2060 Carbon Neutrality Goal: Solar Opportunity in China

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At the United Nations General Assembly on Sept. 22^nd, China's President Xi Jinping announced that China will strive to reach peak carbon emission by 2030 and become carbon neutral by 2060. This means China will be removing at least the same amount of carbon it emits into the atmosphere via clean energy resources, capture technologies, and offset. For the world's top carbon emitter and second-largest economy, such a pledge is bold and ambitious. Tsinghua University's Institute of Energy, Environment and Economy, one of China's top climate research institutes, has laid out a roadmap on Sept. 26^th detailing the completely phase-out of coal power and surge in alternative energy for achieving net-zero. Under this plan, China's energy mix for electricity will undergo a drastic transformation: the share of non-fossil fuels in China's total energy demand will grow to 20% in 2025, 62% in 2050, and 84% in 2060. This is a particular opportunity for solar energy – it is estimated that there will be 150 million tce of energy comes from the solar resource by 2025, and by 2060, this number will be 1.03 billion, increasing by 587% (see Figure 1). That says, in the electricity sector, solar will see the greatest boost in the next few decades, offsetting the decline of fossil power as total electricity demand keeps surging.

China has been the world's leading PV installer since 2013 and has generated more solar power than any other country since 2015. In 2017, China was the first to pass 100 GW of cumulative installed PV capacity. Despite that the government slashed its subsidies on solar power plants in 2018 and further switch off all subsidy taps one year later, cumulative PV capacity in China has reached 208 GW by the end of Q1/2020. This is approx. one-third of global installed solar capacity. Despite that there has been a wide range of relevant policies in "13th Five Year Plan" and other guidelines from the National Energy Administration or National Development and Reform Commission (NDRC) that focus on expanding PV applications in China, solar energy still counts toward less than 3% of total electricity generation in 2019. Now, with the most ambitious climate goal ever seen in the world laying out timetables for a

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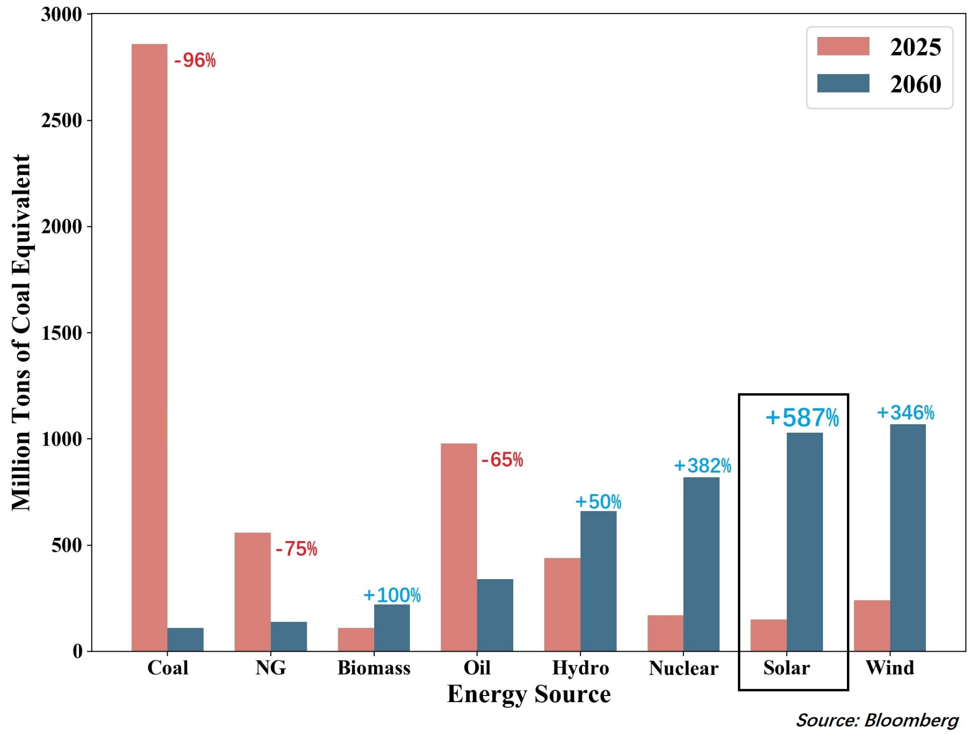

