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China Rural Energy Transition: Integrating Renewable Energy, Heating and Transport Sectors - Potential Areas for EU-China Cooperation

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EU-China Energy Cooperation Platform was launched on 15 May 2019, to support the implementation of activities announced in the 'Joint Statement on the Implementation of EU-China Energy Cooperation'. The overall objective of ECECP is to enhance EU-China cooperation on energy. In line with the EU's Green Deal, Energy Union, the Clean Energy for all Europeans Package, the Paris Agreement on Climate Change and the EU's Global Strategy, this enhanced cooperation will help increase mutual trust and understanding between EU and China and contribute to a global transition towards clean energy on the basis of a common vision of a sustainable, reliable and secure energy system. Phase II of ECECP is implemented by a consortium led by ICF, and with National Development and Reform Commission Energy Research Institute.

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Executive Summary

China is in the midst of a major build-out of distributed rooftop PV in rural areas, occurring in tandem with a rapid expansion in the adoption of electric vehicles (EVs) in rural areas. China is also the world's largest market for electric heat pumps, which a prior analysis showed have potential to increase absorption of excess PV output in rural areas while also earning attractive economic payback in most regions when replacing heating from fossil fuels.

This study extends the analysis of rural PV and heat pumps to include an evaluation of the potential for bidirectional EV charging. In rural China, average incomes are lower than in cities, and EV ownership tends to focus on the cheapest vehicles, including especially two- and three-wheeled vehicles, though low-range four-wheeled EVs are not uncommon. Rural residents have less predictable driving schedules than urban commuters, and higher economic motivation to participate in smart charging or bidirectional charging if it saves money on charging.

Chapter 1 of the study provides background on the topic of the energy transition in rural China, examining the history of solar in rural areas and the Whole County PV Programme, as well as the effort to clean up rural heating and promote EV adoption in the countryside. Both the PV and EV markets are booming in rural areas, especially in eastern China, making this a timely moment to consider the economics of pairing the two technologies to ameliorate the longstanding problem of inadequate distribution grid investment in rural China.

In Chapter 2, the results of interviews with Chinese and international experts are presented. The interviews show that experts in both China and Europe have a diversity of views about the potential contribution of bidirectional charging as a component of the energy transition. In Europe, the cost of bidirectional charging and the lack of vehicle models are viewed as major barriers, along with regulatory barriers and the lack of dynamic electricity prices in most regions. In China, experts believe many rural residents are likely to participate in bidirectional charging once it becomes available, especially households that own a four-wheeled EV but are able to rely on smaller, two- or three-wheeled vehicles for some daily tasks.

Chapter 2 also includes interviews with experts on international cooperation in the fields of power market reform and low-carbon energy transition. Both Chinese and European experts are optimistic that cooperation in these fields remains relevant and useful to both sides. Although Europe and China are increasingly becoming commercial and industrial rivals in the field of EVs, experts in both regions argue that their markets and economies remain highly complementary, and their experiences relevant for exchange on the policy level. As one expert notes, if both regions attempt to find solutions to the low-carbon transition only on their own, neither will be able to achieve their climate goals on schedule. Charting separate paths can only slow and weaken the clean energy transition.

Modelling analysis is presented in Chapter 3. The analysis, which draws on county-level data of hourly solar output and climate data, shows:

1. **Bidirectional charging offers modest electricity cost savings** in most Chinese provinces studied – around RMB 250 to 300 per year (EUR 33 to 40 per year). This rises to RMB 600 to 700 per year if excess solar production is

compensated at lower prices. The upfront cost of bidirectional charging and structure of time-of-use tariffs (including for solar output sent to the grid) would need to change before bidirectional charging becomes economically attractive for rural households in China.

2. **Bidirectional charging also increases PV household self-sufficiency** to around 50 to 60 per cent, up from 30 to 40% in the absence of bidirectional charging.
3. Bidirectional charging to increase uptake of midday PV output has a **limited impact on the ability of most drivers to complete daily trips** with only residential charging.
4. However, even with bidirectional charging, households still have excess solar output at certain times, and **do not reach full self-sufficiency**, implying that V2H does not represent a complete solution to the problem of inadequate rural distribution grid investment.

Overall, bidirectional charging remains an area of heated debate in China and abroad, with many touting the benefits and other experts remaining sceptical of its potential. Barriers remain in multiple aspects, including consumer acceptance, electricity pricing, market design, taxation, technology standards, and uncertainty about battery degradation. On the flip side, the rapid introduction of new car models and bidirectional-capable charging equipment for CCS and Chinese chargers could accelerate adoption of bidirectional charging in different applications, even if commercial adoption is limited to a small number of vehicles or user types, such as for large EV fleets. In the US and Europe, vehicle-to-home bidirectional charging appears attractive, especially to those with distributed energy. In China, fleet and industrial applications of bidirectional charging may be the initial focus.

Regarding the subject of this study, rural integration of EV charging with renewables and other clean energy technologies, there are few concrete policies in China, though in 2023 several policies have mentioned or alluded to the possibility of using smart charging or V2G in rural areas or to balance renewables in rural areas. The rapid expansion of rural rooftop PV underway since 2021 under the Whole County PV programme, combined with increasing EV penetration in rural areas, is likely to result in significant developments, in terms of both policy and practice, that could ultimately translate to policy momentum around promoting V2G specifically for integrating distributed rooftop PV at the village or household levels.

Potential for business and commercial collaboration

European and Chinese rural areas are notable for their large differences. Just as China's cities are larger and denser than their European counterparts, China's rural areas are poorer and more agricultural. However, rural areas in both regions are highly diverse, in terms of incomes, employment, and energy sources. In Europe, rooftop solar PV is common in some of the wealthier rural areas, including some regions with poor solar resources; in China, rooftop PV is expanding rapidly in the provinces of Henan, Hebei, Shandong, and Jiangsu – middle income provinces with good solar resources and, in many cases, local solar supply chains. For EV adoption as well, rural regions differ: European rural areas are often wealthier, whereas Chinese rural areas are focused on adopting EVs to save money, especially smaller, cheaper EVs.

The results of the interviews in this study suggest that Chinese and European rural areas each have their own unique advantages and disadvantages for the adoption of bidirectional EV charging, either for vehicle-to-home or vehicle-to-grid applications. Europe's advantage lies in its vibrant, real-time wholesale power markets and efforts to expand the role of time-of-use or dynamic pricing to the field of EV charging. However, Europe's disadvantage lies in the high cost of equipment for bidirectional charging, and in various regulatory barriers that need resolution. In contrast, such equipment is available at low cost in China, and rural residents are likely already motivated to consider bidirectional EV charging. However, the structure of residential electricity prices – both for consumption and for excess solar PV output – will discourage interest in bidirectional charging in the near term.

European companies are likely to take the lead in offering sophisticated, user-oriented bidirectional charging services involving partnership between electric utilities and charging providers. Such business models already exist in certain regions and countries with time-variant power prices, and more countries are promoting such business models. As more car models with bidirectional charging capabilities come on the market, car companies and charging providers will have more opportunities to gain experience with bidirectional charging for home or grid applications. With EV charging aggregation, European companies are likely to gain more experience in the field of using bidirectional charging to offer lower charging prices, especially for certain fleet vehicles.

Chinese companies have the advantage of lower cost bidirectional charging equipment and, potentially, greater ability for grid companies to rapidly expand large pilot projects to vast areas that have recently installed significant amounts of distributed rooftop PV. In the near-term, China's bidirectional charging market is more likely to be driven by policy and local pilots than by commercial players active in retail energy markets, as might be the case in Europe. However, low-cost Chinese bidirectional charging products could help resolve one of the biggest barriers to bidirectional charging in Europe, and the speed of adoption of bidirectional charging in China will be important for European companies to monitor and learn from.

Table of Contents

Executive Summary **1**

Introduction **5**

1. The Overall Potential for Accelerating China's Rural Energy Transition via Integrating PV, Heat Pumps, and EV Charging **7**

1.1. Overall situation and trends regarding rural smart charging and V2G for integrating renewables—in China and abroad 7

1.2. Rural PV policy in China 10

1.3. China's EV market 17

1.4. EV charging 19

1.5. Smart charging in China and abroad 20

1.6. V2G policy in China 23

1.7. V2G outside China 25

1.8. China's policies on rural renewable integration, demand response, EV charging and V2G 28

1.9. Summary: Smart charging and V2G are at an early phase, but progress is accelerating 35

2. Expert Views of EV charging and EU Cooperation Potential **37**

2.1. Introduction 37

2.2. Background on rural EVs and bidirectional charging in Europe and China 39

2.3. Interview results: international EV charging experts 41

2.4. Chinese EV expert views of bidirectional charging and rural EV usage 58

2.5. Chinese views on international cooperation regarding integrating EV charging and renewable integration 67

2.6. International policy expert views on EU-China cooperation on bidirectional charging for renewable integration 73

2.7. Overall summary of Chapter 2 79

3. Modelling and Analysis of Combining V2H with PV and Heat Pumps **81**

3.1. Introduction 81

3.2. Results: savings from V2H 86

3.3. Regional differences in savings from V2H 87

3.4. Sensitivity analysis of battery and V2H characteristics 89

3.5. Conclusions: V2H offers solar and EV households modest savings at little cost to convenience 98

4. Conclusions and Lessons for EU-China Cooperation on EV Charging and V2G **101**

5. List of Figures **104**

Introduction

Although renewable energy sources are often located in rural areas, in China historically the energy transition has tended to focus on large, centralised projects, as opposed to smaller communities that could also benefit from distributed renewable energy. Similarly, for energy efficiency investments, vehicle electrification, or heating electrification, rural areas have lower incomes and hence are often less of a focus for policies that promote these technologies or investments.

This has started to change in recent years. In 2021, China's National Energy Administration (NEA) launched the Whole County PV pilot policy, which despite some setbacks has resulted in a surge in household solar PV additions in rural areas, especially in a handful of provinces in north-central China such as Shandong, Henan, and Jiangsu. However, a widely recognised problem is that small villages often have insufficient demand to absorb the highly variable solar output locally, which also exceeds the capacity of the distribution grid and causes oversupply of electricity at the provincial level. While policy makers seek to bolster the capacity of local grids, reducing the investment cost necessitates policies to boost local electricity demand and energy storage to absorb peak solar output.

This study seeks to analyse the potential for rural electrification to contribute to the integration of distributed renewable energy, particularly distributed rooftop PV at the village level. It builds upon prior analysis of the synergies between distributed PV, heat pumps, and energy storage, which have the potential to substantially increase the self-consumption of local PV – from roughly 20% - 30% self-consumption without storage to 40% - 60% with energy storage.[1]

The prior research also found the investment costs of storage would be difficult to justify economically. For this reason, adoption of electric vehicles has the potential to contribute to the absorption of surplus PV output, either through smart charging or through bidirectional charging. Bidirectional charging could function at the level of an individual home, known as vehicle-to-home (V2H) or vehicle-to-load (V2L), or it could serve a whole local community at vehicle-to-grid (V2G) level through bidirectional public charging posts or shared posts exclusively for the local community, while still reducing grid investment costs.

To address these topics, this study employs three approaches. First, the analysis builds upon modelling of household and village energy consumption under the Whole County PV pilots, combined with prior research of current trends in rural adoption of electric vehicles, which tend to emphasise low-cost two- and three-wheeled vehicles. Second, because of the limitations of modelling and uncertainty about future technology development and costs, the study will incorporate interviews with Chinese grid and EV experts. Third, to assess the potential for this topic to contribute to international cooperation as a means to accelerate the clean energy transition in China and abroad, the study includes expert interviews with European and American industry insiders, and seeks to compare progress and experiences on

[1] Anders Hove, 'Synergies between China's Whole County PV program and rural heating electrification,' Oxford Institute for Energy Studies, May 2023, at https://www.oxfordenergy.org/publications/synergies-between-chinas-whole-county-pv-program-and-rural-heating-electrification/.

smart charging and bidirectional charging as a basis for comparison and mutual exchange on the topic.

- Chapter 1 consists of an overview of the current trends in renewable energy and EV adoption in the rural energy transition. It includes a review of relevant literature and policy on China's rural transition, and a brief discussion of the current status of power markets, EV charging and bidirectional charging in Europe and China.
- Chapter 2 consists of the results from a total of 30 semi-structured expert interviews conducted for this study. Two sets of experts were consulted: The first group consisted of EV and EV-charging related experts working in the EV or charging industry or focused on EV charging policy in their work in academia, NGOs, or grid companies. The second group consisted of policy experts working on international cooperation between Europe and China, mainly on topics related to the electric power sector. For each expert group, results of the interviews are presented to compare the responses of international experts and Chinese experts.
- Chapter 3 focuses specifically on the topic of electrification of rural transportation, including conventional EVs and small-scale EVs such as three-wheeled vehicles, with a focus on integration with renewable energy. The analysis incorporates modelling of EV charging in rural areas based on interview-based data collection for this study. This data is used to model the match between electric load and distributed renewable output on an hourly basis, and to understand better the economic potential of, and barriers to, smart charging and/or V2G as a means of increasing self-consumption of renewable energy.

The primary point of comparison is the EU, for several reasons. First, the EU and China each have advanced and comprehensive strategies for addressing climate change. Second, the EU and China are each large car markets and manufacturers, and each has a similar percentage of electric vehicles in new sales. Third, although rural areas in Europe are substantially different from those in China in terms of income, energy consumption and vehicle ownership, both Europe and China have high adoption of solar and electric vehicles in rural areas. Rural areas in both regions are highly diverse in terms of all the characteristics mentioned.

The results of modelling show that bidirectional charging has good potential to drive electricity cost savings in rural China, and to increase uptake of electricity produced by rooftop solar PV. This backs up the results of an earlier analysis of pairing PV with heat pumps in rural areas, showing that the rural energy transition has ample potential to result in significant cuts to fossil fuel emissions and boost local uptake of renewable energy. However, this optimistic result faces a number of practical obstacles, in particular investment costs and policy coordination. The area of EV smart charging and bidirectional charging similarly offers a mix of opportunity and challenges. Many areas of policy and technology uncertainty are likely to see significant change over the next three to five years, due both to the arrival of new car models and chargers and to the implementation of new policies once smart charging and bidirectional charging have become widespread. International cooperation offers some opportunities for mutual sharing of experiences and lessons learned in this field, while acknowledging the stark differences in conditions in rural areas of China versus Europe or North America.

1. The Overall Potential for Accelerating China’s Rural Energy Transition via Integrating PV, Heat Pumps, and EV Charging

Chapter Summary

- As China scales up rural rooftop solar PV under the Whole County PV programme, there are growing concerns about how to integrate PV into the grid, given the midday oversupply of solar energy and the weakness of rural distribution grids.
- Electrification of heating and transport offer potential solutions for absorbing excess PV output, but only under the right conditions, and both technologies face barriers in China and abroad.
- China is a leader in EV adoption, and has initiated a new campaign promoting EVs and charging infrastructure in rural areas. Many rural residents already own electric two- and three-wheelers.
- China’s power market reforms include several elements that could eventually encourage flexible charging to help absorb local solar output, including more widespread time-of-use pricing.
- V2G is referred to increasingly often in Chinese electricity market and EV policy documents. Chinese and international carmakers are introducing bidirectional-charging-capable models.
- These trends, along with widespread deployment of rooftop PV in many rural regions of China, could ultimately translate to policy momentum around promoting V2G for integrating distributed rooftop PV at the village or household levels.

This study provides an overview of renewable energy and EV adoption in the rural energy transition, assessing the adoption of PV and EVs in rural areas, as well as the overall situation and trends regarding integrating PV and EV charging in these regions. The analysis in this report serves as the foundation for the semi-structured interviews conducted in Chapter 2, as well as for the modelling analysis presented in Chapter 3.

1.1. Overall situation and trends regarding rural smart charging and V2G for integrating renewables—in China and abroad

Background on China’s rural energy transition

In a sense, China’s rural clean energy transition has been under way for decades: the country’s rural areas have undergone a gradual shift away from traditional non-commercial sources of energy such as straw and firewood to coal, oil, and electricity. More recently, coal use has shifted towards cleaner forms of coal and alternatives to coal such as electricity, gas, and solar. Today, electric vehicle adoption has risen in rural China, thanks to the advent of low-cost two- and three-wheeled EVs.

Although there has been clear progress both in reducing emissions of traditional pollutants from rural energy and in increasing energy access, the clean energy transition faces immense barriers in rural areas of China. A sharp urban-rural income disparity, as well as huge differences in construction standards and infrastructure, mean that rural residents and businesses often opt for the lowest-cost materials and energy sources, even when cleaner options would be more economical on a long-term basis. For this reason, rural areas are often dependent on major policy initiatives targeting rural livelihoods, such as the Poverty Alleviation PV programme, or the rural clean heating campaign that formed part of the War on Air Pollution.

Most recently, the Whole County PV programme has sought to bring PV to a much wider area of China, using a unique model to scale up rooftop PV. This study builds on prior research that evaluated the potential to utilise the Whole County pilot project concept to combine PV with other clean energy technologies, namely electric heat pumps, which offer substantially improved energy efficiency compared with traditional heating technologies. In this study, the analysis is carried one step further, to evaluate the potential for combining PV, heat pumps, and electric vehicle technology, either through smart charging or V2G.

In terms of fuel mix, rural households have seen a profound shift in energy sources over the past three decades. Coal has fallen as a share of rural household commercial energy use from 93.7% in 1991 to 57.4% in 2012, whereas electricity's share has risen from around 4% to 27% over a similar time frame, and oil rose from 2% to 15%. These commercial sources of energy have largely displaced traditional biomass such as straw and firewood, which accounted for 77% of household energy consumption in 1990 but only 38% in 2015. However, the most remote and rural areas of China may continue to rely on such traditional energy sources, despite having access to electricity, coal and other energy sources. The provinces of East China such as Shandong and Jiangsu have seen a far greater shift in the proportion of electricity and oil as compared to coal or traditional biomass.[2]

Over a similar time frame, efforts have been under way to reduce rural energy emissions and expand access to clean energy, both to improve rural livelihoods and indoor air quality and to address regional air quality issues. Low-cost solar hot water heating took off rapidly during the 2000s, and has increased from 10 million m^2 of heating area in 2000 to over 80 million m^2 in 2018.[3] Rural PV has also been a policy focus, as will be discussed further below. However, the main focus of clean heating policies has been switching from coal to either electricity or gas, either via direct electrification such as with heat pumps or resistance heating, or by expanding district heating networks. As a result of the effort to switch away from the dirtiest forms of coal stoves for household heating, over 70% of household floor area had

[2] Xinxin Zhang et al., 'A Review on the Rural Household Energy in China From 1990s—Transition, Regional Heterogeneity, Emissions, Energy-Saving, and Policy,' Front. Energy Res. 10, 25 May 2022, at https://doi.org/10.3389/fenrg.2022.907803.

