Indeed, western China was singled out for development of "wind bases" and "solar bases" in central government energy planning,[120] due to "extremely favourable" conditions.[121]

107 NDRC 2007a.

108 NEA 2011; Zhao and Chang 2013.

109 CEC 2016.

110 Sufang Zhang, Andrews-Speed and Ji 2014. China also faced an anti-dumping challenge in the early 2010s in the World Trade Organization (WTO), with the US and European countries accusing Chinese manufacturers of artificially lowering their prices; see "China appeals WTO ruling on solar panel dispute with the U.S.," *Reuters*, 22 August 2014, https://www.reuters.com/article/us-trade-wto-china/china-appeals-wto-ruling-on-solar-panel-dispute-with-u-s-idUSKBN0GM1FP20140822. Accessed 12 April 2022.

111 Yuan Ying, "Burned by the sun," *Yale Environment 360*, 14 April 2011, https://www.chinadialogue.net/article/show/single/en/4232-Burned-by-the-sun. Accessed 20 December 2021.

112 IEA 2013.

113 Dawei Liu and Xu 2018, 860.

114 NDRC 2011.

115 Dawei Liu and Xu 2018, 861.

116 CEC 2016.

117 CEC 2008.

118 "Xibu da kaifa 10 zhounian: Neimenggu huanjing gaishan fengdian da fazhan" (The tenth anniversary of the Great Western Development Strategy: improving Inner Mongolia's environment), *Xinhua*, 5 January 2010, http://www.gov.cn/jrzg/2010-01/05/content_1503739_2.htm. Accessed 19 December 2021.

119 "Qinghai gaoyuan guangfu dianzhan leiji fadian 10 yi qianwashi" (Qinghai's solar plateau PV plants collectively generate one billion kWh)," *China Broadcasting Network*, 27 September 2012, http://native.cnr.cn/city/201209/t20120927_511009493.shtml. Accessed 20 December 2021.

120 NDRC 2012a; NEA 2012a.

121 NDRC 2007a.

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Provincial governments in western China, keen to attract investment, produced maps of wind capacity factor and solar radiation highlighting their province's vast resources. Yet, while this discourse was couched in the context of national low-carbon transition, government and industry proponents also made a point to link wind and solar expansion to GWDS goals of poverty alleviation and ecological protection. Wind and solar were emphasized as key industries in the 12th (2011–2015)[122] and 13th (2016–2020)[123] Western Development Five-Year Plans, alongside continued state investment in solar-based rural electrification.[124] In this way, wind and solar symbolized a new phase in the GWDS that would pull the region closer to eastern China and boost its economy through electricity transfers.

The actual infrastructure of wind and solar farms – turbines, PV panels and modules, and generators – enabled firms to enclose low-carbon value. This process occurred extremely rapidly with little coordination between projects, as industry and local governments sought to capitalize on subsidies. In the wind industry in the 2000s, local governments offered tax incentives, rebates on land purchases and a streamlined approvals process to attract investment in wind farms of under 50 MW of capacity – the upper limit of what the province could approve. NDRC lists of wind projects in western China in that period showed that nearly all had a nameplate installed capacity of between 49 and 50 MW[125] – many of them situated right next to each other as part of the same farm. The shift to central approvals for wind projects in 2011 (and then back to the province level in 2013) did little to cool off investment due to highly attractive FiT rates, as established SOEs and private companies flocked to western China to build infrastructure. The solar industry, too, experienced a construction blitz, but one that was largely led by private enterprises drawn to western China by subsidies and the 2011 FiT. Like in the SHP industry, investment capital came from PV manufacturers and developers situated in eastern China, while utility-scale solar was primarily located in western China. New companies entered the sector seemingly every day to supply components for western China's solar farms, while local officials signed 20-year leases for hundreds of square kilometres of solar development.

Like with hydropower, the vast majority of wind and solar energy in western China was exported to consumers in eastern China. Indeed, the western provinces had less need for additional electricity and could only consume a fraction of overall generation.[126] Some local officials followed the example of SHP and sought to attract energy-intensive industries to the region, though with varying levels of success due to their inability to set a sale price for electricity. Moreover, though local governments received an influx of revenues from land lease agreements, tax benefits from electricity sales were limited by policies discounting or exempting firms from initial income tax and VAT.[127] In the wind industry in particular, local governments lacked tax jurisdiction over SOE developers registered at the central level or in other provinces, causing tax collection uncertainty.[128] Local officials in wind and solar districts became increasingly dependent upon attracting new installations oriented towards long-distance transmission in order to meet their fiscal and economic growth targets.