Figure 1: China's energy mix change from 2035 to 2060

new round of energy revolution, what's needed next is a more specific roadmap accompanying all existing and new PV policies. In this writeup, several pathways for driving solar energy expansion are proposed, including Solar plus building, roadside PV, solar-powered agriculture or aquaculture, self-consumption household, Point-to-Point solar energy trade, solar-powered ecological restoration and poverty alleviation, etc. These methods are feasible not only in China but also in the whole world. As mentioned by President Xi, all countries should "seize the historic opportunities" to "achieve a green recovery of the world economy in the post-COVID era and thus create a powerful force driving sustainable development." As one of the most emission-intensive countries in the world endeavors to go solar and transit to net zero, China now has seized the opportunity to lead strategic transition among all countries in the future.

1 Solar-powered world

Solar PV energy has increasingly become a familiar part of our lives, and as the cost of PV panels falls further, innovation will continue to drive new applications of solar energy technology that can improve our daily lives and help power a cleaner world. Several solar products can be promoted or reinforced in China:

Building-integrated PV (BIPV)

BIPV systems are usually planned during the architectural design stage and are used to replace conventional building materials during initial construction. It can also refer to PV panels integrated into the building envelope after construction / during the retrofit. Unlike traditional photovoltaic-based energy systems that require large swaths of land, BIPV lacks the racks and mounting equipment for installation. It can be integrated into the sides of buildings as windows with semi-transparent thin-film or used to replace roofing material. Therefore, the system can both fulfill classic building functions and generate electricity for on-site use or export back to grids, thus achieving a better economic and ecological balance over their lifetime than conventional buildings. Depending on specific needs of building residents, designers can also choose from a variety of technologies and consider the possible use of different PV products. Around the world, Europe constitutes the largest BIPV segment (42% in 2018), particularly contributed by France, Italy, and Germany.

China launched the BIPV projects relatively late. In 2015, there was only 645.2 MW of BIPV being produced, and in 2016, only about 2% of installed PV capacity in China was integrated into the building. Overall, the market mechanism and policy design of BIPV in China was not sophisticated enough. Nevertheless, according to data from the National Bureau of Statistics and China Academy of Building Sciences, the existing rooftop area in China can reach approx. 80 billion square meters. In the meantime, nearly 100 million square meters of lighting roof space is added to the market each year. Once putting into a large-scale application, these buildings will produce a market of nearly one trillion RMB for BIPV. In November 2019, the China NDRC updated the "Catalogue for Guiding Industry Restructuring". In the renewable energy section, design and manufacture of integrated solar building components have been considered as a key industrial structure adjustment to promote. In the next few decades, BIPV can be an important component of transformation for buildings to reach net zero. There might be problems from building construction capacity, production scaling-up capability, or others related to costs of electrification. However, as more industry leaders like Longji, Yingli, and CITIC entering the BIPV field, a rapid development of BIPV from both technology side and cost side is possible in the future.

Roadside solar panels

There are two ways to harvest solar energy along the road: embedding solar cells directly into pavement infrastructures and placing PV panels on roadside lands. The former one is highly recognized among the industry, though less commonly adopted because current thin film PV cells are not yet suitable for pavement due to the premature corrosion and wear caused by mechanical load and high-temperature conditions. A new solar cell design is still needed to overcome these problems. While the latter seems more viable – massive unused lands alongside the roads can be transformed into a collection of productive solar farms, with several road physical characteristics complementing the energy generation: ease of access to the electrical transmission lines adjacent to roads; minimal presence of trees or other objects that obscure sunlight; and negligible deleterious effects upon wild habitats. Many countries have attempted the deployment of solar arrays along highways. For instance, the Germany government explicitly encourage the construction of PV panels in 110 m corridors along motorways and railways, via a feed-in tariff incentive. This was included in the Renewable Energy Resource Act (EEG) revised in 2010. By 2017, over 12% of ground-based PV plants in Germany were located along the federal roadsides.