[3] Xinxin Zhang et al., 'A Review on the Rural Household Energy in China From 1990s—Transition, Regional Heterogeneity, Emissions, Energy-Saving, and Policy,' Front. Energy Res. 10, 25 May 2022, at https://doi.org/10.3389/fenrg.2022.907803.

clean heating in seven of China's 15 northern provinces.[4] Despite relatively low prices, household electricity usage remains below that of the US or Europe—though it has risen strongly over the past two decades—and rural households use less electricity than urban households.[5]

Poor building energy efficiency remains the norm in rural China, leading to higher energy costs and lower comfort. Rural residents consume more energy due to poor construction quality.[6] Typical building materials have barely changed over the past few decades, with the emphasis remaining on low-cost, locally-available materials such as concrete blocks or bricks. [7] Residents often construct or renovate on their own with locally available materials, leading to poor airtightness and high degrees of moisture infiltration. In some areas, fewer than 20% of new buildings meet government efficiency standards,[8] while the efficiency of existing buildings is undoubtedly even lower. As a result of poor efficiency and lower incomes, rural households are often forced to accept a far wider range of indoor air temperatures and humidity than would be common in cities. In rural areas, it is not uncommon for households to maintain a winter interior temperature of 10˚C.[9]

While rural incomes are lower than that those in urban areas, the situation has improved steadily in recent decades. Rural household incomes rose by a factor of 3x from 2010 to 2020,[10] and the rural-urban income gap appears to have peaked. The central government has long made rural development a policy priority, even as rural populations have declined and cities have lured working-age population to jobs in the largest, most developed coastal regions. Many remote regions are home to 'hollow villages' with few working-age residents and mostly older populations caring for grandchildren. Such villages are likely especially reluctant to invest in major energy-saving or clean-energy technologies.

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[4] Niu Yuhan, 'What next for clean heating in rural China?,' China Dialogue, 25 May 2023, at https://chinadialogue.net/en/energy/what-next-for-clean-heating-in-rural-china/.

[5] Dong Wu et al., 'Features and drivers of China's urban-rural household electricity consumption: Evidence from residential survey,' Journal of Cleaner Production, 365, 10 September 2022, at https://doi.org/10.1016/j.jclepro.2022.132837.

[6] He Bao-jie et al., 'Overview of rural building energy efficiency in China,' Energy Policy, 69, 2014, at https://doi.org/10.1016/j.enpol.2014.03.018.

[7] Baiyi Li et al., 'Energy consumption pattern and indoor thermal environment of residential building in rural China,' Energy and Built Environment 1(3), July 2020, at https://doi.org/10.1016/j.enbenv.2020.04.004; Rongdan Diao et al., 'Thermal performance of building wall materials in villages and towns in hot summer and cold winter zone in China,' Applied Thermal Engineering, 128, 5 January 2018, at https://doi.org/10.1016/j.applthermaleng.2017.08.159.

[8] Rongdan Diao et al., 'Thermal performance of building wall materials in villages and towns in hot summer and cold winter zone in China,' Applied Thermal Engineering, 128, 5 January 2018, at https://doi.org/10.1016/j.applthermaleng.2017.08.159.

[9] Baiyi Li et al., 'Energy consumption pattern and indoor thermal environment of residential building in rural China,' Energy and Built Environment 1(3), July 2020, at https://doi.org/10.1016/j.enbenv.2020.04.004.

[10] 'Annual per capita disposable income of rural households in China from 1990 to 2021,' Statista, January 2022, at https://www.statista.com/statistics/289182/china-per-capita-net-income-rural-households/.

1.2. Rural PV policy in China

China's domestic solar PV industry began to take off in the early 2000s, aimed first at the export market, and subsequently at large, utility-scale projects connected to the high-voltage grid. However, from the early 2010s, the government also focused on policies to promote distributed solar PV in both rural and urban areas. In 2013, China piloted the Poverty Alleviation PV programme, and it was transformed into a national policy in 2016, led by the National Development and Reform Commission (NDRC), the National Energy Administration (NEA), State Council Leading Group for Poverty Alleviation and Development, the China Development Bank, and the Agricultural Development Bank.[11] Under the programme, 35 000 poverty-stricken villages located in 471 counties in 16 provinces received PV investments, which included community-level PV arrays as well as household PV.

Research on the Poverty Alleviation PV programme showed that it was associated with an increase in incomes for participating villages, but there were problems reported in the program in terms of who benefited.[12] Barriers to effective implementation included lack of financing for small-scale solar, lack of funds for maintenance and upkeep, and a lack of incentives for local officials.[13] The programme suffered from subsidy payment delays, insufficient rural distribution grid infrastructure, low quality of PV equipment supplied to rural residents, and inflexible revenue allocation. These factors reduced the revenue from PV for local residents – due less to curtailment than to low energy production and inadequate compensation – and ultimately increased the costs of PV deployment on a per kWh basis.[14]

Since the Poverty Alleviation PV programme, China's annual installation of PV of all types has risen, and the country now adds more PV capacity annually than any other type of electricity source. The steady decline in the upfront cost of PV, including for distributed and rooftop PV, has also led to increased interest in distributed PV, including in more rural areas. Meanwhile, transmission constraints between the large energy bases planned in western China have encouraged the government to push for adoption of more distributed PV in eastern China.

The confluence of improved economics and transmission constraints ultimately led to the adoption of a new pilot programme known as the Whole County PV programme. The policy was announced in June 2021,[15] and requires participating counties to install rooftop solar on 50% of government buildings, 40% of public buildings such as schools and hospitals, 30% of commercial and industrial buildings, and 20% of

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[11] Huimin Zhang et al., 'Solar photovoltaic interventions have reduced rural poverty in China,' Nature Communications, 23 April 2020, at nature.com/articles/s41467-020-15826-4.

[12] Sam Geall et al., 'Solar energy for poverty alleviation in China: State ambitions, bureaucratic interests, and local realities,' Energy Research & Social Science, Volume 41, July 2018, Pages 238-248, at https://doi.org/10.1016/j.erss.2018.04.035.

[13] Suzanne Fisher Murray, 'Solar PV can help China's poorest,' China Dialogue, 2016, at https://chinadialogue.net/en/energy/9420-solar-pv-can-help-china-s-poorest/.

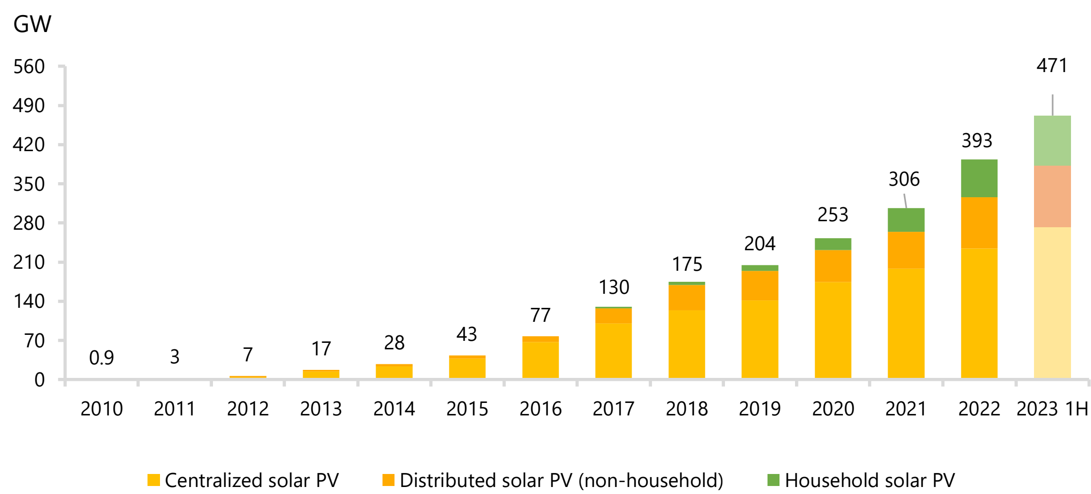
[14] Yan Li et al., 'A review of photovoltaic poverty alleviation projects in China: Current status, challenge and policy recommendations,' Renewable and Sustainable Energy Reviews, Volume 94, October 2018, Pages 214-223, at https://doi.org/10.1016/j.rser.2018.06.012.

[15] '国家能源局综合司关于报送整县（市、区）屋顶分布式光伏开发试点方案的通知 [NEA Comprehensive Department Issues Whole County/City/District Rooftop Distributed PV Pilot Plan],' National Energy Administration, 20 June 2021, at http://www.chic.org.cn/home/index/detail?id=1100.

households. The main benefit of participation is that counties are permitted to organise a single tender for a company that will install solar across all the required rooftops, with the potential to substantially reduce the various soft costs – customer acquisition, planning approvals, grid connection procedures – that normally burden smaller rooftop solar installations. By September 2021, over 650 counties or other entities had joined the programme,[16] accounting for roughly half of China's counties and around one quarter of the country's population.

The adoption of the Whole County PV programme has substantially increased an already clear trend towards distributed solar PV and especially rooftop solar PV in China, which had initially focused on large utility-scale PV plants in remote regions. In 2022, the NEA reported that China added a total of 87 GW of solar PV, of which 51.1 GW was distributed. Of the latter figure, roughly half was household rooftop PV. Much of the new rooftop PV has been concentrated in the provinces most active in the Whole County PV programme, particularly Henan, Hebei, Shandong, Anhui and Jiangsu provinces, all in East Central China. Distributed PV (both commercial and residential) now makes up around 40% of China's solar capacity.[17]

Figure 1: China's total installed solar capacity by category

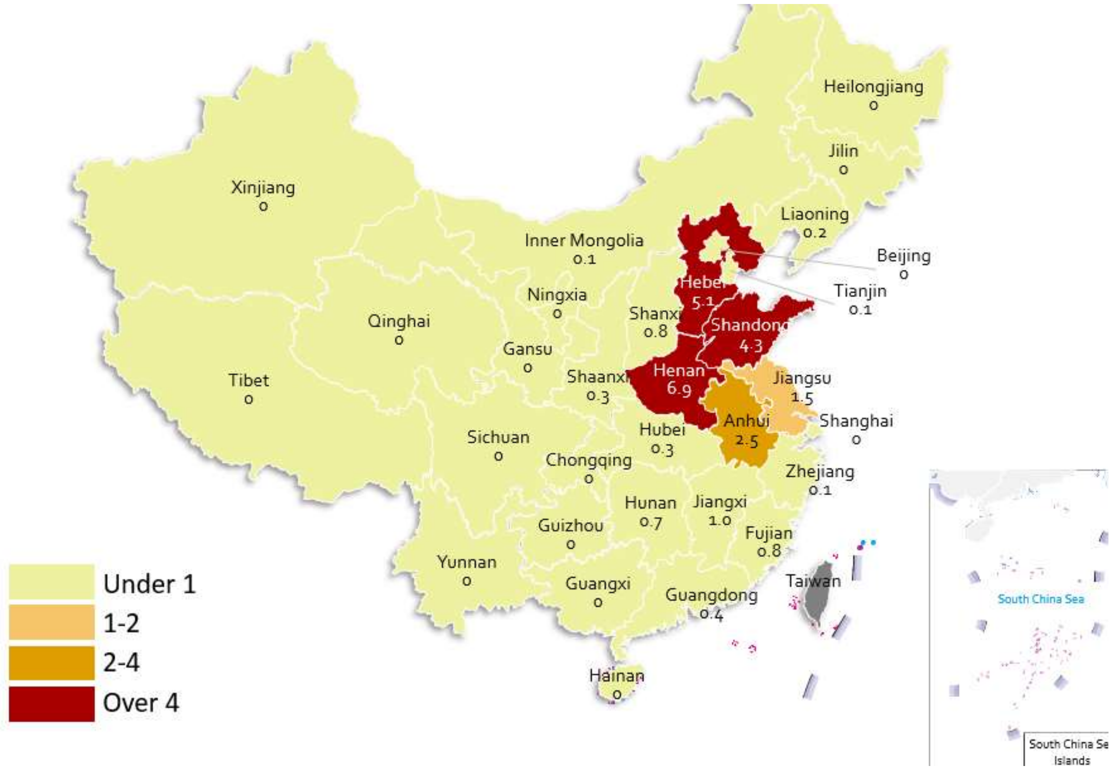


Source: OIES, based on NEA data.

[16] '国家能源局综合司关于公布整县（市、区）屋顶分布式光伏开发试点名单的通知 [NEA Comprehensive Department Issues Whole County/City/District Rooftop Distributed PV Pilot List],' National Energy Administration, 8 September 2021, at http://www.gov.cn/zhengce/zhengceku/2021-09/15/content_5637323.htm.

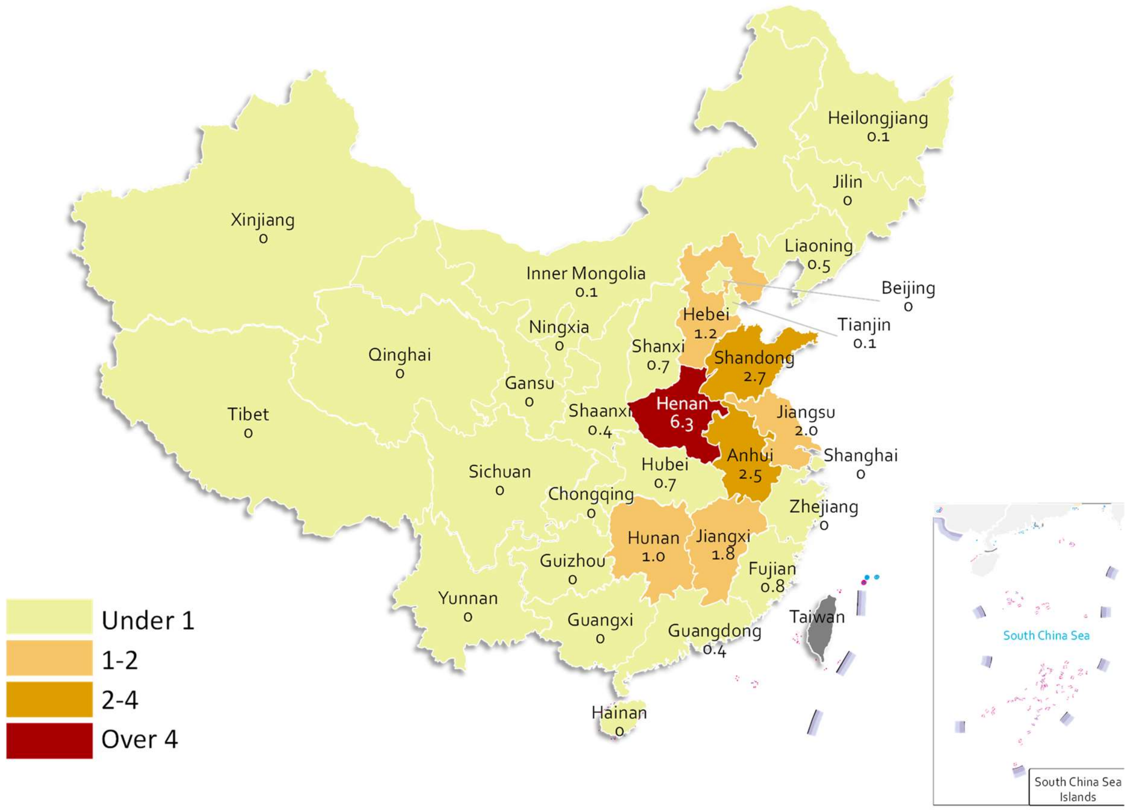
[17] '2022年光伏发电建设运行情况 [2022 PV electricity additions situation],' National Energy Administration, 17 February 2023, at http://www.nea.gov.cn/2023-02/17/c_1310698128.htm.

Figure 2: Household PV additions by province, 2022, in GW



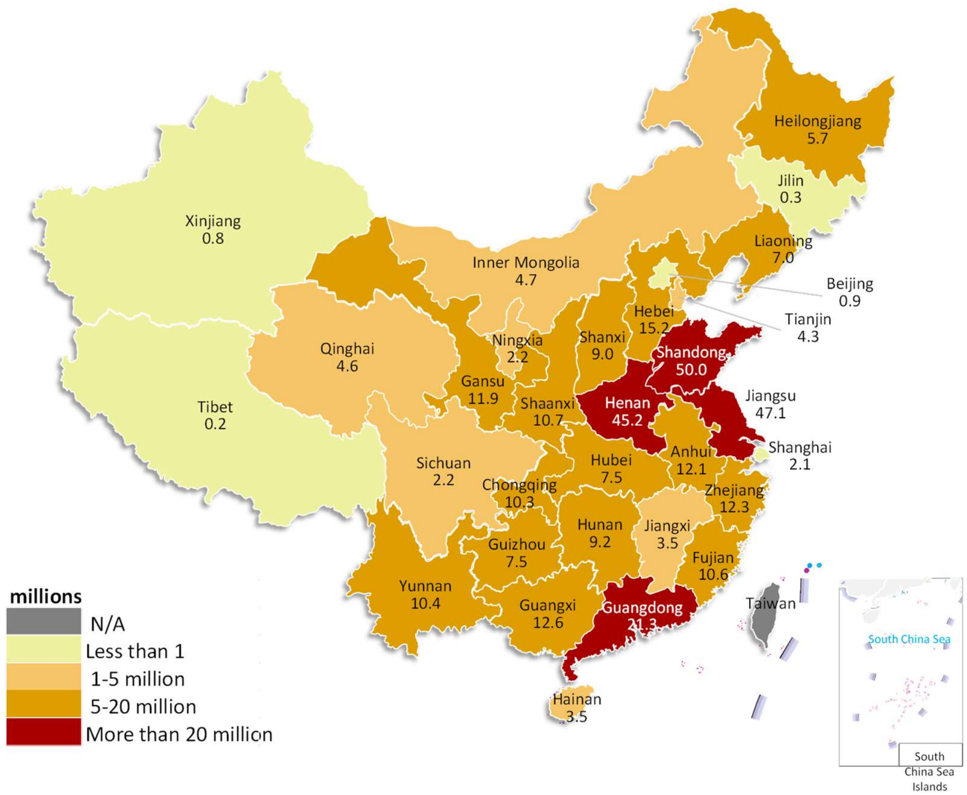
Source: NEA, 2023.

Figure 3: Household PV additions by province, 1H 2023, in GW



Source: NEA, 2023.

Figure 4: China’s Whole County PV programme by total county population covered, in millions



Source: Anders Hove, OIES, 2023.

Although the Whole County PV programme has resulted in a substantial burst of distributed PV installations in eastern China, problems have been reported from an early stage.[18] Smaller, private solar installers have complained that large energy companies or locally-connected state-owned enterprises (SOEs) have won tenders despite lacking experience or the ability to follow through. Most of the counties have adopted the ‘one enterprise one county model,’ and most of these have been won by the Big Five electricity SOEs or by local SOEs. This has sparked criticism that the terms offered to residents and businesses are less attractive than in counties with more open competition.[19] China’s national Big Five were aggressive in pursuing projects under the Whole County PV programme. Within four days of the programme’s launch, SPIC developed a plan for capturing as many counties ‘as soon as possible’, targeting 100 counties, of which it has developed at least 87. China Datang Corporation has won at least 51 counties. China Energy has tendered in 37 counties. China Resources, China National Nuclear Corporation, China Energy

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18 ‘分布式光伏，山东为何'整县推‘不’进'? [Why can’t distributed PV get into Shandong’s Whole County PV program?],’ Huaxia Energy Net, 10 March 2022, at https://m.jiemian.com/article/7191779.html; ‘光伏'整县推进'为何陷入'四方尴尬'? [PV Counties facing embarrassing ‘Why can’t we get in’ questions],’ WeChat Energy Net, 12 April 2022, at https://mp.weixin.qq.com/s/5aeB7XsRgLEMYJpSCPeJlQ.

19 ‘一项676个县参与的浩大工程：整县光伏 [A huge project involving 676 counties: Whole County Photovoltaic,’ Capital Research Association, 10 July 2023, at https://mp.weixin.qq.com/s/dTf-wtoIhyvz0eE9m7fA2A.

Conservation, and China Guangdong Nuclear Power are also active, as are local SOEs promoted by local governments. System integrators and construction majors are also heavily involved, including state-owned construction giant CHINT and Chinese PV manufacturing major Trina Solar.