This expansion of solar and wind in western China generated an electricity surplus that was not being fully exported to eastern China, forcing installations to curtail production beginning in the

122 NDRC 2012b.

123 NDRC 2017.

124 Geall, Shen and Gongbuzeren 2018.

125 NDRC 2007b; NEA 2012b.

126 Zifa Liu et al. 2015.

127 In the late 2010s, wind and solar projects in China received a full exemption from income tax for the first three years of operation, and half exemption for the second three years. VAT was exempted by 50 per cent. As noted by Xia and Song, given the high initial investment and low operating costs of wind projects, the VAT discount substantially decreased VAT payments from developers to local governments. Changliang Xia and Song 2017, 268–69.

128 Fang Xia and Song 2017, 269.

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late 2000s.[129] Scholars have identified several factors that contributed to this curtailment.[130] One important factor was the over-building of solar and wind installations in western China, and an under-provision of high-voltage transmission infrastructure. Indeed, reports also identified hundreds of MW of new installed capacity that had no grid connection and was effectively "abandoned."[131] More important, however, were institutional and regulatory barriers to renewable power purchasing and cross-provincial transmission. The grid companies, for example, did not compensate solar and wind producers for curtailed energy (despite a requirement for them to do so), and were also contracted with thermal plants in eastern China to uphold minimum operating hours.[132] The lack of effective inter-provincial market-based pricing also made it difficult for producing and receiving provinces to agree on sale terms.[133] After a pause in 2013–2014, curtailment continued to increase, with curtailment of wind reaching 47 per cent in Gansu and 45 per cent in Inner Mongolia by 2015, and curtailment of solar surpassing 30 per cent in both Gansu and Xinjiang in the same year.[134] Despite central government regulatory countermeasures,[135] by 2017 curtailment was so severe in western China that the NDRC began repeatedly halting construction in Gansu and Xinjiang, and extended restrictions to the Tibet Autonomous Region in 2019.[136]

In the late 2010s, the NDRC decided to take the step to vastly reduce the FiT for wind and solar. The new wind FiT was announced in mid-2016 and took effect on 1 January 2017, with developers in western China rushing to finish projects before the cut-off.[137] The new solar FiT, in contrast, took effect without warning on 31 May 2018 – a date so consequential for the industry that it was dubbed "5-3-1" (*wu san yi* 五三一) for short. Utility-scale solar projects in western China that had been highly profitable were suddenly much less economic for all but the largest firms; as a result, demand for panels and components began to rapidly dry up, and smaller companies exited the industry or went bankrupt.[138] Curtailment rates for wind and solar improved in 2018 and 2019, but operators complained of thin margins and profit losses from western China installations that faced a backlog in subsidies. In a move paralleling the SHP industry, SOEs used their preferential access to loans to purchase wind and solar infrastructure from private firms.[139] By 2020, utility-scale construction had fully resumed in western China, with local governments encouraged to develop their own policy instruments to support investment.[140] A continued fall in curtailment rates and the price of components has made

129 Dave Elliott, "Green power curtailment in China," *Physics World*, 17 July 2019, https://physicsworld.com/a/green-power-curtailment-in-china/. Accessed 22 December 2021.

130 Cai and Aoyama 2018; Qi et al. 2019; Tang et al. 2018; Hongye Guo et al. 2020.

131 Hanjie Wang et al. 2016.

132 Qi et al. 2019; Tang et al. 2018.

133 Hongye Guo et al. 2020, 3.

134 Sara Shapiro-Bengtsen, "Wasting less renewable energy could boost China's air quality," *China Dialogue*, 13 April 2017, https://www.chinadialogue.net/blog/9695-Wasting-less-renewable-energy-could-boost-China-s-air-quality/en. Accessed 22 December 2021. Yuning Zhang et al. 2016, 323.

135 NDRC 2015.

136 "China blocks new solar in 3 NW regions amid overcapacity fears," *Reuters*, 14 February 2019, https://www.reuters.com/article/us-china-solarpower/china-blocks-new-solar-in-3-nw-regions-amid-overcapacity-fears-idUSKCN1Q404G. Accessed 26 April 2022.