China is the third-largest country in the world by land and has a gigantic network of highway and roads all over the territory. As the major civil structures for transportation, these roadways lead to approx. a quarter of the country's total carbon emission. If we were to lay down a tremendous number of solar panels along the roadways, they are possible to absorb enough sunlight to power electric cars on the road. This may in turn raise the mileage of electric vehicles after one charge in a station and accordingly make internal combustion engines less attractive. In recent years, the deployment of roadside PV in China just starts to grow. On Aug. 6th, the Ministry of Transport of China issued a "Guideline on promoting the construction of new transportation infrastructure". In the Alternative energy and new material applications section, the guideline encouraged industries to rationally construct PV power facilities along highways or service center and connect them to the locational electricity grid. These lands are either green land or interfile arable land, therefore, placing PV panels does not change the original land use nature. From the perspective of expanding province or city's ability to supply clean energy, and under the broad trend of transportation sector electrification, roadside PV can help significantly raise solar PV generation and cut emissions if well planned with land management. Nevertheless, driver's safety issue, highway operation and maintenance, as well as possible ecological impact, could be potential concerns associated with roadside solar arrays. Therefore, land conditions need to be thoroughly evaluated before accordingly formulating different policies.

Solar in agriculture and fishery

One of the main problems of extensive solar power installations is that panels require large areas – it is estimated that each MW of solar capacity requires an average of 1.7 hectares of land, which could alternatively be utilized for many other purposes. However, a growing number of farmers and solar installers around the world are looking at the co-existence of solar and agriculture now: the so-called "agrophotovoltaics" (agro-PV) involves little more than mounting the racks for solar panels high enough off the ground to permit conventional farming activities operating beneath them. Solar modules here share the same land with arable farming and can serve multiple purposes: 1). they provide electricity for powering farm machinery' daily operations, which reduce farmer's electricity costs; 2). they improve the per acre yield of many crops. The experiments in Germany and South America conducted by Fraunhofer ISE have proved that placing solar panels can increase land productivity by at most 40%, because panels protect crops from hail, lower their temperatures, and keep shade-loving crops out of direct sunlight; 3). the modules also have the potential to reduce evaporation and hence irrigation water usage. In the meantime, solar developers can have the synergies of reduced installation costs, reduced legal risks of using undefined lands, and potentially increased PV performance – growing vegetation beneath contributes to lower soil temperature and higher PV efficiency.

Similar synergies are sought by fisheries. "Aquaphotovoltaics" (aqua-PV) involves placing floating PV panels above reservoirs or laying racks of solar panels above smaller-scale ponds. Fishermen can therefore earn a diversified revenue stream from selling electricity to the grid other than their main income of producing seafood. By providing shade, the solar modules also offer a lower water temperature which enhances shrimps and other aquatic organism growth.

In China, land constraint overall is not a primary factor that limits Solar PV market growth. However, near cities, where require the most electricity, there is still a short of land for clean energy production. Currently, China has established one of the most advanced agro-PV and aqua-PV markets in the world. Multiple industry participants like Tongwei Group and Hangzhou Fengling have installed more than gigawatts of solar power capacity above the arable land and fishery across the country. According to BNEF data, from 2014 to 2018, 4 GW of arable land solar power capacity is installed in China. And by 2019, fish farm PV plants represent approx. 9% of cumulative solar capacity installed in the country. These programs have significantly complemented the country's PV capacity expansion plan without sacrificing valuable land resources. To push the move even further, the next step, industries can focus on small and medium-sized businesses or local food suppliers, to develop a standard approach accessible for average rural inhabitants who have technical and financial barriers. This huge network of agriculture / aqua-feed farmers may not have broad market reach yet, but it has enormous potential to support solar capacity growth. It also deserves emphasizing that while exploring lands for solar power plants, agriculture and aquaculture activities remain the core parts. This means that whatever energy infrastructures or solar facilities should not disturb farmer's usual work.