Aside from the topic of which companies win projects, the Whole County PV programme has been the target of other criticism. Counties have reportedly been blocking any new solar installations other than via their preferred entities. The NEA has tried to prevent counties from shutting down new projects arbitrarily, but counties continue to resist efforts to open up the programme to competition. In addition, local governments have sought to claim ownership of rooftops to capture the financial benefits of programme, despite NEA instructions that building owners and residents should benefit and retain rights.[20] One expert likened the local implementation of the NEA's Whole County policy to a 'monk with a twisted lip reading the wrong sutra.'[21]

As a result of these and other difficulties, participating counties have achieved wildly different levels of progress in implementing the targets of the Whole County PV programme. Some provinces, like Shaanxi, have achieved very little, with some counties in the province adding just a few hundred kW of PV.[22] However, the provinces with the most population-weighted participating counties have shown strong installations, led by Henan in 2023, with 7.4 GW of distributed PV added in 2023, of which 6.3 GW was household PV, followed by Shandong, with 2.7 GW of household PV, Anhui with 2.4 GW, and Jiangsu with 2 GW. Notably, whereas household PV additions dominated in Henan and Shandong, commercial and industrial installations dominated in Jiangsu and Zhejiang.[23]

Though the programme is on track to deliver a major increase in rural solar PV capacity, aside from policy barriers the inadequate distribution grids in many rural areas pose a challenge to further scaling up the programme. The NEA, in its policy document noting examples of local governments blocking new PV installations, stated that 'in the process of promoting distributed photovoltaics in the whole county, some areas have experienced the phenomenon that the distributed power generation connected to the grid exceeds the carrying capacity of the grid in a short period of time, and the application for filing and grid connection of distributed photovoltaics has been postponed.'[24] In other words, the rapid build-out of rooftop

[20] Dai Tengteng, '分布式光伏整县推进两周年：备案暂停、'一刀切'仍屡禁不止 [On distributed solar Whole County PV's two-year anniversary, policy faces interruptions of work, government repeatedly bans one-size-fits-all approaches],' PV People, 7 June 2023, at https://mp.weixin.qq.com/s/FJX6BUV0fCJBq5k0DAyI5w.

[21] '光伏'整县推进'扭曲变形，大量民营企业主被逼到死亡边缘 [Whole County PV policy distortions are driving many private companies to the edge of death],' Huaxia Energy News, 15 August 2022, at https://mp.weixin.qq.com/s/eKxd1zIZ1BV-eHmQBETrzA.

[22] '难点何在？整县光伏并网率仅6% [Where's the problem? Whole County PV connections only 6%], PV Net News, 25 April 2023, at https://mp.weixin.qq.com/s/nO6wSQv2TDtp078fZxESGQ.

[23] '国家能源局公布2023年各省装机明细数据 [National Energy Administration publishes 1H 2023 provincial solar installation statistics],' WeChat Energy Net, 27 July 2023, at https://mp.weixin.qq.com/s/I2ZDrRbV3-5CNJir2lEMgw.

[24] '国家能源局：不得以任何方式增加新能源不合理投资成本！ [National Energy Administration: Do not increase the unreasonable investment cost of new energy in any way],' China Power Net, 19 April 2023, at http://mm.chinapower.com.cn/tynfd/zcdt/20230426/198097.html.

PV has resulted in local officials blocking new additions due to insufficient grid capacity.

Even more advanced eastern provinces, with strong PV installations, have experienced problems with local grids. Many areas have periods of local oversupply, especially in 'hollow villages' – smaller, more remote villages where most of the working-age population has migrated to cities, leaving mainly older or younger residents. As a result, the NEA has stated that 'due to the insufficient carrying capacity of the distribution network, the contradiction of distributed photovoltaic participation in the electricity market has been put on the agenda.'[25] The government clearly recognises the need to bolster rural grids and develop other solutions to alleviate local grid bottlenecks. Bidirectional charging could form part of the answer.

Electricity pricing is one area where policy makers have sought to make adjustments that might help with the absorption of distributed solar. In the 2010s, China already had widespread time-of-use pricing available at the retail level. Peak rates have trended higher and valley rates lower, with peak rates currently around 70% above shoulder rates, valley rates 58% below shoulder rates, and in some provinces a super-peak rate in the early evening, and sometimes mid-morning, 20% above the peak rate.[26] Most recently, in the NDRC/NEA power pricing work plan for 2023, the central government urges provinces, localities, and grid companies to increase the granularity of retail time-of-use electricity prices from three to five daily price segments to more than five, and to adapt them to reflect both peak demand and wind and solar output conditions.[27] Provinces across China have begun to offer time-of-use prices that include low midday power prices, whereas previously low prices were mainly offered at night. As of mid-2023, at least ten provinces had low midday retail pricing to encourage shifting of loads to periods when surplus solar is available.[28]

Time-of-use pricing has the potential to incentivise self-consumption of midday solar and, potentially, installation of energy storage, but it has significant limitations. First, time-of-use rates are typically set far in advance, as much as a year ahead or more. Variable renewable energy can see dramatic changes in output on a daily or even sub-hourly basis. Some days may have a surplus of midday solar output, while other days have a shortage of electricity supply over the same period. This lack of flexibility could worsen, rather than help resolve, the problem of insufficient distribution grid capacity.

Further, building out local grids is likely necessary in any case, given rising incomes, adoption of new appliances and electrification of heating and transport. Some

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[25] '分布式狂飙 [The distributed energy craze],' Southern Energy Observer, 31 July 2023, at https://mp.weixin.qq.com/s/NEwtighOiUeHL4YQmnnCEg.

[26] '全国23个省市完善分时电价机制政策汇总 [Comprehensive summary of 23 provincial policies to improve time-of-use pricing mechanisms],' In-en.com, 9 December 2021, at https://m.in-en.com/article/html/energy-2310448.shtml.

[27] '发改委、能源局发布关于做好2023年电力中长期合同签订履约工作的通知 [NDRC, NEA publish 2023 mid-to-long-term contract coverage work notice],' National Development and Reform Commission, 2 December 2022, at https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=19042.

[28] '10省中午执行谷段电价！[10 provinces have instituted midday trough power prices],' WeEnergy Net, 1 August 2023, at https://mp.weixin.qq.com/s/S0M8tB6jd9vao8skngWvMg.

villages have used microgrids to boost local consumption of midday solar electricity.[29] Studies have shown that when it comes to bolstering rural grids, the main challenge is coordinating the involvement of various interested parties, not just the cost of building out the grid.[30]

To some extent, electrification of heating and transport could result in greater demand for building out local grids, but could also substantially increase self-consumption of PV. Depending on the specific situation, increased self-consumption could alleviate the need for additional grid investment while delivering cheaper heating and transportation services. As noted above, previous research has shown that heat pumps paired with storage could increase self-consumption of locally-produced PV in most regions of China. Although China's winter PV output as a share of summer PV output is relatively strong compared to other world regions, heat pumps on a stand-alone basis can only result in self-consumption of 20% to 30% of PV output in the top provinces participating in the Whole County PV programme. Adding two hours of energy storage can boost this self-consumption rate to 40% or as high as 60% in these provinces, but storage capital costs involve a substantially longer payback period versus adoption of heat pumps paired with PV.[31]

1.3. China's EV market

China is the world's leading manufacturer of EVs and the largest market for EVs. In China, the term New Energy Vehicle (NEV) includes pure battery-electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs). The bulk of NEVs are either BEVs or PHEVs. Although China's NEV market share stands above 30%, it has seen a dramatic increase in the past three years, rising from around 1 million NEV sales annually in 2020 to 5.8 million in 2022. In September 2023, the Ministry of Industry and Information Technology set a target or forecast for NEV sales of 9 million for the full year, which would represent annual growth of around 50%.[32] In 2023, China surpassed its 20% NEV share target for 2025 three years ahead of time. (The target was set in 2019 and has not been adjusted since then.)

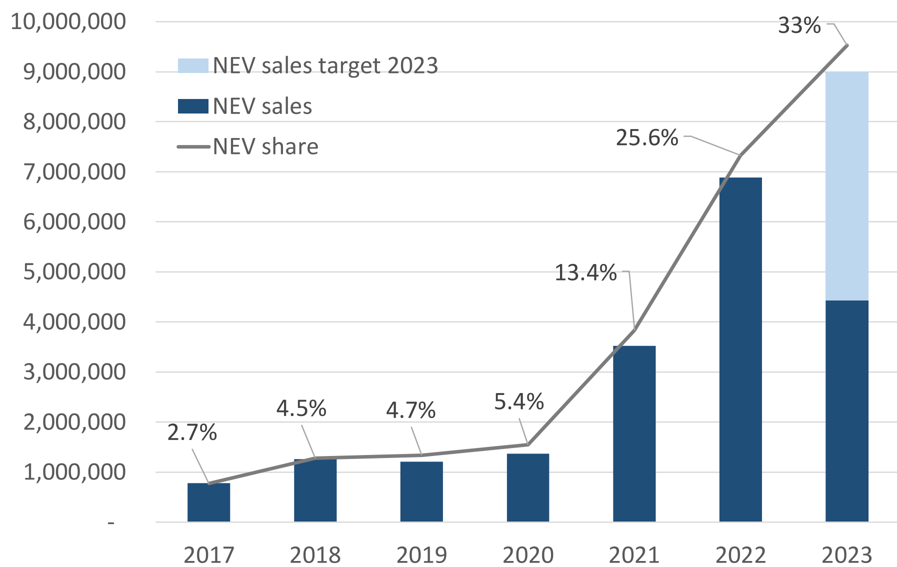
[29] Lixin Zhu and Ruisheng Sui, 'Villagers Embrace Solar Energy Project in Shanxi,' China Daily, 13 September 2021, https://www.chinadaily.com.cn/a/202109/13/WS613ea40ea310efa1bd66ef09.html.

[30] Yang Xiaoran, '农村电网巩固升级再提速 [Village electricity grid resilience improvement accelerates],' China Energy Reports, 30 July 2023, at https://mp.weixin.qq.com/s/yjy8QVk2sMsx_LsWO-VxDg.

[31] Anders Hove, 'Synergies between China's Whole County PV program and rural heating electrification,' Oxford Institute for Energy Studies, May 2023, at https://www.oxfordenergy.org/publications/synergies-between-chinas-whole-county-pv-program-and-rural-heating-electrification/.

[32] '工业和信息化部等七部门关于印发汽车行业稳增长工作方案 [MIIT and seven ministries issue auto sector stable growth plan],' Ministry of Industry and Information Technology, 1 September 2023, at https://mp.weixin.qq.com/s/p52GfxG7ajFVW-qWCluvvQ.

Figure 5: China sales of New Energy Vehicles, as share of passenger vehicle market, 2017-23



Source: China Association of Automobile Manufacturers (CAAM), 2023; MIIT September 2023 target.

The early EV market in China was characterised by the 'barbell pattern' of very high-end vehicles in major cities for the luxury market and low-cost, short-range city cars at the low end plus two- and three-wheeled vehicles. In 1H 2023, total domestic EV passenger car sales were 2.9 million, an increase of 40% versus the same period the previous year. Market share remained above 30% for most months, and topped 33% in June. The smallest passenger car size, A00, saw sales drop 42%, while A0 compact cars saw rising sales, while sales of larger B-class sedans as well as SUVs and MPVs surged. Analysts attributed the shift to market saturation by the smallest, cheapest models and increasing uptake of longer-range, larger hybrids outside major cities.[33]

Most rural customers are sensitive to the vehicle purchase price. The majority of NEVs selected for promotion in the rural market are sold at a price of less than CNY 150 000 (EUR 20 000). Demand from rural areas partly explains the popularity of the small Hongguang Mini EV, until recently China's top-selling EV, priced between CNY 30 000 and CNY 50 000 (EUR 4 000- 6 000).[34]

In part due to their relatively low cost, two- and three-wheeled EVs are common in rural areas. In a 2022 survey of a rural agricultural village (population 1 140) in Shandong province, researchers found 560 two-wheeled electric vehicles, 400 three-wheeled electric vehicles, and 50 four-wheeled electric vehicles, plus 170 four-

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[33] Shu Chang, '2023年上半年新能源&纯电乘用车市场总结,' EV Observer, 27 July 2023, at https://mp.weixin.qq.com/s/_XZUDn6TQwY6gT_mPRebHg.

[34] Du Junzhi, 'How new energy vehicles find their market in rural China,' CGTN, 30 April 2022, at https://news.cgtn.com/news/2022-04-30/How-new-energy-vehicles-find-their-market-in-rural-China-19E67ADnaww/index.html.

wheeled internal combustion vehicles.[35] Hence, rural areas are not necessarily lagging in EV adoption, when considering smaller vehicles. Furthermore, while car ownership in China's rural areas is low compared to urban areas, it is rising rapidly, from fewer than two per 100 households in 2007 to over 25 per 100 households in 2020.[36]

Typical three-wheeled vehicles range from passenger tricycles to small cargo vehicles, and are gradually being overtaken by small four-wheeled cargo vehicles with similar size and battery capacity. The smallest personal tricycles range from CNY 2 500-6 000, and the mid-range three-wheeled cargo vehicles range from CNY 10 000-15 000. Battery sizes marketed for these vehicles range from as little as 1.5kWh to 15kWh.[37]

In 2023, China's central government has taken steps to encourage greater uptake of EVs in rural areas. On 15 June 2023, the Ministry of Industry and Information Technology (MIIT) together with NEA, NDRC, and the Ministry of Commerce announced a series of 2023 New Energy Vehicles (NEV) for Countryside Activities. The series of activities, to be coordinated by the China Association of Auto Manufacturers (CAAM), includes having EV makers recommend EV models suitable for the rural market, formulating promotional policies, improving after-sales services in rural areas; coordinating charging providers to improve rural charging facilities and launch charging preferential policies; and organising live car sales or virtual exhibitions.[38]

1.4. EV charging

As the world's largest market for EVs, China is naturally also a leader in charging infrastructure. According to mid-year figures from the EV Charging Infrastructure Promotion Alliance (EVCIPA), as of July 2023 China has 6.9 million charging points, an increase of 74% from the same month the previous year. Of these, 2.2 million are public charging points, split between 900 000 DC chargers and 1.3 million AC chargers.[39] The more developed coastal provinces were responsible for the bulk of EV charging electricity consumption, led by Guangdong, Zhejiang, Jiangsu, Shanghai, Hubei, Beijing, Shandong, Anhui, Henan, and Fujian. In July, EV charging

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[35] Bing Xue et al., 'Pursuing a low-carbon rural energy transition in China and Germany,' Deutsche Gesellschaft für Internationale Zusammenarbeit, May 2022, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/GIZ_Rural_energy_transition_report_EN.pdf.

[36] Yan Wang et al., 'Impact of the Built Environment and Bicycling Psychological Factors on the Acceptable Bicycling Distance of Rural Residents,' Sustainability, 11, 2019, at https://doi.org/10.3390/su11164404; Yan Li, 'Vehicle ownership, sustainable mobility and well-being in rural China,' Environment, Development and Sustainability, 22 September 2023, at https://doi.org/10.1007/s10668-023-03890-x; 'Number of cars per 100 households in urban and rural China between 2019 and 2020,' Statista, 23 March 2023, at https://www.statista.com/statistics/233678/number-of-cars-per-100-households-in-china-by-income/.

[37] Author analysis, based on Taobao prices as of August 2023.

[38] '关于开展2023年新能源汽车下乡活动的通知 [Developing the 2023 New Energy Vehicles for the Countryside Activities,' Ministry of Industry and Information Technology, 23 June 2023, at https://www.gov.cn/zhengce/zhengceku/202306/content_6886788.htm.

[39] '2023年7月全国电动汽车充换电基础设施运行情况,' EV Charging Infrastructure Promotion Alliance (EVCIPA), 10 August 2023, at https://mp.weixin.qq.com/s/xBhOVSgQv8-KHCn_e09-lg.

was estimated to have consumed 3.25 TWh.[40] (Annualised, this would represent roughly 0.5% of national electricity consumption.)

In the past several years, as EV adoption has surged in China, prices for charging have undergone significant changes. Early on, China adopted time-of-use pricing for charging, particularly public charging, and recently peak prices have risen. Charging prices are reportedly up by as much as 80% in some cities versus just a few years earlier. Many drivers are choosing to charge at night to avoid high costs.[41] In addition, during power shortages, such as in Sichuan in mid-2022, local officials and grid companies shut down chargers entirely at midday, or even for several days, stranding drivers and encouraging some to switch back to driving internal combustion vehicles.[42] Effectively, failing to prioritise EV chargers during outages or throttling charging speeds constitute a form of uncompensated and involuntary demand response, while also sending a powerful signal to consumers about the potential unreliability of EV chargers during emergencies or power shortages.

1.5. Smart charging in China and abroad

Smart charging has long been recognised for its potential to improve integration of renewables worldwide. In a 2019 report on China's power system, the International Energy Agency wrote, 'Utilising advanced flexibility measures such as smart EV charging, demand-side response, and electricity storage can support the reliable integration of extremely high shares of variable generation … while simultaneously reducing power system operational costs between 2%-11% and reducing the need for fossil generation capacity by up to 30%.' Similarly, a May 2023 IEA study of India found smart charging to be particularly helpful at reducing costs at the distribution system level in rural areas with high amounts of rooftop solar.[43]

However, the IEA has also noted major barriers to adoption of smart charging. In an August 2023 study, the IEA observed that regulatory and market design in developing countries presents an obstacle to using EVs to improve distribution grid flexibility. In particular, the lack of spot markets and ancillary services markets, inadequate incentives for grid companies to encourage smart charging, and inconsistent standards for charging infrastructure and related communications protocols could hinder smart charging.[44]

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[40] '2023年7月全国电动汽车充换电基础设施运行情况,' EV Charging Infrastructure Promotion Alliance (EVCIPA), 10 August 2023, at https://mp.weixin.qq.com/s/xBhOVSgQv8-KHCn_e09-lg.

[41] Cao Tingting, '开电车，不省钱了吗？ [Does driving an EV no longer save money?]' Super Electric Lab, 11 August 2023, at https://mp.weixin.qq.com/s/Se4He80B4kcZ_m7qgQNCsA.

[42] Zeyi Yang, 'China's heat wave is causing havoc for electric vehicle drivers,' MIT Technology Review, 26 August 2022, at https://www.technologyreview.com/2022/08/26/1058727/chinas-heat-wave-electric-vehicle/.

[43] Zoe Hungerford, 'How can smart charging steer electric vehicle uptake in India?,' International Energy Agency, May 2023, at https://www.iea.org/commentaries/how-can-smart-charging-steer-electric-vehicle-uptake-in-india.

[44] 'Facilitating Decarbonisation in Emerging Economies Through Smart Charging,' International Energy Agency, August 2023, at https://iea.blob.core.windows.net/assets/5a566669-2883-4d8d-9c2f-61dbd92a6a6f/Decarbonisationthroughsmartcharging_.pdf.