137 Cai and Aoyama 2018.

138 Liu Bin, "China's solar industry is at a crossroads," *China Dialogue*, 13 August 2018, https://www.chinadialogue.net/article/show/single/en/10775-China-s-solar-industry-is-at-a-crossroads. Accessed 19 December 2021.

139 "China's wind investment strong till 2022; SOEs lead solar development," *Fitch Ratings*, 6 August 2020, https://www.fitchratings.com/research/corporate-finance/china-wind-investment-strong-till-2022-soes-lead-solar-development-06-08-2020. Accessed 22 April 2022.

140 "China to halt subsidies for some types of wind, solar projects: NDRC," *S&P Global*, 11 June 2021, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/061121-china-to-halt-subsidies-for-some-types-of-wind-solar-projects-ndrc. Accessed 25 April 2022.

wind and solar investment attractive once again,[141] though without government subsidies of the previous decade. Whether local governments will be able to reap more sustained rewards from future growth in installations remains to be seen.

## Conclusion

Renewable energy infrastructure is central to successful low-carbon transition, and China leads the world in its deployment. In western China, where the majority of utility-scale installations are located, renewable energy carries the potential for major local economic benefits. Yet this paper has argued that benefits are spatially uneven – with firms in eastern China capturing the most value while producing regions in western China contend with volatile policies and energy demand that inhibit sustained local development. Indeed, while local governments can prosper during the boom, their over-dependence on a single industry means that local economic benefits are precarious and may dry up. Smoothing out these fluctuations and securing longer-term revenue streams is possible for solar and wind, which are booming once again, but this requires a stable policy environment for the industry and persistent central state support for robust local economic development.

The findings of this paper call into question the guaranteed local economic benefits often ascribed to utility-scale renewable energy infrastructure in rural and remote areas. Scholarship is rife with examples of how small-scale solar, wind and hydropower can be used for rural electrification[142] – much as they were in China in the 1980s and 1990s. These small systems are usually subsidized by governments and locally managed for use in the community.[143] However, when installations grow larger, and are connected to the grid, their operators are incentivized to generate electricity for profit and sell it to consumers living elsewhere.[144] Capturing and retaining economic benefits in production areas is certainly possible – particularly if local governments and communities take an ownership stake – but this requires overcoming dependency and smoothing out booms and downturns.[145] Moreover, in the absence of adequate land and resource protections, local communities can lose access to land and water, be forced to change their livelihood patterns, or (in the case of LHP) be resettled altogether.[146] Thus, while new utility-scale renewable energy is greener than traditional extraction – and an essential feature of decarbonizing energy systems – it is not innately just or equitable.[147]

Indeed, the recent trajectories of hydropower, solar and wind highlighted in western China underscore the importance of sustained state backing that prioritizes local development. In the case of hydropower, SHP offered the most opportunity for local autonomy and local economic benefit, but fleeting central state support led to its bust and decline, and the industry seems unlikely to fully recover. Meanwhile, the Chinese state will continue to direct its SOEs to build LHP, including on some of China's last free-flowing rivers, but with significant local and downstream consequences. It is possible that wind and solar may take a middle ground between these two extremes: becoming a stable, SOE-dominated industry that avoids the bust experienced by SHP, but without the most significant environmental and social impacts of LHP. Renewed growth in solar and wind since 2020 – led by SOEs eager to invest – makes it likely that local governments in western China will continue to attract new infrastructure. How local officials on the frontier

141 Jason Deign, "What is going on with China's crazy clean energy installation figures?," *Green Tech Media*, 2 February 2021, https://www.greentechmedia.com/articles/read/what-is-going-on-with-chinas-crazy-clean-energy-installation-figures. Accessed 25 April 2022.

142 Kaygusuz 2012; UNCTAD 2010.

143 Huang 2009; Hussain 2012.

144 Harlan 2018.

145 Newell and Mulvaney 2013; O'Sullivan, Golubchikov and Mehmood 2020.

146 Avila 2018; Yenneti, Day and Golubchikov 2016; Brown 2011; Tilt, Braun and He 2009.

147 Newell, Geels and Sovacool 2022.

respond to this growth, and the benefits and costs for local communities, are an essential topic for future research.

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