Solar based ecological restoration

Defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed", ecological restoration can happen in many ways. Within which, solar energy systems could provide an integrated solution for mitigating land degradation and restoring ecosystem services – in a way similar to agro-PV. For instance, in desert areas where high evaporation and extremely low precipitation are not conducive to plant growth, placing PV panels above can effectively preventing damages caused by wind shears and inhibiting evaporation. This thus improving the agricultural bio environment and combating soil and water loss. On the other hand, these lands usually span a large piece of area, which reduce the average upfront cost and risks for solar installer. In constructing racks and panels on the deserts, solar businesses themselves will also have the initiative to mitigating desertification and land loss for reducing panel maintenance costs.

China has been the leader in integrating solar energy systems with ecosystem management. Since the early 2010s, a large number of PV power stations have been built on the barren deserts in western China like Qinghai, Ningxia, and Inner Mongolia. Aside from harnessing one of the most abundant sunlight resources in the country for electricity generation, these panels have achieved remarkable ecological restoration effects – by providing shade and shelter, plain grassland vegetation, and even economically productive crops can now survive on the sterile lands. One of the largest solar-powered ecological restoration projects was launched by Baofeng Group in Yinchuan, Ningxia Province starting 2013. There used to be a Gobi land with a serious desertification problem in Yinchuan, which substantially influences people's life quality. In 2016, Baofeng Group introduced a set of 640MW PV power station and started to grow wolfberries on the 7000-hectares land. Thereafter, the combination of solar technology and traditional agriculture has completely transformed the barren deserts to productive farmlands. In addition, by July 2020, the solar farm has generated 3.87 billion kWh of clean electricity and reduced 1.841 billion kg of carbon emissions. This is equivalent to approx. 80 million of trees per year.

The priority of ecosystem restoration topic over the world has been raised by the United Nations after it officially declared the years from 2021 to 2030 as the UN decade of Ecosystem Restoration. And in China, more industry participants are entering the pool to improve technology design, business model, and residential participation of similar restoration projects. In the next few decades, solar energy systems constructed with degraded grassland, woodland, and even destroyed cultivated land can continuously contribute to improving ecological environment and reducing carbon emissions.

2 Facilitate electricity market reformation

Self-consumption households

The on-site generation and consumption of electricity from distributed solar PV generators is becoming increasingly popular for households and small-scale businesses. Each household can put a group of PV panels above the rooftop, sometimes along with a battery system, to generate clean energy for powering electrical appliances. Many countries have adopted a net metering policy to incentivize the installation of distributed generators. Under this schema, household can sell excess solar energy back to the grid when generation exceeds load requirements during daytime and extract electricity from the main grid as a supplement at night. Depending on different regulation frameworks, the electricity company will then compensate net metering participants the amount of electricity they fed back to grid at a different pre-determined price, therefore reducing households' electricity bills. Such financial benefits, though has criticisms regarding compensation rate design and electricity rate justice, have effectively driven the adoption of distributed generators in many countries, and raised the proportion of clean energy resources in the local energy mix.

China has been relying on high feed-in tariff subsidies for driving distributed solar generation in the last decade. However, considering that the feed-in tariff for residential solar generation has dropped to eight RMB cent (approx. 1.2 dollar cent) in 2020 and will probably be lower in the future, promulgating a new compensation policy, like net metering model, to further stimulate household participation in building rooftop solar capacity has never been more critical. China government once launched a project to support household PV installation by paying a large share of initial rooftop systems' investment and allow them to sell electricity back to grid in 2014. Nevertheless, the program only worked in a small scale. Overall, there has never been a sophisticated net metering schema in China, which is now much needed for approaching the ambitious carbon neutral goal. Drawing upon the experiences and lessons of other countries' net metering implementation, China government could optimize the design of self-consumption and electricity feedback to fit the condition of domestic electricity market. For instance, in China's highly populated city areas where over 80% of the population lives in apartment buildings, it is not always feasible to construct independent rooftop solar facilities for each household. Therefore, residents of a same building could share one set of PV system on the rooftop and obtain evenly distributed clean electricity through smart meters. In the next few decades, this path could hold the most potential to continuously keep distributed solar capacity growing.