While the EV industry and charging providers have offered various smart charging technology solutions, it is widely understood that policy is essential for encouraging smart charging. The development of widely-accepted standards is one area where policies have lagged worldwide. The IEA notes that policy makers can take the lead by offering subsidies for installation of smart charging-capable infrastructure, or by mandating such infrastructure, as has been done in the UK, which judged that private players would be unlikely to agree on a standard or voluntarily install smart chargers based on incentives alone.[45] In 2023, the Regulatory Assistance Project (RAP) reviewed the status of smart charging in Europe, finding that most of Europe either does not have smart charging or only has time-of-use tariffs. However, as in China, time-of-use rates have become more fine-grained and offered higher incentives to shift consumption patterns. The small number of countries that do offer smart charging based on dynamic tariffs (in other words, tariffs that change on a daily or hourly basis, as opposed to static time-of-use rates and intervals) offer a variety of different pricing schemes. Charging tariffs in some cases are based on price alone, or on a combination of factors such as renewable availability or the carbon emissions of the current grid electricity mix.[46] In Denmark, public charging stations are available with dynamic pricing related to renewable energy availability, and charger screens also display real-time information on renewable output and grid carbon emissions.[47] Such dynamic tariffs have greater potential than time-of-use prices to help integrate renewable energy. A recent review of smart charging in California estimated that grid savings would be more substantial using smart charging as opposed to time-of-use prices, which have the potential to worsen renewable curtailment by promoting off-peak charging.[48]

As to which types of customers would participate in smart charging or bidirectional charging, it seems evident that users who are focused on total cost of ownership, such as fleet owners, and private consumers with dedicated parking and private charging such as single-family homeowners, might be most likely to take advantage of smart charging or bidirectional charging—though RAP notes that it is important not to exclude those who lack home charging from such benefits.[49]

In China there have been several studies of the impact of smart charging on integration of renewable energy. One early study in *Nature Energy* found that smart charging had little impact on reducing renewable curtailment in the Jing-Jin-Ji region, and EV charging had the potential to increase emissions of air pollutants due to corresponding increased output from thermal plants. However, the analysis

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[45] 'Grid Integration of Electric Vehicles: A manual for policy makers,' International Energy Agency, December 2022, at https://www.iea.org/reports/grid-integration-of-electric-vehicles.

[46] Julia Hildermeier et al., 'A Review of Tariffs and Services for Smart Charging of Electric Vehicles in Europe,' Energies 16:1, 2023, at https://www.mdpi.com/1996-1073/16/1/88.

[47] Michelle Lewis, 'This EV fast charging station tells you when its power is at its cheapest and greenest,' Electrek, 22 September 2023, at https://electrek.co/2023/09/22/ev-fast-charging-station-better-energy/.

[48] Julia K. Szinai et al., 'Reduced grid operating costs and renewable energy curtailment with electric vehicle charge management,' Energy Policy 136, January 2020, at https://doi.org/10.1016/j.enpol.2019.111051.

[49] Julia Hildermeier et al., 'A Review of Tariffs and Services for Smart Charging of Electric Vehicles in Europe,' Energies 16:1, 2023, at https://www.mdpi.com/1996-1073/16/1/88.

assumed that EV charging was spiky and not controlled to prevent spikes and to closely match renewable electricity output.[50]

A subsequent Tsinghua School of Environment study of coordinated charging from renewables showed only minor environmental benefits in terms of air quality improvement, but unlike the *Nature Energy* study, the Tsinghua analysis demonstrated no adverse impact of EVs either on carbon or other emissions.[51] A related evaluation of different charging scenarios based on various power generation profiles and driving patterns showed similarities between charging scenarios based on low power price, peak-shaving-valley-filling (net load) optimisation, and renewable availability.[52] The similarities between these patterns across scenarios suggests that a single set of incentives, such as pricing based on the net load for a given day, would be sufficient to accomplish several objectives—provided drivers responded.

In terms of charging behaviour, as in most countries Chinese EV drivers rarely use a large proportion of battery capacity in their daily routines. A second study looked at driving and charging patterns in Beijing and found that EV owners typically discharge only around 13% of battery capacity daily, though there is substantial seasonal variation of up to 20%.[53] Regarding driving patterns, parking, and charging in Beijing, most drivers seek to charge almost to full charge, but rarely connect to chargers when they are at a low state of charge (SOC). Most charging events appear to be opportunistic, based on timing and convenience, as opposed to necessity. The authors of the study also considered Beijing time-of-use tariffs and locations where smart charging would be attractive given trip patterns, SOC, and parking durations.[54] Other studies have found that urban and rural passenger EV users are broadly similar in terms of parking time, charging times, and driving times. Rural EV users had substantially greater average travel distance but a similar number of trips, traveling from 26% to 42% more per day depending on age group and weekday versus weekend usage.[55]

As EV adoption gathers pace, it is likely that introduction of various forms of smart charging will yield benefits. Looking at EV charging demand out to 2050 in China based on driving and charging patterns, analysts have estimated that peak loads could increase by 8% with unconstrained charging, but only 2.6% with what the

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[50] Xinyu Chen et al., 'Impacts of fleet types and charging modes for electric vehicles on emissions under different penetrations of wind power,' Nature Energy 3, 30 April 2018, at https://doi.org/10.1038/s41560-018-0133-0.

[51] Yiliang Jiang et al., 'The future air quality impact of electric vehicle promotion and coordinated

charging in the Beijing-Tianjin-Hebei region,' Environmental Pollution 332, 2 June 2023, at https://doi.org/10.1016/j.envpol.2023.121928.

[52] Jiahui Chen et al., 'Emission mitigation potential from coordinated charging schemes for future private electric vehicles,' Applied Energy 308, 15 February 2022, at https://doi.org/10.1016/j.apenergy.2021.118385.

[53] Yang Zhao et al., 'Assessment of battery utilization and energy consumption in the large-scale development of urban electric vehicles,' Proceedings of the National Academy of Sciences (PNAS) 118, 19 April 2021, at https://doi.org/10.1073/pnas.2017318118

[54] Mingdong Sun et al., 'Uncovering travel and charging patterns of private electric vehicles with trajectory data: evidence and policy implications,' Transportation 49, 2022, at https://doi.org/10.1007/s11116-021-10216-1.

[55] Bo Li et al., 'Electric vehicle's impacts on China's electricity load profiles based on driving patterns and demographics,' Energy Reports 8, April 2021, at https://doi.org/10.1016/j.egyr.2021.11.003.

authors call 'last-minute charging' protocols.[56] Combining smart charging with PV specifically also has potential in China. A study of combining EV smart charging and PV in Shenzhen showed substantial economic benefits, although only in later years after PV penetration rises significantly.[57]

1.6. V2G policy in China

Vehicle-to-grid technology has received significant attention in China. A study of V2G in Shanghai, where several smart charging pilots have taken place, identified substantial economic benefits from using V2G to capture low-priced electricity, but far greater benefits associated with pairing V2G with solar PV as opposed to only time-of-use. [58] A separate study of smart charging and V2G shows that they have substantial potential to reduce carbon emissions in rural Ruicheng county in Shanxi province, a location noted for its early adoption of renewable energy and efforts to deploy renewable energy in rural areas as a poverty alleviation strategy.[59]

Modelling studies have also identified substantial benefits associated with V2G. Research has included developing planning models to optimise deployment of V2G given constraints in the distribution grid as well as the current and future deployment of PV and EVs.[60] Studies on the overall impact of smart charging and V2G, given forecasts of RE penetration and carbon emissions from the power sector, have found that V2G offers benefits beyond those of smart charging: 'Although smart charging is a cost-efficient EV [demand response] coordination strategy in the short term, V2G could be more economically attractive in the long run', write the authors of a 2019 paper.[61]

In Chinese popular and social media, there exists a lively debate about the costs and benefits of V2G. Some major experts have touted the benefits of V2G for helping absorb intermittent renewables. Arguing in favour, Hang Hewu of the Innovation Center for Energy and Transportation (ICET) notes that by 2040 there could be 300 million EVs on the road in China with battery capacity of 20 billion kWh, sufficient to balance the daily renewable energy output at a national level provided V2G becomes

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[56] Bo Li et al., 'Electric vehicle's impacts on China's electricity load profiles based on driving patterns and demographics,' Energy Reports 8, April 2021, at https://doi.org/10.1016/j.egyr.2021.11.003.

[57] Takuro Kobashi et al., 'Techno-economic assessment of photovoltaics plus electric vehicles towards household-sector decarbonization in Kyoto and Shenzhen by the year 2030,' Journal of Cleaner Production 253, 20 April 2020, at https://doi.org/10.1016/j.jclepro.2019.119933.

[58] Jianhong Chen et al., 'Strategic integration of vehicle-to-home system with home distributed photovoltaic power generation in Shanghai,' Applied Energy, 263, 1 April 2020, at https://doi.org/10.1016/j.apenergy.2020.114603.

[59] Dexi Sun and Jianjun Xia, 'Research on road transport planning aiming at near zero carbon emissions: Taking Ruicheng County as an example,' Energy 263, 15 January 2023, at https://doi.org/10.1016/j.energy.2022.125834.

[60] Lizi Luo et al., 'Coordinated allocation of distributed generation resources and electric vehicle charging stations in distribution systems with vehicle-to-grid interaction,' Energy 192, 1 February 2020, at https://doi.org/10.1016/j.energy.2019.116631.

[61] Jian Liu and Caifu Zhong, 'An economic evaluation of the coordination between electric vehicle storage and distributed renewable energy,' Energy 186, November 2019, at https://doi.org/10.1016/j.energy.2019.07.151.

widespread.[62] Tsinghua University EV expert Ouyang Minggao has proposed a three-step process for adopting V2G, starting with establishing industry standards and safety measures and then beginning to upgrade charging infrastructure while adopting smart charging by 2030, then proceeding with V2G on major traffic corridors and charging stations by 2040.[63] Against V2G technology, some Chinese commenters have argued V2G economics will never pan out, either for home chargers or for commercial or grid players.[64] One reason cited is cost: converting a home charger to V2G carries an added cost of CNY 7 000,[65] and while private EVs are parked most of the time, given that most cars charge overnight there are relatively few hours in the year when peak-shaving needs overlap with parked cars that have available battery capacity for providing V2G.

Other commonly-cited major obstacles to V2G include the high cost of converting existing charging infrastructure, concerns about safety, lack of consumer interest, concern about battery degradation (whether or not such concerns are justified), lack of V2G at-home chargers and, for EVs that mainly slow-charge at home, lack of time for injecting power back to the grid. Aggregators can resolve some issues around coordination of market players,[66] but there is no near-term solution to some of the other obstacles. For example, regulations and pricing for V2G might require power market reforms and supporting policies from the central and local governments and grid companies. (See below for discussion of Chinese power market policies and EV charging.) Commentators on the practicalities of V2G have noted the cautionary experience of stationary energy storage in China, which has faced a patchwork of changing local regulations that are hindering development of a national policy.[67]

Meanwhile, major companies operating in China have promoted V2G in new car models. Nissan has long boasted the bidirectional charging capability of the Nissan Leaf, but only began selling a bidirectional home charger in 2022.[68] Renault, Ford and Volkswagen have all stated they are pursuing V2G, and Chinese domestic brands that have explored V2G or made V2G announcements include Great Wall Motors, BYD, Geely, FAW, Xiaopeng, NIO, and Seres Automobile.[69] V2G was also a major theme at the 2023 Shanghai auto show, including V2G technology showcased

[62] Hang Hewu, '道路交通碳排放或将在2025年前达峰 [Road transport emissions will peak in 2025],' China Clean Transportation Partnership, 9 August 2023, at https://mp.weixin.qq.com/s/v0h_dsYJ0H78ALmxgHnGUw.

[63] Zhang Yueyue and Wang Wei, '欧阳明高：从有序充电到消纳绿电，V2G技术应更有作为,' Energy Comments, 7 March 2022, at https://mp.weixin.qq.com/s/q9IEleDL5Dpn4w5FH7uJBw.

[64] 'V2G这门生意，可能真的不是想象中那样的美 [The V2G dream may not be as beautiful as people imagine],' Power Meow, 29 August 2022, at https://mp.weixin.qq.com/s/mwPFfzH0znG8VBTXL-LA7Q.

[65] Based on products available on Taobao in mid-2023 bidirectional home charger, such as the Star Charge 220 Volt, 6.6kW bidirectional DC charger, could cost up to RMB 20,000, lower but comparable to prices for similar equipment in Europe.

[66] 'V2G技术介绍系列 [V2G technology examples],' EV Charging Home, 15 March 2023, at https://mp.weixin.qq.com/s/N2Iavwd-fu63JVh6ZI9HQQ.

[67] Liu Guanwei, '为什么我看好电动汽车有序充电，不看好车电互联（V2G） [Why am I optimistic on orderly charging and not on V2G?],' Sohu, 2020, at https://www.sohu.com/a/395114261_100209427.

[68] Umar Shakir, 'The Nissan Leaf can now officially power buildings using bidirectional charging,' The Verge, 12 September 2022, at https://www.theverge.com/2022/9/12/23349971/nissan-leaf-bidirectional-charging-approved-v2h-v2g-fermata-energy.

[69] Zhang Changlong and Shi Xueqian, 'V2G：电动汽车的'能源V2X' [V2G: EV's energy V2X],' Severn Transport Net, 10 August 2023, at https://mp.weixin.qq.com/s/4pG-hqgZbbh0s21IyisShQ.

by both GAC Aon and Dongfeng Motors.[70] GAC Aon has also touted the potential benefits of V2G for individual vehicle owners. Most recently, in July 2023, battery-swap pioneer NIO completed its first 20 V2G charging points (at the Qilian National Park pilot, discussed in more detail below), launched a 20kW version of its V2G charger, and touted plans to operate as a virtual power plant.[71]

V2G remains at the early pilot stage in China. The country's largest V2G pilot got under way in 2022 in Qilian National Park, with a V2G-capable charging station co-located with a PV station.[72] Other V2G pilots have mainly been carried out by State Grid at its own facilities or in large industrial parks. As of April 2021, State Grid Electric Vehicle Service Company reported that it had completed 42 V2G pilot projects in 15 provinces and cities including Zhejiang, Shanghai, Jiangsu, and Hebei, with 612 V2G terminals deployed and involving almost 4 000 electric vehicles. The largest State Grid demonstration was at Baoding Great Wall Automobile Industrial Park where it installed 50 sets of 15kW DC V2G charging piles.[73]

At present, there are few local government initiatives related to V2G. The only one that has been announced is a policy from Guangdong, one of the leading provinces for EV adoption, which plans to encourage V2G for major EV fleet owners, such as logistics vehicles, while also encouraging integration of PV, storage, and charging.[74]

1.7. V2G outside China

Outside China the situation is similar, with V2G still at the pilot stage. As of August 2023, V2G Hub, a website that tracks V2G projects worldwide, had recorded 128 V2G projects involving 6 700 chargers in 27 countries. Many of the listed projects were completed pilots.[75] Although V2G is still in the pilot phase, demonstrations and experiments are growing larger and are more commercially-oriented. Initial V2G pilots were conducted with small, self-contained fleets at single charging facilities, while more recent pilots have included hundreds of privately-owned EVs using bidirectional home or office chargers, such as the OVO pilot in the UK.[76]

Case studies of V2G pilots have generally identified benefits, but have also raised multiple issues and concerns. A major study of V2G in Denmark looked at the results

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[70] '车企纷纷布局V2G，电动车车主躺赚时代到来？ [As more car companies adopt V2G, is the V2G era coming to EV owners?],' Global Zero Carbon Research Centre, 20 April 2023, at https://mp.weixin.qq.com/s/AN-bQTNcK5jp0afW0OM2sg.

[71] Yusuf Latief, 'Self-consumption V2G system launched for Chinese national park ,' Smart Energy International, 22 August 2023, at https://www.smart-energy.com/industry-sectors/electric-vehicles/self-consumption-v2g-system-launched-for-chinese-national-park/; 'NIO launches V2G charging pile, new pricing standard for battery swap service,' Gasgoo, 23 July 2023, at https://autonews.gasgoo.com/m/70024822.html.

[72] '光伏+新能源车新应用！蔚来全球首个V2G光伏自循环补能体系落成 [PV + EVs: NIO completed the world's first V2G PV system],' SolarZoom, 20 August 2023, at https://mp.weixin.qq.com/s/--Crr3fPlXKgnAogOlqAOA.

[73] 'V2G技术介绍系列 [V2G technology examples],' EV Charging Home, 15 March 2023, at https://mp.weixin.qq.com/s/N2Iavwd-fu63JVh6ZI9HQQ.

[74] '1000亿！最强省会储能目标 [100 GW! Strongest provincial storage plan],' We Energy Net, 16 August 2023, at https://mp.weixin.qq.com/s/1Kz00u5bcOYpDJk_czBqyQ.

[75] 'Insights: Map,' V2G Hub, accessed 23 August 2023, at https://www.v2g-hub.com/insights#graphs.

[76] Sabrina Weiss, 'The Future of EV Charging is Bidirectional, If You Can Afford It,' Wired UK, 22 April 2022, at https://www.wired.co.uk/article/the-future-of-electric-vehicle-charging-is-bidirectional-if-you-can-afford-it.

of using V2G for various grid services, with various vehicle types and classes. It found Denmark's distribution grid was adequate but expressed concern about grids elsewhere.[77]

Cost and availability are the two major concerns about V2G outside China. For vehicle-to-home bidirectional charging, Spanish company Wallbox's Quasar bidirectional vehicle-to-home charger costs GBP 6 000 in the UK,[78] though it was marketed at closer to USD 4 000 in Europe, according to InsideEVs. Wallbox initially only offered the CHAdeMO 7.4kW charging cable, which was only useful to Nissan Leaf owners, and was only available in Europe. A new Quasar 2 with CCS is expected to be priced similarly and will be offered in North America.[79] Other charger makers planning to offer bidirectional chargers include Rectifier Technologies, Delta and Nuuve Holding Corp. In the US, Ford is partnered with Sunrun to use a DC charger for the F-150 Lightning electric truck. VW plans to offer bidirectional charging on all its ID models.[80] The startup Emporia has stated it plans to offer a USD 1 500 bidirectional charger in 2023.

The actual cost of bidirectional charging equipment is only a part of the equation, however. Following the introduction of the Ford F-150 Lightning electric truck, which is advertised as offering vehicle-to-home capabilities, there have been multiple reports of homeowners needing over USD 15 000 in upgrades to allow Ford bidirectional charging, since most houses need higher amperage lines/electric box and cutoff switch. The charger alone costs nearly USD 10 000.[81] Some analysts believe if the cost of bidirectional charging falls below USD 5 000, it will become commercially viable,[82] but this is difficult to evaluate. In the case of the OVO Energy-Nissan trial, the V2G charger was GBP 3 700 (EUR 4 300) more expensive than a unidirectional smart charger that can automatically top up a car at the cheapest times and thus save money. Installation costs would have to drop to GBP 1 000 (EUR 1 150) to make the technology commercially viable, according to those involved in the project.[83]

Some pilot programs have directly subsidised installation of home bidirectional charging. California's Pacific Gas and Electric is running a trial that pays residential and commercial Ford Lightning owners to install bidirectional charging. The only EV

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[77] Peter Bach et al., 'The Parker Project Final Report,' Energy Technology

Development and Demonstration Program, 31 January 2019, at https://parker-project.com/wp-content/uploads/2019/03/Parker_Final-report_v1.1_2019.pdf.

[78] 'Quasar Wallbox 7.4kW The First Bidirectional Charger Of Its Kind,' Voltacon Solar, accessed 28 August 2023, at https://voltaconsolar.com/quasar-bidirectional-ev-charger.html.

[79] Tom Moloughney, 'Wallbox Reveals Quasar 2 Bidirectional CCS EV Charger At CES,' InsideEVs, 4 January 2022, at https://insideevs.com/news/558708/wallbox-quasar2-charger-introduced-ces/.

[80] Jim Motavalli, 'Are bidirectional EV chargers ready for the home market?,' Techcrunch, 28 April 2022, at https://techcrunch.com/2022/04/28/are-bidirectional-ev-chargers-ready-for-the-home-market/.

[81] Christian Seabaugh, 'For Us, It'll Cost $18K to Power a House With Our Ford F-150 Lightning,' Motor Trend, 27, January 2023, at https://www.motortrend.com/reviews/2022-ford-f-150-lightning-yearlong-review-update-1-sunrun-backup-power/.

[82] Daniel Bleakley, ''An immense amount of competition:' V2G charging station costs set to plummet,' The Driven, 29 March 2023, at https://thedriven.io/2023/03/29/an-immense-amount-of-competition-v2g-charging-station-costs-set-to-plummet/.

[83] Sabrina Weiss, 'The Future of EV Charging is Bidirectional, If You Can Afford It,' Wired UK, 22 April 2022, at https://www.wired.co.uk/article/the-future-of-electric-vehicle-charging-is-bidirectional-if-you-can-afford-it.

to qualify is the Ford F-150 Lightning, but Hyundai, Kia, VW, and Polestar vehicles are expected to join the program starting in late 2023 or early 2024.[84] The Inflation Reduction Act includes bidirectional charging equipment which means it qualifies for subsidies under the Alternative Fuel Refueling Infrastructure Credit.[85]

Barriers to V2G cited outside China include lack of consumer interest, concerns about battery degradation, regulatory and pricing barriers, and poor economics.

Regarding consumer interest, a 2021 study in the Netherlands found that many EV owners were interested in V2G and willing to adopt it with the right compensation, though many expressed worries about battery degradation.[86] Notably, the survey found that those interested in V2G did not necessarily require high levels of compensation, or evaluate the choice in terms of total cost of ownership; instead, respondents mentioned parking and charging discounts or compensation for battery degradation as sufficient incentives.

A drawback associated with many studies of consumer acceptance is their reliance on surveys or choice experiments among respondents with no prior experience with V2G, or even no practical experience of EV charging. A 2022 study limited to Dutch users with actual experience using V2G in daily driving—based on 17 drivers with Nissan Leafs and V2G at home or work—found substantial differences in consumer attitudes after a period of using V2G. While compensation for V2G remained a central concern, users shifted their motivation for compensation—no longer focusing on battery degradation, but instead expressing the need for compensation for any uncertainty on the state-of-charge when the vehicle was needed for the next trip.[87] The admittedly small survey also noted that many participants found the ability to contribute to balancing clean energy on the grid remained relevant and rewarding even after they had experienced V2G in practice.

Consumer acceptance is far from the only concern. Other studies have noted barriers related to energy pricing, especially for EV charging and rooftop PV, with complications for countries with special feed-in tariffs for distributed PV or net metering for PV-only systems.[88] In some regions, such as the Nordic countries, there are concerns that V2G may be unnecessary or uncompetitive with other forms of storage, or that its value could be superseded by other storage or flexible load technologies.[89] In the long run, there are concerns that if V2G becomes widely

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[84] Peter Johnson, 'New V2X program will study how bidirectional EV charging can lower utility costs,' Electrek, 6 December 2022, at https://electrek.co/2022/12/06/v2x-program-uses-bidirectional-ev-charging-to-lower-utility-costs/.

[85] David Cullen, 'Inflation Reduction Act Will Spark Greater, Faster Switch to Electric Trucks ,' Trucking Info, 14 October 2022, at https://www.truckinginfo.com/10183357/inflation-reduction-act-will-spark-greater-faster-switch-to-electric-trucks.

[86] Koen van Heuveln et al., 'Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands,' Travel Behaviour and Society, 24 Julyl 2021, at https://doi.org/10.1016/j.tbs.2020.12.008.

[87] Rishabh Ghotge et al., 'Use before You Choose: What Do EV Drivers Think about V2G after Experiencing It?,' Energies 15(13), 20 May 2022, at https://www.mdpi.com/1996-1073/15/13/4907.

[88] Johannes Kester et al., 'Promoting Vehicle to Grid (V2G) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion,' Energy Policy 116, 2018, at https://doi.org/10.1016/j.enpol.2018.02.024.

[89] Lance Noel et al., 'Navigating expert skepticism and consumer distrust: rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region,' Transport Policy, April 2019, at https://doi.org/10.1016/j.tranpol.2019.02.002.

available, the incentives to engage in V2G for price arbitrage or integration will disappear, or be too insignificant for the wider public to take interest.[90]

As regards this study, it is important to note the differences between rural EV adoption and potential for smart charging or V2G in rural areas in Europe and North America versus rural China. Two studies in the past several years have examined the pace of EV adoption across Europe and found that rural EV adoption is generally on a par with EV adoption generally, and within countries—with rural EV penetration roughly equivalent to urban EV penetration and only modestly below EV penetration in 'intermediate' or suburban regions.[91] Rural areas in Europe differed widely in terms of charging infrastructure, and unlike urban areas the presence or absence of public charging infrastructure appears less correlated to EV adoption, given the higher rates of single-family home ownership and availability of home charging. According to Eurostat data, in Europe, 28% of the population live in rural areas, of which over 80% live in houses, compared to suburban areas where two-thirds live in houses and urban areas where around 40% live in houses.[92] Rural residents in Europe are more likely to own a car than urban residents.[93] Incentives for EV adoption in rural areas also differ widely across countries, but given the prevalence of home charging, purchase incentives and subsidies for purchase of home chargers were more important. Notably, several European countries—notably Austria and the UK—have offered higher subsidies for purchase of smart chargers.[94]

1.8. China's policies on rural renewable integration, demand response, EV charging and V2G

In general, policies to promote integration of distributed solar, storage, local loads, and EV charging have only really accelerated in recent years, since China's market for these technologies has begun to achieve scale. However, policies on smart charging and V2G, whether for commercial or residential users, have a long pedigree and also relate to progress on China's ongoing electric power market reform. A full discussion of China's power market reform efforts is beyond the scope of this paper; a detailed recent overview of progress in this regard, 'Assessing China's power

[90] George Hilton, 'Vehicle-to-grid inches closer to reality, but barriers remain,' PV Magazine, 10 August 2021, at https://pv-magazine-usa.com/2021/08/10/vehicle-to-grid-inches-closer-to-reality-but-barriers-remain/.

[91] Kyle Morrison and Sandra Wappelhorst, 'Battery electric vehicle access in Europe: A comparison of rural, intermediate, and urban regions,' International Council on Clean Transport, June 2022, at https://theicct.org/wp-content/uploads/2022/06/bev-access-europe-jun22.pdf; Sandra Wappelhorst, 'Beyond major cities: Analysis of electric passenger car uptake in European rural regions,' March 2021 at https://theicct.org/wp-content/uploads/2021/06/Ev-europe-rural-mar2021.pdf.

[92] 'Statistics on rural areas in the EU,' European Commission, 2020, at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Statistics_on_rural_areas_in_the_EU&direction=next&oldid=501292.

[93] For example, rural car ownership per household in Finland is roughly 50% higher than urban populations but similar to suburban populations. Timo Liljamo et al., 'The Effects of Mobility as a Service and Autonomous Vehicles on People's Willingness to Own a Car in the Future,' Sustainability, 2021, at https://doi.org/10.3390/su13041962.

[94] Kyle Morrison and Sandra Wappelhorst, 'Battery electric vehicle access in Europe: A comparison of rural, intermediate, and urban regions,' International Council on Clean Transport, June 2022, at https://theicct.org/wp-content/uploads/2022/06/bev-access-europe-jun22.pdf.

sector low-carbon transition,' was published by OIES in February 2023.[95] Briefly, China's current power market reform efforts began in 2015 with the publication of Document #9 on Deepening Reform of the Electric Power Sector, a policy which called for market-oriented reforms including wholesale power trading, spot markets, new pricing for transmission and distribution (T&D) grids, and greater integration among provinces.

Power market reform policies: Since 2015 China has made significant progress with many elements that Document #9 declared a priority. Much of the power sector has transitioned from static, planned operating hours contracts towards bilaterally-negotiated mid-to-long-term (MLT) contracts that have durations of around one month or one year, though longer and shorter terms are available. Wholesale electricity prices have been partially liberalised, though within a narrow trading band capped at 20% above a fixed tariff set by government regulators based on coal prices. T&D prices have been reformed and grid revenues separated from electricity sales. Time-of-use prices have been expanded. Spot markets have been introduced at the pilot level in many provinces, and some provinces have established capacity payment mechanisms.

While these developments represent a significant change for the sector, in many respects the market remains much more tightly constrained than in other countries and regions that have undergone similar restructuring processes. In most respects, administrative planning remains much more important than market signals in determining investments or determining short-term dispatch. Spot markets, where they have been introduced, have operated with low volumes and the largest players, namely coal plants, sell most of their volumes via long-term contracts. Administrative policies, such as the provincial renewable obligation which is set by the central government on an annual basis, have tended to proliferate alongside market reforms.

In September 2023, the NEA finalised a national spot power market design that leaves most market design decisions in the hands of provincial governments,[96] which have tended to prioritise investment in new coal capacity to meet peak electricity demand, instead of pursuing demand response or inter-provincial trading.[97] China's new coal plants are typically described as meeting peak loads instead of acting as baseload assets, but many analysts have noted that simply adding more peak generation capacity is far more expensive than flexible spot trading over inter-provincial grids and giving a larger role to spot-market-driven demand-response.[98]

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[95] Anders Hove, 'Assessing China's power sector low-carbon transition: a framing paper,' Oxford Institute for Energy Studies, February 2023, at https://www.oxfordenergy.org/publications/assessing-chinas-power-sector-low-carbon-transition-a-framing-paper/.

[96] '电力现货市场基本规则（试行） [Spot power market basic principles (trial)],' National Development and Reform Commission, September 2023, at https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/202309/P020230915357678894853.pdf.

[97] Xiang Chenxi and Lin Jiang, 'Local protectionism is slowing China's energy transition,' China Dialogue, 25 August 2023, at https://chinadialogue.net/en/energy/local-protectionism-slowing-chinas-energy-transition/; Jiang Yifan, Gao Baiyu and Sam Geall, 'China's Five Year Plan for energy: One eye on security today, one on a low-carbon future,' China Dialogue, 23 June 2023, at https://chinadialogue.net/en/climate/chinas-five-year-plan-for-energy-one-eye-on-security-today-one-on-a-low-carbon-future/.

[98] Zhang Yongping, Zhou Feng, Peng Linan and Yu Yang, 'The current state of China's electricity market,' China Dialogue, 1 September 2023, at https://chinadialogue.net/en/energy/the-current-state-of-chinas-electricity-market/.

Despite time-of-use prices being incorporated into retail power prices and long-term contract terms, price caps and a reluctance to accept price volatility are limiting the ability to draw on market signals to incentivise flexible operation of power plants, investment in energy storage, or demand response. In many cases, spot markets have been suspended during power shortages or periods of high prices, when such investments would have had greatest value. China's spot market policy also specifies that officials can suspend power markets at any time in the case of price volatility, high prices, or simply 'other reasons.'

In sum, power market reforms are proceeding slowly and tend to favour stable prices and long-term power contracts from centralised generation, with most investment guided by administrative planning and provincial government project approvals rather than by market signals. This system, in which market signals mainly help around the edges, does notdoes not necessarily favour decentralised actors such as rooftop PV owners, EV owners, or private companies that could provide flexibility services related to aggregating such assets or integrating distributed energy assets with local demand response or storage. However, over the years Chinese policy makers have also clearly indicated support for distributed energy, demand response, and aggregation services. Not only is China the leading adopter of EVs and, more recently, rooftop PV—as described above—but power market policies have specifically mentioned the need for the demand side to play a larger role.

In mid-2012, the Ministry of Finance and NDRC launched demand-side management (DSM) city pilots, subsidised by funds from the central government.[99] Over the years, the size and scope of such pilots has steadily increased. In 2015, citing experiences gained from the Shanghai DSM pilot, the NDRC and NEA urged other city DSM pilots to encourage participation of third-party energy services companies in DSM activities and incentivise users to engage with online energy management platforms.[100] A 2017 NDRC policy on demand-side management called on provincial governments to set annual targets for DSM energy savings and monitor the realisation of these targets by provincial grid companies. While the policy mentioned interruptible load contracts, time-of-use pricing, and tiered electricity pricing, it omitted any mention of virtual power plants, EV charging, or distributed energy.[101]

Coordinating renewables, loads and storage policies: In the last five years, Chinese policy has put increased emphasis on coordinating generation with loads and storage. In 2019, NEA issued a draft policy on establishing a Clean Energy

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[99] '电力需求侧管理城市综合试点工作中央财政奖励资金管理暂行办法的通知 [Measures on Electricity Demand Response Management City Comprehensive Pilot and Central Government Financial Incentives],' Ministry of Finance and National Development and Reform Commission, 3 July 2012, at https://www.gov.cn/gongbao/content/2012/content_2256576.htm.

[100] '关于完善电力应急机制做好电力需求侧管理城市综合试点工作的通知 [Notice on Improving Electricity Emergency Mechanism and Implementing Electricity Demand-Side Management City Pilots],' National Development and Reform Commission and National Energy Administration, 10 April 2015, at http://www.nea.gov.cn/2015-04/10/c_134139728.htm.

[101] '关于深入推进供给侧结构性改革做好新形势下电力需求侧管理工作的通知 [Notice on deepening promotion of supply-side structural reform and completing new-type electricity demand-side management],' National Development and Reform Commission, 26 September 2017, at https://www.gov.cn/xinwen/2017-09/26/content_5227721.htm; '电力需求侧管理办法（修订版） [Electricity Demand-Side Management Measures (Revised)],' National Development and Reform Commission, 26 September 2017, at

Revised at ' https://yyglxxbs.ndrc.gov.cn/file-submission/20230519102727235060.pdf.

Consumption Mechanism, emphasising a variety of measures including integrated planning, timely grid connections, the renewable obligation policy, and accelerating spot markets and bilateral trading. The policy explicitly called for EV charging networks and virtual power plants to participate in the market.[102]

In 2021, after a lengthy consultation process, the NDRC published a notice on integrating generation, grids, loads, and storage, particularly emphasising the need to integrate wind and solar with storage and loads, especially at the local level.[103] The policy notes the need for better integrating generation, grids, loads, and storage services multiple goals, including system reliability, efficiency, reducing overall system costs, and offering ecological benefits by reducing emissions and improving renewable integration. While the policy places provincial governments in charge of implementing the policy, and encourages participation of 'social capital' (a category that can include private companies), it only briefly mentions distributed energy and EV charging, specifying that urban residential districts with PV and EVs should combine distributed solar with flexible charging. The policy also calls for 'virtual power plants to participate in market transactions such as the medium and long-term power market, ancillary services market and spot market.' The policy does not specifically refer to rural areas. Since the policy's issuance, many source-grid-load-storage projects are simply grid scale renewable projects paired with storage and industry, often in remote areas.[104]

A NDRC 2022 policy on energy storage allows third-party storage owners to act as independent entities for market trading purposes, including in projects where storage is paired with renewable energy. Previously, storage paired with generation might not be permitted to trade on its own behalf given the structure of feed-in tariffs and other contracts specific to renewable energy. The policy also mentions encouraging aggregation of EV charging.[105]

Related to the issue of demand response, storage, and renewable integration is the topic of opening up the wholesale power market to trading by owners of distributed energy itself, with or without storage, which has been mentioned in a range of policies but faces various barriers. Jiangsu province has piloted various forms of such trading, under two different models. In the first, consumers band together to sign a collective supply contract with grid companies, effectively sharing their loads and distributed energy outputs and only paying the grid company for their net load and network tariffs. In the second, the grid company acts as a coordinator for participating entities and markets their output in the wholesale market.[106]

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[102] '关于建立健全清洁能源消纳长效机制的指导意见（征求意见稿） [Establishing a Clean Energy Consumption Long-term Mechanism, Guiding Opinion, draft for comments],' National Energy Administration, 19 May 2019, at http://www.nea.gov.cn/2020-05/19/c_139069819.htm.

[103] '关于推进电力源网荷储一体化和多能互补发展的指导意见 [Guiding Opinions on Promoting Source-Grid-Load-Storage Integration and Multi-Energy Complementarity],' National Development and Reform Commission, 25 February 2021, at https://www.gov.cn/gongbao/content/2021/content_5602023.htm.

[104] 'China's Source Grid Load Storage Projects,' Global Energy Monitory, May 2023, at https://www.gem.wiki/China%27s_Source_Grid_Load_Storage_Projects.

[105] '关于进一步推动新型储能参与电力市场和调度运用的通知 [Notice on Further Promoting New Type Energy Storage Participation in Power Market and Dispatch],' National Development and Reform Commission, 24 May 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202206/t20220607_1326854.html.

[106] '试点区域实行什么样的分布式光伏市场交易模式? [What type of distributed PV trading models are pilot projects trying out?],' 21SPV.com, 10 August 2023, at http://www.21spv.com/news/show.php?itemid=195704; '深度解

Demand response policies: In 2022, the NDRC and NEA published an outline of plans to establish a unified national power market design by 2025. The document explicitly calls for development of a mechanism to recover costs for various types of capacity including storage and virtual power plants.[107] The 14th Five-Year Plan for a Modern Energy System also mentions the need to encourage storage and virtual power plants.[108] The NEA's work plan for 2023 mentions the need to promote rooftop solar, including in rural areas, to accelerate construction of smart distribution grids in order to improve flexibility and integrate renewable energy, and the need to promote a 'rural energy revolution'.[109]

Virtual power plants have been implemented as pilots at an early stage in Guangdong, Hebei, Shanghai and Jiangsu, and more recently in Beijing, Anhui and Zhejiang provinces.[110] However, despite progress implementing demand response pilots or developing virtual power plants (VPP), their impact remains limited, and Chinese commentators have noted that demand response, aggregation, and virtual power plants remain commercially uninviting in the absence of further developments in the spot power market, such as short-term price signals wide enough to incentivise consumers and businesses to participate.[111] Indeed, several Chinese power market experts quoted by *People's Daily* mention market design as the primary barrier to the commercial viability of coordinating or aggregating distributed energy with flexible loads such as heat pumps or EV charging.[112] If policy rhetoric in China on demand response and integration of distributed energy and EV charging remains unrealised in practice, it is worth reiterating that integration of PV, storage, demand response, and EV charging is at an early stage worldwide, with even the most liberalised wholesale and retail markets still only experimenting with different programmes and policies.

Smart charging and V2G policies: Given the limitations on rural distribution grids, and efforts in 2023 to encourage adoption of EVs in rural areas, more attention has recently been paid to the issue of integrating EVs via smart charging, demand response programmes, or V2G – with the latter confined to small pilots and studies. The 2020 New Energy Vehicle Development Plan (2021-35) called on local governments to launch demonstrations of V2G and to support 'other policies to

析分布式光伏市场化交易与光储一体化的未来机遇 [Understanding the market opportunity for distributed PV trading and integrated PV-storage projects], Kesolar, 2 June 2023, at https://www.kesolar.com/expo/230490.html.

[107] '关于加快建设全国统一电力市场体系的指导意见 [Guiding Opinions on Accelerating the Development of a Unified National Power Market System],' National Development and Reform Commission and National Energy Administration, 28 January 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202201/t20220128_1313653.html.

[108] '十四五'现代能源体系规划 [14th Five-Year Plan for a Modern Energy System],' National Development and Reform Commission and National Energy Administration, January 2022, at http://www.nea.gov.cn/1310524241_16479412513081n.pdf.

[109] '2023年能源工作指导意见 [Guiding Opinions on Energy Work in 2023],' National Energy Administration, 6 April 2023, at http://zfxxgk.nea.gov.cn/2023-04/06/c_1310710616.htm.

[110] Pu Junyi et al., '全国统一电力市场建设加速推进，虚拟电厂蓝海市场打开 [Unified National Power Market Work Accelerates, Virtual Power Plant Market Opens Wide],' Orient Securities, 6 December 2022, at https://pdf.dfcfw.com/pdf/H3_AP202212061580849596_1.pdf?1670322429000.pdf.