Peer-to-Peer solar energy trade

Equipping building rooftops with distributed solar PV systems is indeed a promising way to add clean solar energy into household's electricity mix. Nonetheless, as increasing rooftop PV systems set up to form a locational energy community, peer-to-peer (P2P) trading of distributed generation can move a step further to increase clean energy utilization efficiency and reduce carbon emissions. P2P trading is a business model based on an interconnected platform, it can serve as an online marketplace where consumers and producers meet to trade electricity. Under a P2P transaction mode, residents can trade excess energy from their own PV systems to either other residents in the area or neighbors of a same apartment building at a lower-than-retail price, instead of feeding unused energy to main grids for intermediate agency's secondary dispatch. In this way, clean energy loss along distribution lines is minimized. In addition, generation buyers could pay a lower rate which reflects true costs of solar PV systems instead of higher fee charged by electricity companies. Transactions usually happen directly between distributed generator owners but can also have grid companies involved on behalf of one party. Either way could be a win-win for both power producers and consumers. Pilot projects based on P2P transaction are already flourishing around the world, including the UK, Germany, and Netherlands.

Since the P2P electricity trading mode was born as a consequence of increasing deployment of distributed energy resources connected to the main network, and the intention to provide more incentives to promote further deployment, its application in China is still far from mature. In addition, because P2P trading will hurt the conventional business model of almost absolutely monopolized electricity companies in China and incur revenue loss, they may be reluctant in launching pilot programs to promote P2P models. In light of all these uncertainties around penetration level of rooftop systems and market situations, it might be a challenge for solar developers when it comes to real adoption, the electricity market also needs a reformation to incorporate such a new model. Nonetheless, if effectively promoted, P2P electricity trading can empower consumers, leading to increased solar energy deployment, and make better use of valuable clean resources, which holds another potential path to the 2060 carbon neutrality goal.

3 Solar with Internet-Of-Things

With increasing solar energy facilities being connected to the electricity grid from everywhere in the area, this decentralization can lead to increased operational complexity. How to synchronize and monitor all the generator information also becomes a factor to consider. To create a finer balance between centralized and decentralized assets and combine them together to produce a more efficient power system, it is essential for the solar companies to embrace new technologies like Internet of Things (IoT) to navigate uncertainties around distributed generations. IoT refers to the concept of devices connected to and operated via the internet. It was first proposed to track inventory levels in stores by adding internet-connected sensor to products. It is now used by solar installers as the software part to interact with physical energy facilities and transmission grid. For instance, IoT logs the generation of distributed rooftop systems or energy stored in batteries in a cloud database, which is then used to guide energy flow through the physical medium on the command from electricity users. Therefore, the digital transformation power of IoT makes it easier for solar companies to resolve common challenges associated with management of panels and energy output. One key technology used along with IoT is blockchain, which refers to a specific type of database characterized by decentralization and trust mechanism. While IoT connects each device to the network to become an integral part, blockchain makes the delicate balanced system less centralized to operate. It also offers increased security and transparency via authorizing and identifying every panel or other energy assets within the grid. Point-to-Point (P2P) electricity trading is one application of IoT plus blockchain: as solar energy produced by panels on seller's rooftop, this data is caught by microcontroller and continuously updated in the cloud database. When the neighbor is short of electricity, as long as specific required conditions are met, a block will be created and added to the blockchain which enabling an automatic electricity transaction. On the physical side then, the IoT devices receive a command to allow power flow from the seller to the neighbor node for meeting load needs. Therefore, with an advanced and automated platform, customers' demands are promptly met, and overall solar energy efficiency is improved.