[111] '我国电力需求响应现状分析与发展建议 [China electricity demand response analysis and development suggestions],' China Power.com, 11 August 2020, at http://mm.chinapower.com.cn/zx/zxbg/20200811/27296.html.

[112] Yang Xiaoran, '需求侧响应将成新型电力系统特征,' People's Daily, 21 February 2022, at http://paper.people.com.cn/zgnyb/html/2022-02/21/content_25904398.htm.

achieve efficient interaction between new energy vehicles and grid energy, and reduce the electricity costs of new energy vehicles'. The Plan also called for EV charging to be coordinated with wind and solar output and advocated 'encouraging the construction of distributed PV-storage-charging-and-discharging multi-functional integrated stations'.[113]

In October 2020, the Society of Automobile Engineers presented a New Energy Vehicle Roadmap 2.0, commissioned by the Ministry of Industry and Information Technology (MIIT), which laid out various targets developed following an industry-wide expert consultation.[114] The Roadmap, which includes the present 20% NEV target for 2025, also mentions a timetable for smart charging and V2G, namely to achieve 'interactive commercialisation of V2G electric energy with regular charging facilities in residential areas and parking lots' by 2030 and reach 'basic dissemination of V2G electric energy interactive capability in parking facilities such as residential areas and the application of solar charging in industrial areas' by 2035. New vehicles and newly-added chargers would all have V2G capability by 2035.

Since 2022, the pace of policies mentioning EV smart charging and V2G has picked up. In early 2022, the NDRC and several other ministries issued a policy opinion on EV charging service quality.[115] The policy calls on the industry to 'promote pilot demonstrations [of smart charging], explore implementation paths for new energy vehicles to participate in the electricity spot market, and study and improve trading and dispatch of new energy vehicle consumption and green power storage'. The policy says companies and industry parks should pilot 'integrated PV-storage-charging-discharging',[116] which could refer to bidirectional charging and/or V2G. Zhejiang, Henan, and Sichuan have since instituted pilots under the 'integrated PV-storage-charging-discharging' heading that include V2G,[117] and Zhejiang, Hebei and

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[113] '新能源汽车产业发展规划（2021—2035年） [New Energy Vehicle Manufacturing Development Plan],' National Development and Reform Commission, November 2020, at https://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm.

[114] '节能与新能源汽车技术路线图2.0正式发布 [Energy-efficient and New Energy Vehicle Technology Roadmap 2.0 formally released],' China Society of Automotive Engineers, 27 October 2020, at https://www.sae-china.org/news/society/202010/3957.html; Li Jun, '节能与新能源汽车技术路线图2.0 [Energy-efficient and New Energy Vehicle Technology Roadmap 2.0],' PowerPoint Summary and Evaluation, Society of Automotive Engineers, 17 February 2022, at http://www.evinchina.com/uploadfile/file/20220217/2022021709402808334.pdf; China Energy-saving Vehicle & NEV Roadmap 2.0: Curbing Carbon Emissions for a Green Society,' Marklines, 23 April 2021, at https://www.marklines.com/en/report_all/rep2142_202104#report_area_6.

[115] '关于进一步提升电动汽车充电基础设施服务保障能力的实施意见 [Opinions on Further Raising EV Charging Infrastructure Service],' National Development and Reform Commission, 10 January 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/202201/t20220121_1312634.html.

[116] In Chinese: '光储充放一体化.'

[117] '浙江: 14个光储充一体化项目建成投产,2023年将重点推广 [Zhejing: 14 integrated PV-storage-charging projects built; will strongly promote in 2023],' Kesolar, 30 May 2023, at https://www.kesolar.com/headline/229970.html; '西南首个 '光储充放'一体化停车场在四川成都投运 [Southwest's first integrated PV-storage-charging-discharging parking lot starts operating in Chengdu, Sichuan],' Beijixing, 21 September 2023, at https://m.bjx.com.cn/mnews/20230921/1333416.shtml; '国家电投调研全国首个风光储充放一体化综合智慧零碳电厂 [CPIC researches nation's first wind-solar-storage-charging-discharging integrated smart grid low carbon power plant],' Beijixing, 10 August 2023, at https://m.bjx.com.cn/mnews/20230810/1324786.shtml.

Shandong have built the concept into their provincial NEV plans (rural charging infrastructure is included in Shandong's plans).[118]

A draft policy on demand response released in March 2023 encourages participation of EVs in demand response, encourages aggregation of EV loads, and encourages rural areas to participate in demand response.[119] A May 2023 policy issued by NDRC explicitly mentions V2G.[120] The policy states that China will promote rural EVs to include smart charging capability and encourage vehicles to come with smart home chargers as a default. The policy states that China will study 'two-way interaction between electric vehicles and the power grid (V2G), and coordinated control of PV, storage and charging; and explore the construction of charging infrastructure that provides integrated photovoltaic power generation, energy storage, and charging in rural areas where the utilisation rate of charging piles is low'. The policy also reiterates calls to implement time-of-use for EV charging, while calling for rural areas to develop models for sharing of residential parking spaces for charging to boost charger utilisation.

Charging infrastructure policies are increasingly referring to the need to integrate EV charging with renewables. A June 2023 charging infrastructure policy issued by the State Council noted the need to integrate charging with storage and PV, as well as including it in demand response.[121] The policy calls for officials to 'implement peak and valley time-of-use electricity price policy, and guide users to participate in intelligent and orderly charging and car-network interaction. Before 2030, demand (capacity) electricity charges will be exempted for centralised charging and swapping facilities that implement a two-part electricity price system.'

Policies that aim to bolster rural grids also discuss the need to increase flexible loads to absorb renewable energy. A June 2023 policy on improving rural grids emphasises the need to strengthen grids to handle increased distributed renewable capacity, while also improving the local consumption of renewable energy and the ability to use renewable energy in nearby areas. In other words, the policy calls for the grid to move beyond promoting self-consumption by individual households or businesses. The policy also encourages streamlining applications for distributed renewable energy by combining procedures 'as much as possible'. While the policy

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[118] '河北：支持开展光储充放充电站技术创新与试点应用 [Hebei: Support Development of PV-Storage-Charging-Discharging Station Technology and Pilots],' Beijixing, 17 August 2023, at https://m.bjx.com.cn/mnews/20230817/1326310.shtml; '省政府新闻办举行新闻发布会，解读山东省推动新能源汽车下乡三年行动计划（2023-2025）[Provincial government press conference on the Shandong Promotion of New Energy Vehicles in the Countryside Three-Year Plan],' Shandong Provincial Industry and Information Department, 4 September 2023, at http://gxt.shandong.gov.cn/art/2023/9/4/art_299272_10335468.html.

[119] '电力需求侧管理办法: 征求意见稿 [Electricity Demand-side Management Rules: Draft for Comment],' National Development and Reform Commission, 5 March 2023, at https://yyglxxbs.ndrc.gov.cn/file-submission/20230519102727235060.pdf.

[120] '关于加快推进充电基础设施建设 更好支持新能源汽车下乡和乡村振兴的实施意见 [Opinions on Accelerating Charging Infrastructure Construction and Increasing Support for New Energy Vehicles in the Countryside and Implementing the Rural Revitalization Programme],' National Development and Reform Commission and National Energy Administration, 14 May 2023, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202305/t20230517_1355814.html.

[121] '关于进一步构建高质量充电基础设施体系的指导意见 [Opinions on Further Building Out Charging Infrastructure System],' China State Council, 8 June 2023, at https://www.gov.cn/zhengce/content/202306/content_6887167.htm.

does not explicitly mention EV charging, the need for local consumption could potentially drive smart charging or EV charging policy.[122]

Figure 6: Timeline of key 2023 policies on charging infrastructure relating to rural areas or power markets

Date	Policy	Issuer	Relates to
March 2023	Electricity Demand-side Management Rules: Draft for Comment	NDRC	Demand response, rural EV charging
• encourages participation of EVs in demand response, encourage aggregation of EV loads, and encourage rural areas to participate in demand response			
May 2023	Opinions on Accelerating Charging Infrastructure Construction and Increasing Support for New Energy Vehicles in the Countryside and Implementing the Rural Revitalization Programme	NDRC, NEA	Charging infrastructure, rural EV charging, smart charging, V2G
• Promote rural EVs to include smart charging capability and smart home chargers • Study two-way interaction between electric vehicles and the power grid (V2G), and coordinated control of PV, storage and charging			
June 2023	Opinions on Further Building Out Charging Infrastructure System	China State Council	Charging infrastructure, smart charging
• Calls for implementation of time-of-use prices for EV charging • Guide users to participate in demand response and orderly charging • By 2030, exempt smart charging and swap stations from electricity demand charges.			
July 2023	Opinions on Raising the Quality of Rural Electricity Grid Stability	NDRC, NEA, National Rural Revitalization Dept	Rural renewable integration
• strengthen grids to handle increased distributed renewables, and raise local consumption of renewable energy			

Source: OIES, 2023.

1.9. Summary: Smart charging and V2G are at an early phase, but progress is accelerating

Smart charging is far from widespread worldwide and in China, and remains generally reliant on static time-of-use pricing, with a few countries experimenting with dynamic pricing. China's charging infrastructure often focuses on industry demand response and, in some cases, has seen power cut off during shortages that could risk damaging consumer acceptance of EVs. Aggregation of EV chargers for virtual power plants is practised in a number of regions outside China, and in a few cases, China has also piloted VPPs, albeit at a small scale.

V2G remains an area of heated debate, with many touting the benefits and other experts remaining sceptical of its potential. Barriers remain in multiple aspects, including consumer acceptance, electricity pricing, market design, taxation, technology standards, and uncertainty about battery degradation. On the flip side,

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[122] '关于实施农村电网巩固提升工程的指导意见 [Opinions on Raising the Quality of Rural Electricity Grid Stability],' National Development and Reform Commission, National Energy Administration, and National Rural Revitalization Department, 4 July 2023, at https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/202307/t20230714_1358371.html.

the rapid introduction of new car models and bidirectional-capable charging equipment for Combined Charging System (CCS) and Chinese chargers could accelerate adoption of bidirectional charging in different applications, even if commercial adoption is limited to a small number of vehicles or user types, such as for large EV fleets. In the US and Europe, vehicle-to-home bidirectional charging appears attractive, especially to those with distributed energy. In China, fleet and industrial applications of bidirectional charging may be the initial focus.

Regarding the subject of this study – rural integration of EV charging with renewables and other clean energy technologies – there are few concrete policies, though in 2023 several policies have mentioned or alluded to the possibility of using smart charging or V2G in rural areas or to balance renewables in rural areas. The rapid expansion of rural rooftop PV under way since 2021 under the Whole County PV programme, combined with increasing EV penetration in rural areas, is likely to result in significant developments, in terms of both policy and practice, that **could ultimately translate to policy momentum around promoting V2G specifically for integrating distributed rooftop PV** at the village or household levels.

2. Expert Views of EV charging and EU Cooperation Potential

Chapter Summary:

- The expert interview process confirms widespread uncertainty and disagreement about the potential of EVs to help integrate renewable energy. There is little consensus on which use cases will be most attractive for bidirectional charging or which barriers will prove most important to resolve.
- The main barriers in the international context include the cost of equipment, the inadequate availability of dynamic pricing, too few bidirectional-capable vehicle models, and regulatory barriers such as taxes or fees, insufficient grid codes, or lack of standards.
- In China, by contrast, bidirectional charging is a relatively new technology and not widely available, but most experts feel that rural residents would be both interested and able to participate, though unpredictable driving and charging patterns and low awareness could be major barriers.
- As for international cooperation, the experts consulted in this study express a high degree of optimism on the potential for international cooperation in the fields of power market reform and EV charging. Chinese and European experts emphasise the importance of continuing to learn from one another on the topic of EV charging as a technique for increasing renewable integration.

2.1. Introduction

The value of bidirectional charging (either for stabilising the grid and integrating renewables or serving individual customer needs) and its potential, given various obstacles to its adoption, remain subject to wide debate, both in China and internationally. Up to the present time, few vehicle models have had the capability to engage in bidirectional charging, making it difficult to evaluate its potential or customer interest.[123] There are only a handful of commercial chargers capable of bidirectional charging, and outside China most have been limited to the CHAdeMO charging standard used by a few Japanese and European makes – reflecting the bidirectional capabilities of the Nissan Leaf.[124] While more bidirectional charging-capable models are expected to become available soon, and new charging equipment is also expected to reach market, there remains widespread uncertainty about all aspects of the future of this technology: its cost, economic potential, user interest or willingness, and paths to resolving policy and regulatory barriers.

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[123] Jane Ulitskaya, 'What's Bidirectional Charging and Which EVs Offer It?,' Cars.com, 28 September 2023, at https://www.cars.com/articles/whats-bidirectional-charging-and-which-evs-offer-it-457608/.

[124] CHAdeMO, which stands for Charge-to-Move in English and is a play on words in Japanese, was developed by Japanese carmakers and is the only charging standard with bidirectional charging capability already incorporated. In practice, Nissan and Mitsubishi are the main brands that have used the standard in vehicles sold outside of Japan. See 'A decade of in-market experience with V2G/VGI,' CHAdeMo, accessed 24 October 2023 at https://www.chademo.com/technology/v2g.

In situations of high uncertainty, modelling can only offer partial answers, given that many model inputs remain unknown. Similarly, large surveys of consumer interest or expert knowledge may offer limited information, given that most have little knowledge or awareness of technologies that have yet to reach the commercial market at scale.[125] In this context, semi-structured interviews with a small number of qualified experts may offer complementary value to modelling, even if the number of respondents is low. In particular, even a small subset of experts may reveal key areas of uncertainty or disagreement, helping to generate hypotheses for future research and modelling. Expert inputs can also be used as a basis for modelling efforts, such as concerning future cost trends or charging patterns – even if responses are necessarily general or speculative.

In this study, four sets of expert interviews were conducted – two each for China and experts located in international markets with early EV adoption. Most international experts were located in the EU or had direct knowledge and experience in EU markets, while a few individuals were mainly knowledgeable about the US or UK. A total of 30 experts participated in the interview process, including 13 Chinese and 17 international experts. Most interviews were conducted by video call, although a few responses were received in writing. All interviews were conducted on the basis of anonymity and no organisations are mentioned.

In each market (for simplicity, described here as *China* and *international*), two groups of experts were interviewed or asked to respond in writing:

> (1) Those with long-term knowledge and experience in the EV charging industry, especially in companies engaged in efforts on bidirectional or smart charging or at policy-related or academic organisations actively researching such topics; and
>
> (2) Policy experts engaged in international cooperation on power sector and sustainable mobility topics, without explicit prior work in bidirectional charging or V2G.

EV charging expert respondents in the first category were asked a variety of specific questions concerning the overall prospects for V2G for various use cases as well as barriers to adoption of bidirectional charging, and were also consulted about driving and charging patterns. Respondents in the international policy cooperation category were asked to respond to more general questions regarding the most attractive topics for further exchange between Europe and China as regards EV charging overall.

Among the EV experts, while most had a variety of backgrounds, including academic and industry experience, typically they had worked on the topic of EV charging from both commercial and theoretical perspectives. In terms of responses and overall opinion on the topic of bidirectional charging and its potential, the main determining factor appeared to be subjective opinion and individual experiences rather than specific organisational background (EV charging, carmaker, utility, academic,

[125] Chauncey Wilson, 'Semi-Structured Interview,' in *Interview Techniques for UX Practitioners*, 2014, at https://doi.org/10.1016/B978-0-12-410393-1.00002-8.

policy). There were too few responses within each sub-category to generalise beyond this.

The primary finding in the interview phase of the study is that experts have a wide range of opinions on bidirectional charging. They differ in their views of its overall potential, on which users or vehicle types are most suited for it, on which barriers are most important or critical to address, and on the likelihood that it might help solve the issue of renewable integration in rural areas. While this absence of expert consensus might appear discouraging for the overall prospects of the technology, or for the usefulness of international cooperation on this topic, the experts provided a number of qualitative observations and insights that can help form the basis for future research and cooperation.

Among policy experts, there is widespread agreement in China and internationally that cooperation and exchange on policy in this field will serve mutual benefits and interest. However, once again there is an apparent difference in opinions, with European experts more focused on policy exchange, whereas Chinese experts see greater value in technology and industrial partnership for market access. As already mentioned, in each case the experts consulted were those already involved in policy exchange – so this distinction does not appear to reflect differences in background.

If the Chinese side is mainly interested in obtaining technology while the European side is mainly interested in discussing policy, this could become an important gulf to communication and exchange. Alternatively, openness of each side to exchange on both issues simultaneously through one platform could provide an incentive for both sides to participate in dialogue.

In summary, the main finding of the interview segment of this study is that there is a global lack of consensus on the potential of and barriers to bidirectional charging, both overall and as a technique for helping absorb renewable energy at the local level to achieve international and national low-carbon energy targets. However, this is likely to change rapidly in the next two years. By 2025 there could be radically different views on these topics, given the launch of new vehicle models, availability of presumably lower-cost bidirectional charging equipment, expanded deployment of distributed energy (particularly in China), and evolution of electricity tariffs for EV charging and other related policies.

2.2. Background on rural EVs and bidirectional charging in Europe and China

The potential for smart charging and bidirectional charging relates to a number of factors, on each of which there are large differences between Europe and China, as well as regional differences. Major factors include vehicle type, battery size, driving patterns, charging habits or needs, availability of private charging, deployment of distributed renewable energy such as solar, and electricity pricing. Familiarity with and interest in smart charging and bidirectional charging are also considerations.

In Europe, rural areas are perceived as being generally more well-off than rural areas in China: in Western Europe rural incomes may be on a par with or higher than urban incomes. In general, rural residents in Europe tend to purchase similar vehicles to those in urban areas, though urban residents may be more likely to opt for smaller city cars with smaller batteries, while rural residents may be more likely to opt for plug-in hybrid vehicles. In Europe, rural residents are likely to have access to dedicated parking and home charging.

As mentioned above, in China rural areas are on average less well off than those in urban areas. While rural areas have relatively poor public charging infrastructure, they have good conditions for installing private charging facilities. Shorter-range electric vehicles may be more popular in rural areas compared to urban areas, where residents may charge less frequently due to greater reliance on public charging.

Given relatively low incomes in rural areas, price is one of the key considerations in the purchase decision of rural buyers. Interviewees believe the budget of rural buyers for an EV is typically between CNY 50 000 and CNY 70 000 (EUR 6 500 - EUR 9 000). Given that short-range EVs are cheaper, and rural buyers are price sensitive, interviewees believe that rural buyers tend to prefer smaller short-range EVs. Many rural residents may also prefer two- and three-wheeled electric vehicles which are suitable for driving on narrow rural roads.

EV purchase preferences also depend on the types of rural buyers, which can be categorised as migrant workers, farmers who work close to their home, and farmer vendors of agricultural products. Migrants and farmers tend to purchase two-wheeled vehicles which can meet their medium-and short-distance commuting needs, and are less affected by urban traffic jams and access to parking spaces. Farmer vendors of agricultural products tend to buy three-or four-wheeled light-duty electric vehicles to load agricultural products.

As noted in Chapter 1, China's electricity markets are at an early stage of adopting liberalised wholesale electricity markets, and the main form of time-varying electricity pricing consists of time-of-use prices, which may also incorporate a seasonal component in certain regions. There are few examples of smart charging linked to production of wind or solar energy, though certain public bus fleets or car fleets have initiated bidirectional charging pilots.