China first considered implementing the concept of energy IoT in 2018. Mainly drove by State Grid, China's national power company, several companies have attempted to apply industrial IoT capabilities to the energy sector. For instance, JD.com, one of China's largest retailer, has partnered with State Grid to build a smart IoT platform for managing the latter's devices and meters, including power distributors, electricity meters, temperature sensors, and humidity sensors. State Grid will thus be able to collect and analyze information about energy usage across different devices to optimize their operations. In addition, China is already the world's largest vehicle market, and its fleet is expected to continuously swell up. If we were to connect EVs with distributed solar energy systems in an intelligent way such that charging time and location of vehicles can be optimized to ensure efficient use of solar energy, more PV capacity can be added without shift burden on grid managers.

Despite that IoT plus solar has many advantages, there still exist major obstacles even for a tech-savvy companies with a large budget and engineering resources like JD.com. Currently in China, the coverage of data collection from distributed energy assets is far less than enough. There still lacks an equipment-oriented method to approach customers and integrate them into the network. Besides, the most fitted algorithm for achieving multi-PV system optimization, equipment control, or regional capacity planning is still under development. Overall, China's energy IoT industry is still in its infancy. Nevertheless, there can be tremendous potential for its development in the future, which will enable solar system's efficiency optimization and productivity improvement.

4 PV for all people

Citizen's solar power plant

While some residents are able to construct their own solar PV systems on the rooftop, other individual house owners may not afford to pay for a whole set of solar facilities. Similarly, while some housing communities are willing to share a same rooftop system then split clean energy generation through meters, other neighborhoods may not be able to yield a consensus. Therefore, an innovative new model that allows these citizens to participate in the installation of PV panels on public buildings' roof is needed. Citizen's power plant is one of the available modes to implement. In this model, a group of citizens will jointly own one solar power plant. Since facilities were not constructed near to panel owners, the clean energy resources will be fed back to the main grid for other's use, while citizen owners obtain a financial return. One typical case is from Vienne, where the energy provider Wien Energy puts up, plans and operates solar facilities, and then feeds clean energy into Viennese net. Citizens have the option to purchase real PV panels or stock shares of the solar power station to claim the ownership of solar panels. For the latter way, people who have budget constraints also have the opportunity to procure fractional shares, i.e. part of one PV panel. Under either way, the electricity company will re-rent the physical or virtual panel back from these citizens and install those modules on public buildings' roofs or just beyond the city boundary. In brief, each citizen invests in part or all of a set of panels, lease them to Wien Energy for electricity-generating elsewhere, and then receives a specific amount of remuneration annually. In this way, more residents can involve themselves in the city's clean energy transition process, even without physical space to accommodate panels.

The citizen solar power plant model in Vienna manifested a huge success, tens of millions of people in the city have been mobilized to participate in renewable energy generation. In fact, this mode is replicable for many cities in China. A large proportion of residents in China's megacities now are living in a rental house. They do not own the property, neither the right to install panels or enroll the house to a PV sharing project. For those people who want to reduce carbon footprint and source green electricity, a citizen power plant is the best and most convenient public participation model. Considering that participants can obtain stable reimbursement from electricity companies, co-owning the panels also becomes a healthy and low-risk investment activity. All these advantages will enable the electricity provider to engage a large audience into the contract. Even one does have the room and right to place a panel on his own house, people can still divert to the citizen program such that they can avoid complex approval or construction procedure, maintenance work, and technical expertise acquisition. On the other hand, electricity company could collect capital via the form of citizen power stations then used for managing and operating solar facilities holistically. This not only helps to reduce unnecessary maintenance and labor costs but also increase the efficiency of adding new solar capacities. For both citizens and electricity provider, it is a win-win situation.

Overall, cities play an important role in facilitating renewable capacity expansion and carbon reduction. Citizen power plants provide an option for different type of residents to contribute to the energy transition journey of the city such that each citizen could be engaged. In consideration of the large population base in China's city areas, even 10% of all residents were mobilized to participate, this could potentially produce gigawatts of new installed solar capacity in the area.