In Europe, by contrast, liberalised wholesale power markets exist across most of the continent and in most countries, and a wide variety of retail electricity price plans is available, including not only time-of-use pricing, but also dynamic pricing. In a few areas, such as Denmark and the UK, dynamic pricing plans may be linked to the availability of renewable energy. EV-specific charging prices are available in many regions. Europe has also piloted bidirectional charging for private vehicles in several countries, albeit in limited numbers due to the small number of vehicles with this capability and the cost of charging equipment. As more models are introduced, more bidirectional charging should get under way in countries where dynamic or highly time-variant pricing exists for residential customers. However, a caveat is that in many countries taxes and fees make it economically unattractive to inject electricity back into the grid. Grid codes and regulations may also prevent bidirectional charging in some countries.

2.3. Interview results: international EV charging experts

Purpose and questions: For this section of the study, a total of nine international EV experts were interviewed on the potential for and barriers to smart charging and bidirectional charging. The interviewees can be grouped into the following categories: Two respondents are at NGOs involved in power sector research, two are academics researching the EV charging field, three respondents lead or work at EV charging companies or EV charging divisions within larger energy companies, and one is an EV market analyst.

The interviews with international EV charging experts had several objectives, including determining whether there is any industry consensus on bidirectional charging, evaluating the relative importance of various barriers to bidirectional charging and which use cases would be most suited for it, and finally gathering data on rural driving and charging patterns. Interviewees were not required to answer every question. Questions included:

- How do Europe's rural areas differ from urban areas in terms of EV adoption and EV purchase preferences, such as range and size?
- Are there major differences in overall rural driving patterns, in terms of time of day and purpose? Do you believe most rural users seek to have a full charge daily?
- Do you estimate that the proportion of rural EV owners willing to participate in bidirectional charging could be greater or less than in urban areas?
- What types of customers do you believe are most likely to participate in smart charging?
- What are the barriers to EV adoption in rural areas compared to urban areas? Are there some areas where rural buyers face fewer barriers?
- Is the distribution grid a limitation to either rooftop solar or EV charging in rural areas in Europe?
- How would you evaluate the overall impact of various barriers to bidirectional charging, including cost, revenue potential, consumer interest, policy maker interest, and regulatory barriers?

EV adoption and charging in rural areas: the international view: In general, the international interviewees agree that EV ownership is easier for those with single-family dwellings and private parking garages, and these are more common in suburban and rural areas. Rural residents may have multiple vehicles and ample power connection capacity, particularly those with co-located work operations such as farms or small businesses. Even for a small minority of rural residents with very long driving times, EV ownership may eventually be more attractive due to fuel savings:

> 'In my experience, rural drivers have longer distances to cover, plenty of rural drivers are more sceptical of EVs and have heard of charging nightmares. Some have range anxiety as well. I've talked to rural drivers covering 300 miles per day. In my mind, that makes them more attractive possible EV drivers because the fuel savings could be larger. Access to home charging is more likely to be available in rural areas, and I do think that having that is essential for rural drivers'.

At the same time, public charging infrastructure in rural areas is weaker than along major highways or in urban areas:

> ‘In rural areas, there is more off-street parking, which offsets a weaker charging infrastructure. My feeling is that there is a higher proportion of people charging at home and a lower proportion of people participating [in smart charging] unless they have potential to charge at home, because public infrastructure is not up to the needs of rural EV ownership.’

Onsite solar is economically attractive in the rural areas of many European countries, and combining solar with EV charging is viewed favourably by many rural residents, both for economic and environmental reasons. As one interviewee in Germany noted:

> ‘I think they’re slightly ahead, depending on the country. In Germany, rural areas have a higher uptake and started a little bit earlier. There’s a quite logical reason such as a higher share of single-family houses and people having rooftop solar, which is generally a good indicator for purchasing an EV.’

Similarly, another European interviewee felt bidirectional charging was attractive for rural residents with EVs and solar:

> ‘More attractive for rural owners especially solar PV owners. Rural areas have oversized PV installations versus daily consumption. So there is a bigger interest in bidirectional charging for energy storage.’

However, balanced against the attraction of using solar for EV charging was the possibility of double taxation, which could then lead to regulatory barriers that would prevent discharging the vehicle, even for vehicle-to-home applications. (Barriers are discussed in detail in the following section.)

> ‘In the EU I would say it goes mainly to the country level. Here, whether you have your own energy or not, you still need to pay the energy tax, even if you generate your own energy with your solar panels. As a private user I pay energy tax which is one-third of the electricity bill. A business pays nearly nothing. That means that if I have my own company as a farmer I have an advantage. If I have an EV and I am charging my ‘company car,’ from a regulatory point of view I cannot allow this to discharge for private use.’

As with other customers, V2G in rural areas faces many of the same barriers as those faced by other EV owners or use cases, as will be discussed below. One EV charging provider reflected on their company’s experience with a V2G pilot in a rural area:

> ‘We have a core group of customers that was very engaged and eager to participate in [smart charging and V2G] trials … but even so, V2G was a real headache. People love the idea, but it has to work easily, so that users don’t have to think about it. I would say that those people who’ve had an EV for a while are those who would

> consider a smart tariff and would be more interested in bidirectional charging.'

Most interviewees expressed the view that there is limited data on how rural EV ownership, driving, and charging patterns differ. One retail electricity provider that offers multiple dedicated home EV charging tariff plans said the company does not explicitly track the percentage of rural versus urban customers, but notes, 'We have a dashboard that has a light for every customer and they're very evenly distributed so I'd say we have a lot of rural [customers].'

As for driving and charging patterns, a common view is that average trip distances in rural areas are longer, but daily driving mileage and charging times are not that different from those in suburban or rural areas.

> 'In rural areas they may use the vehicle more often, more on a daily basis, but not necessarily more driving or mileage.'

In rural areas, there may be a greater desire to have the car fully charged if each individual trip is longer. However, here again interviewees did not express strong views or have reliable data as to whether rural and urban customers differed. As with urban customers, rural EV owners are likely to plug in on most days, given the option.

> '[Being fully charged] is not necessarily a preference, just if they happen to have the ability they will do so. People generally know whether they can do their daily driving, even if the car is only at 30% state-of-charge, but sometimes it's more convenient to know it's fully charged.'

For one company with home EV charging tariffs, customers in both rural and urban settings are similar in their preference for full charges. Further, customers clearly have extra battery capacity they could make available for bidirectional charging if available:

> 'You set a charge-by time and a final state-of-charge. We find that pretty much everyone sets their final state-of-charge at over 90%. We recommend 90% [instead of 100%] for better battery health. From our experience, it does seem people like their car to be fully charged. From a system point of view, it's interesting that most people always think in terms of 24 hours [and charging daily], but if you think in terms of three days it might be better to charge the vehicle on one day only. Our average [smart charging] customer charges 8kWh per night, typically for a Tesla Model 3, and so with 70kWh to 80kWh battery capacity, they are only adding about 10% every day. There are some who don't charge daily at all. But most charge [a fairly regular] 8kWh per day, and then there is a long tail of those who charge more.'

One interviewee noted that rural drivers may have greater variability in daily driving patterns, leading to greater potential desire to charge fully:

> ‘A lot of rural workers don’t know what their daily driving requirements are in advance. Their travel might be time-sensitive as well, such as travelling to a work site, and, of course, they want to finish their jobs on time to return home.’

As for smart charging, charging from renewables, or bidirectional chargers, several interviewees had direct experience. While there are various smart-charging solutions available for owners of rooftop solar, customers with solar do not necessarily employ them:

> ‘There are many regions in Europe where it’s more beneficial to charge off your own solar instead of feeding into the grid. I think there’s a tendency to charge on solar, not necessarily through dedicated mechanisms or smart chargers, but sometimes just by plugging in during the daytime.’

One potential advantage of bidirectional charging in rural areas, whether vehicle-to-home or vehicle-to-grid, is that it can reduce the strain on the local distribution grid, which may not be able to handle an increase in both over-generation from local PV and high evening or night-time power consumption associated with charging EVs. Most interviewees were drawn from the EV charging field, not the distribution companies, and could not offer views on this advantage – though it is perhaps telling that as yet this advantage is not necessarily a driver of smart charging or bidirectional charging. However, there was some awareness of the issue in general:

> ‘Yes, limits on the distribution grid are causing problems in rural areas. What we see here is a lot of ground is sold for solar fields in rural areas and that is where the space is. There are a lot of areas in the Netherlands where if you start a company there is no electricity due to the imbalance of solar production and consumption. A lot of people cannot get an electricity connection in rural areas for one or two years. There is also curtailment of solar, or solar owners have to pay to inject it into the grid at certain times.’

Another expert in Germany noted that smart charging or bidirectional charging could help resolve problems with the distribution grid, but that there were other regulatory barriers to overcome before this could be realised in practice:

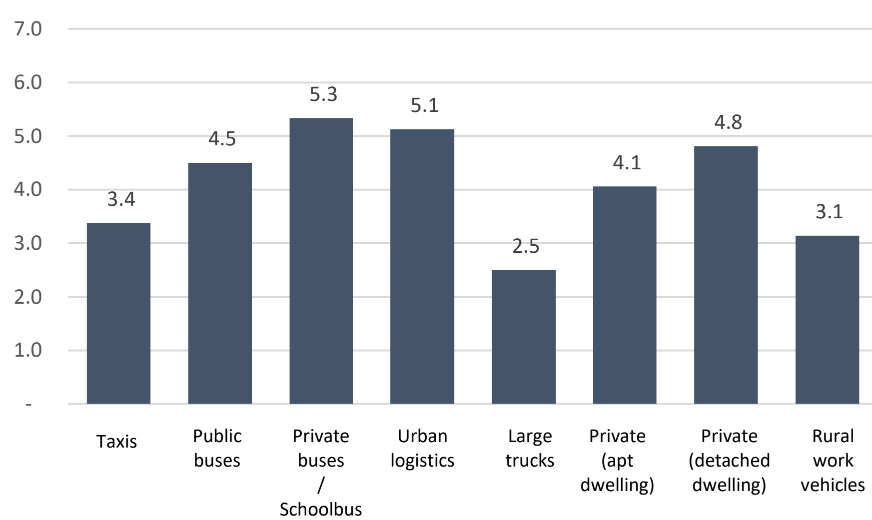
> ‘In many cases in the summer there is an enormous imbalance in the market due to over-generation at some times and under-generation at others. That makes it expensive to maintain the distribution network. We need thicker cables during times of over-generation. The solution is smart grids and smart balancing, which is starting to happen here with a lot of local companies with digital solutions. But they are not really supported by the policy makers… Also, you have concerns about safety and reliability. We have one of the highest reliability rates in the world, but as soon as you have innovative smart grid technologies then you have policy maker concerns that this will affect reliability. This is a regulatory barrier for smart charging or bidirectional charging.’

So, in general, rural areas have significant potential for uptake of smart charging and bidirectional charging of EVs for integrating renewable energy, due to the high availability of home charging and rooftop solar as well as limits on the distribution grid. However, there are significant obstacles to overcome, in terms of both meeting user needs with regard to economics and simplicity, and removing regulatory or tariff barriers.

Use cases for bidirectional charging: Regarding which uses would be most attractive for bidirectional charging in the near future, international interviewee responses showed some areas of agreement and some areas of sharply diverging opinions. Interviewees were asked about eight different vehicle categories, which necessarily leads to generalisations about users that might be included in each category. While interviewees were encouraged to provide qualitative responses about how different categories might contain various sub-categories or situations with greater or lesser potential for bidirectional charging to play a role, all were asked to provide an overall rating for each of the categories, if their knowledge permitted them to do so. The respondents were not asked to make any prior assumptions about electricity tariff structure, costs, vehicle availability, or other incentives or barriers that might have major implications for which vehicles can participate or would likely opt into bidirectional charging if available.

Three categories were rated as most likely to have potential for bidirectional charging: private buses such as school buses or company commuter shuttles and vans; urban logistics vehicles such as small truck;, and privately owned cars with access to private charging at a detached house. There was broad consensus that the largest trucks would have the least potential for bidirectional charging, due to high utilisation patterns, long charging times, and the likelihood of utilisation mainly during daytime hours. In other vehicle categories, respondents gave more diverse answers, suggesting both greater uncertainty and greater sensitivity to factors such as policies at the local and national level.

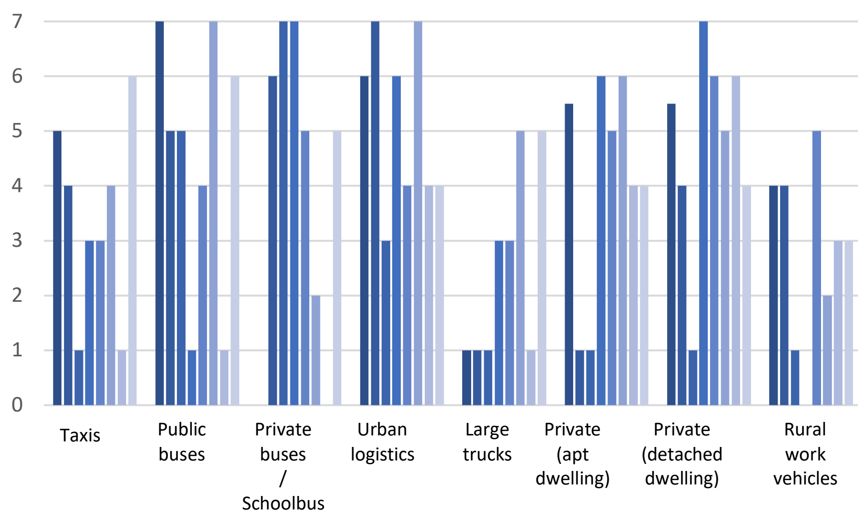
Figure 7.1: Attractiveness of bidirectional charging for different vehicle use cases (response average)



Source: OIES, 2023.

As Figures 7.1 and 7.2 makes clear, respondents offered a diversity of overall opinions about the potential for V2G in general, with several interviewees rating most vehicle categories and use cases as unlikely to participate or benefit from bidirectional charging.

Figure 7.2: Attractiveness of bidirectional charging for different vehicle use cases (by respondent)



Source: OIES 2023.

As already noted, large trucks were rated as unlikely to participate in bidirectional charging by most respondents. Several respondents offered negative views on the likelihood of public buses or private cars owned by apartment residents to participate.

Public buses and taxis were generally considered unlikely to participate in bidirectional charging if they had high utilisation or mainly daytime utilisation. As one interviewee noted, 'For taxi fleets, it varies depending on how they are utilised. Maybe they can do bidirectional charging if they are parked overnight, but that's not when the grid needs V2G resources. V2G is needed at peak times.'

Others considerations could also prevent taxis from actively participating in bidirectional charging:

> 'Taxi owners face huge pressure to minimise costs, but they only have so much [time] margin to charge or discharge, so that is an operational constraint. To the extent you can use their flexibility when they are parked, they would have a huge incentive, but the sector is many small operators and heterogeneous in terms of uptake [of charging technology].'

Concerning public bus fleets, one interviewee said, 'A lot of these are bad use cases, such as high utilisation fleets like public buses that don't have time to charge overnight. I've done a lot of modelling of bus depots and it does not seem to work.'

However, one interviewee noted that the cost of customer acquisition and education would be less for large fleet owners that already need to coordinate charging to minimise infrastructure costs. 'Public and private services seem like an easier target to convince, without needing significant incentives to be a part of a bidirectional charging program. And they would provide the most bang for your buck compared to individual car owners.'

Public bus fleets were better candidates for smart charging, as opposed to bidirectional charging. As one interviewee said:

> 'Buses face similar operational constraints to taxis, but fleet owners have incentives to optimise charging during the night. The clean vehicles mandate has a strong mandate to electrify bus fleet and there will be incentives for municipalities to reduce cost. I've heard of examples like Hamburg, which is looking at how to electrify the bus depots, and found it could save EUR 2-3 million by planning for optimising charging in the beginning. They were able to negotiate an agreement with the grid operator for lower charging costs.'

For private buses, such as company shuttle buses or school buses, opinions were mixed. While a couple of respondents suggested that school buses are ideal, one interviewee pointed out that Europe has relatively few school buses and this is more relevant for North America. An EV charging expert who previously worked in government pointed out that private companies with small bus fleets 'are focused on green signalling, and they get most of their green signalling benefit from saying they're all electric. You don't gain much reputational benefit from adding V2G.'

For urban logistics vehicles such as small trucks, most respondents rated this category as relatively more likely to participate in bidirectional charging. While some interviewees noted that such vehicles resemble taxis in that they are utilised during the day and parked overnight, when bidirectional charging offers few benefits, others were more optimistic:

> 'Urban logistics vehicles and taxis are likely in continual use or do not have as predictable routes or down times. Yet with their larger [battery] size, I ranked them higher than personal vehicles for their potential for V2G.'

Apartment dwellings were rated as unlikely to participate if they lacked charging facilities or incentives for building owners to invest in bidirectional charging or participate in smart charging rate plans. Whereas many envision building owners as lacking incentives to facilitate investment in charging beyond the minimum, one interviewee pointed out that in some countries there will be significant incentives for building owners to integrate renewables with EV charging, which would promote greater uptake of new technologies:

> 'In an apartment building, you may need load balancing to fit all the charging in, so that might see a low level of smart charging, more broadly than just households… Especially for newly-built apartments, they also have incentives to use onsite generation of renewables matched with local demand [that is, consumed within the building or complex], so that's a big incentive [for bidirectional charging].'

Indeed, another interviewee responded that apartment residents are 'probably the best use case other than urban logistics' due to shorter and more predictable driving patterns and long periods parked during the daytime, but that they need 'the right regulatory framework' to incentivise building owners to facilitate bidirectional charging.

For residents of individual houses with dedicated charging, most respondents considered this as a practical use case, but differed as to the likely uptake. Two interviewees considered bidirectional charging for individuals as only a 'niche' for the most well-off and highly-motivated consumers. However, others pointed to rising consumer awareness and interest, along with the introduction of new products.

> 'Individuals and households first want their vehicles available for personal travel or for use in an emergency. [But] as charging becomes more available and reliable, and as these technologies become more known among the public, then individuals and households could become more comfortable using their vehicles for bidirectional charging.'

Aggregation services and attractive utility rate plans were viewed as potentially necessary to interest the typical consumer and ensure the benefits are significant at grid scale:

> 'It's no surprise that residents of single homes have more information and would see more benefits to bidirectional charging [than apartment residents]. But, on the other hand, if you can aggregate more vehicles that are parked, then it behaves more like a fleet, and owners and the grid can get more benefits.'

For rural work vehicles, the long periods spent parked could make them attractive for bidirectional charging, but the small number of EV products available for agricultural equipment and their limited overall number is likely to make this a relatively late category for participation in smart charging or bidirectional charging.

While there was considerable disagreement about the potential for bidirectional charging in different use cases, for almost all categories except large trucks, taxis and rural work vehicles, at least some respondents rated them as highly likely to participate in bidirectional charging at some level. In some cases respondents offered policy examples and successful pilot cases, or theorised about the potential for sub-categories to participate at high levels.

Barriers to bidirectional charging in the international context: International interviewees provided the most diverse responses concerning the potential barriers to bidirectional charging. The diversity of opinions on the scale of the problems posed by each barrier, and their relative importance in hindering the development of bidirectional charging, resulted from a variety of factors. The most important may be national or local policy context, given the diversity of different regulatory tariff structures, grid codes, and charging standards. A second factor leading to diverse responses may be broad uncertainty and lack of successful commercialisation of bidirectional charging, due in part to the lack of vehicle models with bidirectional capability and the lack of standards enabling the adoption of bidirectional charging. Hence, for this question, numerical responses may have less relevance than the context-specific qualitative reasoning behind them.