PV Poverty Alleviation

Residents in cities or town areas can have multiple options to engage into solar energy activities, but there is much less a choice for people in poor rural areas, where there might still be issues regarding energy access. The idea of deploying solar PV systems in these areas is first to ensure reliable electricity resources, and based on which, help poor households out of poverty by reducing electricity cost and even creating extra income from selling PV power generation. These solar facilities are usually installed above farmlands, fishing ponds, and rooftops, i.e. combined with local agricultural or aquacultural lives. Therefore, farmers can benefit from both diversified revenue stream and more efficient farming activities. In China, large proportion of population under poverty line is located in the most remote and isolated areas in the west. A section of which is also nomadic and therefore hard to locate statistically. Different from some Africa countries, 100% electrification is no longer a question in China. However, the harsh environmental and geographic conditions make it difficult for governments to significantly improve local livelihoods in a sustainable way. For instance, in Qinghai province, one of the China's poorer ones, the context of a warming climate and serious grasslands degradation has made the sustainability of rangelands a major concern – desertification of pastures directly resulted in lower survival rate of livestock. Accordingly, in 2014, China initiated a plan to help alleviate rural poverty through deploying distributed PV systems. This method, beyond government subsidies and temporal material assistance, can not only steadily restore ecological condition in a way that combines solar power systems and nomadic activities, but also expand clean, free energy access for local populations. This pilot project aimed to add over 10 GW solar capacity and benefit more than 2 million households across the country by 2020, which is the year President Xi pledged to end absolute poverty in China. Indeed, according to data from National Energy Administration, by the end of 2017, PV power stations had been built in 940 counties in 25 provinces, directly benefiting 965000 poverty-stricken households in China. One of the most successful cases came from the Talatan area of Gonghe County in Qinghai Province, where a subsidiary company of the State Power Investment Corporation installed solar panels on wilds, planted seeds of grass under the panels, and invited local farmers to bring sheep to graze under the solar facilities. This desertified land has now turned into vigorous grassland and see substantial improvement in ecological, social and economic development. As more farmers gather together to form a small urban concentration, there also comes employment opportunities, modern life measures, and even tourism. These all tremendously changed the life qualities of local population.

As one of the most populous country in the world endeavors to shed poverty entirely, there is still every reason to believe that this innovative method will continue to bear fruit in the next few decades as more rural people strike to engage in solar projects and improve their life qualities. This also benefits the country's carbon reduction and solar expansion plan in that: 1). off-grid solar capacity has higher potential in western China than utility-scale solar plants, because more than two million individuals including nomad communities are in need of a portable, safe and sustainable energy supply; 2). despite that some western population above poverty line are already equipped with modern electrical appliances, there is plenty of room to reduce their carbon footprints via the adoption of solar energy systems. Take cooking utensil as an example, biomass and diesel are still primary forms in some areas. Promoting solar cookers can thus avoiding carbon emissions and harmful indoor air pollution from biomass smoke or fossil fuel molecules. Therefore, if the government were to support distributed PV energy systems adoption for each household in rural area, this could potentially expand a substantial amount of solar capacity and cut residential carbon emissions.

5 Summary

China has been an emerging green superpower for many years, with great progress in sustainable technologies being made. Its uptake of renewable energies was on a scale few other countries can match. However, as the most carbon-intensive economy in the world, transforming itself to net zero in the next four decades is a gigantic task. China's energy consumption still relies heavily on coal, and this trend will continue to rise before tremendous efforts and critical shifts are underway. The pathways proposed in this article all hold the potential to continuously keep China's solar capacity growing and decarbonize the power grid, but it may take a while for citizens to feel the effects, and this is just the first step for decarbonizing the whole economy.

Current policies in China would not be enough to indicate whether the country is on track to meet its ambitious goal, and more details of target and legislation are to see in the forthcoming "14th Five-year plan". Nevertheless, this is a golden period for not only solar, but also other alternative energies to replace fossil fuels. Along with the European Union, the UK, and other countries that have committed to carbon-neutral in the next few decades, China can drastically control its emissions to expedite Paris Agreement's goal of limiting global warming to 1.5 degrees.