Respondents were asked to evaluate the barriers to bidirectional charging grouped into five categories:

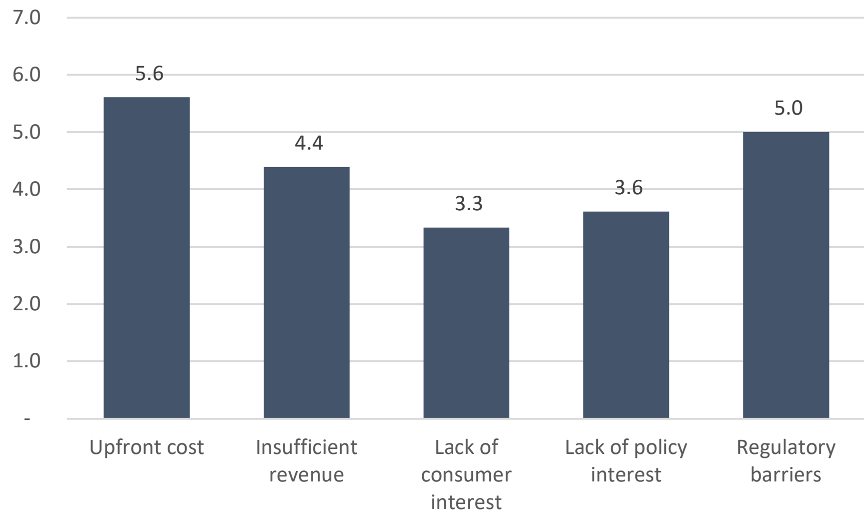
1. Upfront cost, such as the cost of buying a bidirectional-capable charger or the cost of installation, which might include replacement of existing equipment.
2. Lack of overall economic incentives, related to factors such as insufficient revenue potential due to the structure of electricity tariffs, absence of dynamic pricing, taxes on electricity consumption or on sending power back to the grid, or related fees and costs other than the cost of installation or equipment.
3. Insufficient consumer interest, due to low awareness, perceived complexity, the preference always to maintain a full charge, insufficient charging access (such as for users without access to private charging) or concerns about the effect of bidirectional charging on battery lifetime and performance or vehicle warranty.
4. Insufficient policy maker interest, due to greater focus on promotion of electric vehicle adoption in general or greater urgency attached to expanding access to charging infrastructure, or perceived separation of function between those responsible for mobility policy versus those responsible for electricity sector policy or integration of renewables.
5. Regulatory barriers, to include both legal and policy barriers that might directly hinder bidirectional charging as well as utility regulation (such as lack of incentives for utilities to encourage bidirectional charging or invest in related enabling infrastructure) or absence of supportive grid codes. Absence of standards (such as bidirectional charging standards, communications protocols, and vehicle standards) was also included in this category.

During the interviews, several respondents raised the issue of the absence of bidirectional-capable vehicles as well as technology issues separate from those listed above. These are discussed in greater detail below.

Of these five categories, interviewees agreed that the high upfront cost is the most significant barrier to uptake or adoption of bidirectional charging. However, individual responses about the cost issue provided substantial additional colour on how this barrier may evolve over time. Regulatory barriers were rated second in importance, including frequent mentions of the need to upgrade grid codes or adjust utility regulation to incentivise grid companies or private companies to support bidirectional charging. The third-ranked barrier, of insufficient revenues or other economic barriers, was also mentioned by most participants. There is obviously significant overlap between these economic considerations (rate structure, for example) and regulatory barriers, and the two categories are not mutually exclusive.

Perhaps surprisingly, few respondents considered insufficient consumer or policy maker interest as insurmountable barriers. However, on these two categories, responses varied greatly, and interviewees expressed considerable uncertainty as well.

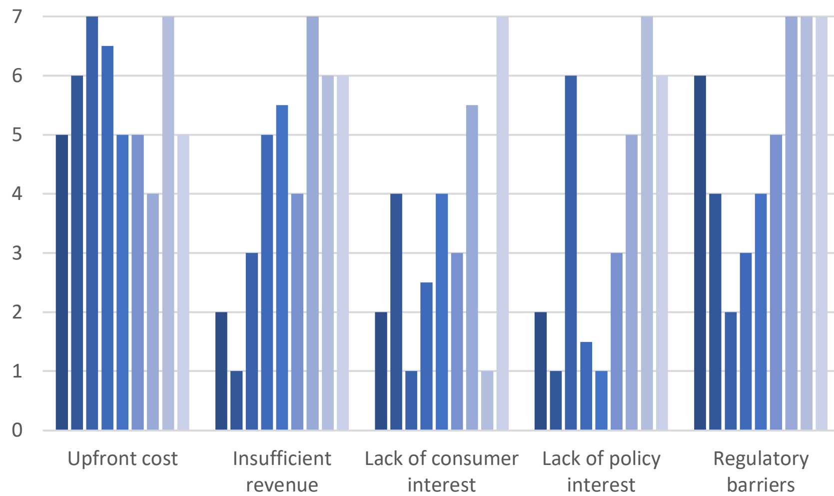
Figure 8.1: Importance of varies categories of barriers to bidirectional charging (response average)



Source: OIES, 2023.

As can be seen from Figures 8.1 and 8.2, respondents showed the highest level of agreement concerning the importance of the upfront cost of charging equipment as a barrier to bidirectional charging. All respondents ranked this at least 4 out of 7, and two interviewees evaluated upfront cost as the most important barrier overall or in their region. Regulatory barriers also drew relatively high responses overall, with only two respondents ranking them as only 2 or 3 out of 7 in terms of importance as a barrier to bidirectional charging. As mentioned above, respondents generally put lower emphasis on insufficient consumer or policy maker interest as a barrier – though two respondents gave a high rating to insufficient policy maker interest as a barrier. For each category, several respondents stated they did not consider these factors to be a major obstacle to bidirectional charging adoption – either on its own or on a relative basis.

Figure 8.2: Importance of varies categories of barriers to bidirectional charging (by respondent)



Source: OIES, 2023.

Upfront cost as a barrier: The upfront cost of installing bidirectional charging was one of the topics on which interviewees disagreed. While some noted the current high cost of charging equipment, others were optimistic that the upfront cost would decline rapidly, thanks both to more competition and new equipment becoming available as more car models offer bidirectional charging capability, and to the inherent cost of the technology.

> ‘A smart charger is not expensive, but bidirectional is not yet economically interesting, because there are only limited charging products on the market and these are quite expensive. Bidirectional charging equipment has a huge cost reduction potential once companies like Enphase or SolarEdge move into the space over next three years.’

One interviewee noted that high upfront costs were less of an issue for public charging applications that are already shifting more towards DC fast charging:

> ‘It definitely affects the economics. But although it’s a big barrier, it is also likely to evolve more quickly as costs drop. It’s just a matter of scale and volume. DC chargers in general cost more than AC chargers, and V2G is mainly done with DC chargers. The preference for DC for bidirectional charging is partly due to interconnection regulations, and partly due to greater efficiency and higher power if the inverter is in the charger instead of in the vehicle. So there’s always going to be an upfront premium relative to an AC charger in the home’.

One interviewee with experience managing a bidirectional charging pilot noted:

> 'Upfront cost is a massive barrier. In our pilot, I think it cost Euro 7 000, but that is probably a bit out of date. In the long run, the main cost of the bidirectional charger is the inverter, and for a solar PV panel of 10kW you can buy an inverter for EUR 1 000. So I would expect the cost will eventually decline to that level, in terms of the cost premium for bidirectional home chargers versus an ordinary smart charger.'

One interviewee noted that the upfront cost includes not only the charger but the potential cost of upgrading other electrical systems.

> 'With the exception of a single make, all bidirectional is DC, and to have your home ready it's almost EUR 10 000, and could be as high as EUR 20 000 in some cases. You can buy a used EV for that. It's only feasible for the rich here. With import tariffs we don't have cheaper Chinese EV charging models … I have a 200 amp panel and solar PV, a home battery, two EV chargers, and I'm about to get a heat pump. I have not needed to upgrade my panel. But for bidirectional charging I would.'

Others focused on different customer classes or the possibility of subsidies and financing, such as including a bidirectional charger in the utility's price offer for participating customers.

> 'I guess at the moment V2G is historically through the CHAdeMO platform, and these are expensive because they have an inverter. Only a few thousand have been sold. The good thing that the price has come down. At first it was over EUR 15 000, but now you can buy a bidirectional charger for EUR 4 000. That's still a reasonably significant barrier if the consumer has to pay upfront. If the cost can be incorporated in the lease or utility tariff, then it could work.'

Similarly, another interviewee suggested subsidies are warranted:

> 'I don't think this is the biggest barrier, though it's not one to underestimate. Rural communities include better-off communities that can afford higher upfront costs for charging equipment, but also poorer areas. For the less well-off group, the cost of a Wallbox will be an issue. It makes sense economically where utilities can offer subsidies to an EV combined with subsidies or other help with the cost of the charger. So we should think about subsidies for low-income groups in rural areas, to enable them not only to participate in e-mobility buying an EV and being able to charge, but to really be part of the [clean electricity] system.'

Limits to economics of bidirectional charging: The economic attractiveness of bidirectional charging depends crucially on whether there is revenue available to enable users to reliably recover the cost of the investment and earn an adequate return. International interviewees were somewhat divided on the extent to which this is a major barrier.

> 'The economics of bidirectional charging goes hand-in-hand with regulation of utilities. Overall, there is a lack of incentives through dynamic tariffs, so that's partly regulatory and partly economic. There are many locations where bidirectional charging would have significant system value, but there is no compensation.'

Similarly, one interviewee in the Netherlands noted:

> 'Yes, consumers are interested … if they get electricity cheaper than they get it today. A lot of input that I get from electricity cooperatives is that it's important we get clean energy and sustainability, but when we did a survey of 1 200 members of our electricity cooperative, 98% said price was the most important. Less CO_2 was important but price was more important. If you look at the real rural areas such as farmlands, for them the [economics] is very important because the margin they get out of agricultural activities is not high.'

An interviewee in North America pointed to the patchwork of regulation on pricing:

> 'I think it depends. Certain states have had no change in utility regulations since the 1950s, and maybe even lack time-of-use pricing. In other areas, there is no economic barrier at all, and there are aggregators who can handle the service for the customer.'

The issue of a regulatory patchwork is also present in Europe:

> 'The fact is that consumers today are not likely to see a price signal to know when to charge or discharge. The lack of availability of dynamic pricing is a big barrier. On the EU level, there's currently a review of the electricity market design that supports more cost-reflective pricing, but we don't see it applied throughout all Member States. Regulators tell us that national officials have more or less visibility and ability to implement such pricing. In addition, there is the fear of double taxation for charging from the grid and sending back to the grid.'

While several cited the absence of dynamic prices at the retail level, others noted that such dynamic pricing schemes are becoming more common.

> 'Uptake of dynamic tariffs is increasing and the interest is quite high amongst EV drivers. A survey of Dutch EV drivers said they would like to use dynamic prices to benefit from low prices. As bidirectional is introduced, interest in dynamic pricing will only grow stronger. However, notably, some dynamic price offers have gone away since the Ukraine crisis, as those offering such plans either were unable to attract customers after prices rose, or decided it was no longer profitable.'

Others expressed the view that full dynamic pricing is not necessary, as customers may prefer the simplicity and relative certainty of fixed time-of-use pricing, and that this is reflected in the design of EV tariffs in some areas, such as for some plans available in Denmark.

> 'In Denmark we have semi-dynamic pricing that helps encourage smart charging, but it is based on a fixed hour duration based on the cost of power at that time. It does not necessarily reflect the use of the grid, but [the regulator] decided not to make it more complicated. Basically, in an ideal situation, charging should be priced along with prices in the spot power market, but that's not the case at the moment.'

Others expressed the view that while the absence of attractive charging tariffs is a barrier, it could be resolved relatively quickly.

> 'I think we are seeing quite a big improvement in tariffs, like Octopus bringing out a range of smart and intelligent tariffs. I think the tariffs are good enough to already give you a good return, but utilities also need to fund the capital equipment cost upfront, which many [users] cannot afford … Tariffs can be created very quickly, and there are already many suitable tariffs now.'

Insufficient consumer interest: Consumer interest was rated as less of a barrier by several international interviewees. This optimism may reflect that the interviews primarily targeted experts with some direct knowledge of and experience with bidirectional charging. Yet there was still disagreement. For example, whereas one academic expert said, 'I think most people are interested in smart charging to improve utilisation and reduce costs,' another expert with a company engaged in EV charging stated that, 'There's a core of energy geeks [who are interested], and other people don't think about it.'

Some noted that individual consumer interest may depend on their background and experiences, such as those with unreliable electricity supply, for example in the US:

> 'Energy nerds are the ones asking for this, or people in Texas who experienced the blackout in 2021, so for those who are able to power their home, some are now zealots about it. But that's the exception … The prime objective for most charging is transportation. In terms of consumer interest, getting paid for grid services is only fourth or fifth on the list of desires.'

Similarly, a European interviewee noted interest from those in areas with either unreliable electricity or a lot of rooftop solar:

> 'I think there are some non-financial drivers [of interest in bidirectional charging], such as being more independent from the grid for one's own resilience when the grid goes down, and having the newest and latest technology and the option value to be able to discharge. The option to store solar might be either financial or non-financial for someone who has decided to go with solar. There is a lot of consumer demand from people who've heard of it. There's plenty of interest.'

One interviewee noted that awareness is still low:

> 'I don't think it's a huge barrier. I don't think very many people know about it yet. Having watched trends for solar and EVs, there

> are lots of people who say they would never do it. They follow predictable paths where it starts as a novelty, then one adopts it, then as more stories and experience they accept it. Awareness needs to improve, but I'm very confident that education will come through peer-to-peer knowledge sharing.'

Similarly, development of new software and apps will both increase awareness and raise the level of consumer satisfaction with bidirectional charging. An expert at an EV charging provider noted:

> 'As people learn how to use smart charging and have an app on their phone that programs their charge for them, the step to gaining an additional [charging price] advantage is not that big. The hurdle is getting consumers to that knowledge level. Yes, there is a barrier when it comes to convincing consumers that the battery can handle it, but once you demonstrate that they can be paid and they can still use their car for the driving they need, they can [be willing]. We emphasise first getting everyone on smart charging and then the rest is relatively easy. I am concerned about truck operators or bus depots, in that case you are much more interested in optimising cost, and you have to provide reliable transport services. This is the bigger barrier to address in terms of reassuring these types of operators that charging at certain times is beneficial.'

Finally, several interviewees noted that awareness and consumer interest will only rise once vehicles are capable of bidirectional charging.

> 'For bidirectional home chargers, I think the theory is fantastic. More people are becoming aware of their energy use and of energy prices. But what cars are capable of bidirectional charging on CCS? I remain disappointed that I can't have one because my Kia e-Niro does not have that ability.'

Insufficient policy maker interest or priority: As with other barriers, expert opinion varied widely on the importance of policy maker interest as a barrier to bidirectional charging.

On one hand, several experts viewed policy maker interest in bidirectional charging as high and supportive. An expert in the UK commented that there was great interest in the UK and this was not a barrier. One expert in Europe noted policy maker interest was less of a barrier than others:

> 'I think we have a decent environment [for bidirectional charging], in Europe at least. I feel what really matters is energy markets. I feel industry can put the rest together and you don't need policy interference or support.'

One European expert said that, if anything, bidirectional charging has been 'overhyped' by policy makers, and another expert in North America commented, 'Here in California, I think policy makers are pushing for V2G too fast, and talking about requirements for all EVs to be bidirectional-charging-ready. That will add costs … I don't view [policy maker interest] as a barrier.'

Yet others rated insufficient policy maker awareness as a potentially significant problem. One expert said, 'I'm not sure there are many policy makers that really understand how it works or the benefits.' Another expert expressed the view that:

> 'Policy makers do need to be [more] aware of bi-directional charging and its capabilities … And the lack of this knowledge and understanding is a major challenge, or barrier, to further deployment up-front as part of deploying EV charging infrastructure and EVs.'

One expert expressed the view that policy makers would like to promote bidirectional charging, but cannot move more quickly than industry:

> 'Government is showing significant interest in enabling bidirectional charging. The grid is very keen to unlock this flexibility. It's probably not yet being displayed through policy measures. The mandate that's just been announced could have included more specifics on bidirectional, but they want to be careful not to push too hard before the OEMs [original equipment makers] can support it.'

One European regulatory expert noted that while there is interest in the topic of bidirectional charging, often it is handled at the technical level rather than promoted through policy:

> 'I would say there is some misunderstanding. Often bidirectional charging is put into the futuristic category of something that's far away in reality and terribly complicated. I rarely see an approach that defines it and what it does and can deliver in addition to smart charging. It is not more technical than smart charging, and it does provide additional benefits … A study by the EU Commission on energy where they calculated the potential value of EV fleet charging using managed charging versus bidirectional charging showed the enormous potential of bidirectional charging. If we had more of this discussion [of the value to the system] instead of putting the topic into the standards committees … it can't happen soon enough. And this is changing. Interest is definitely going up.'

Regulatory barriers, including charging standards and grid codes: Interviewees expressed fairly consistent views about regulatory barriers, viewing them as a significant problem for bidirectional charging and one that may take time to resolve. Both inconsistent or unsupportive grid codes and insufficient bidirectional charging industry standards rated a mention by many interviewees.

> 'I'm optimistic about bidirectional charging, but there are many barriers today, including grid codes not allowing bidirectional charging, or regulations that set requirements for manufacturers of chargers or cars that industry cannot meet. There are uneven grid codes across Europe on aggregators meeting unrealistic requirements on frequency regulation or ramp rate. A second regulatory aspect links to the role of taxes and levies and grid pricing … Some countries have provisions for stationary storage [providing grid services], but not mobile [storage]. There are

> different tax and network tariffs for different [EV] user groups and so there may be totally different rates for charging at work or home discharging.'

Several respondents mentioned the long wait for bidirectional charging standards for CCS as a key barrier, while others mentioned standards for vehicles. One interviewee expressed concerns about the treatment of battery warrantees by carmakers if bidirectional charging becomes more widespread.

The issue of regulatory patchworks came up in several interviews. One expert in North America expressed the view that:

> 'The US is like the EU, in that there many different players with different needs and infrastructure, at different stages. The US has [no region] like Norway and Sweden [in terms of EV adoption], but many places like Greece [with low adoption]. Regulatory problems in each state are totally different.'

Yet some European experts expressed the view that Europe should look to US examples:

> 'California has a senate bill that requires all EVs be bidirectional-capable by 2030. I would like to see that in Europe. These sorts of technology [policy] signals or supportive signals are very important to reassure consumers that this is something important and practical.'

Specific regulatory barriers mentioned included the topic of interoperability for bidirectional charging, and the design of power markets.

> 'There are issues with auto manufacturers introducing bespoke chargers, we want the chargers to be interoperable between EVs. There are some restrictions about how domestic assets can participate in flexibility markets. The metering rules [for injecting electricity into the grid] are defined mainly around larger power stations.'

Taxes and other fees for the transmission and distribution grid are another regulatory issue raised by several interviewees.

> 'From the user perspective, if you are a fleet operator or a consumer you only want to pay [for transmission and distribution] once. From a system perspective, you need the costs to be recovered for the distribution grid, and it's not an easy one to solve. We need a solution that fits both sides. I would rate this barrier pretty high, but it may be because I work in this area.'

Summary: In this small set of interviews, international experts expressed a variety of opinions about the potential of bidirectional charging. While most were optimistic that bidirectional charging could play a role, the barriers to bidirectional charging remain daunting, even after new car models come to the market. The widespread absence of dynamic pricing signals, cost of charging equipment, and country-specific regulatory barriers appear to be major risks, though there was some disagreement on these points. The experts were relatively optimistic about consumer interest in bidirectional charging, especially in rural areas where distributed solar is common.

2.4. Chinese EV expert views of bidirectional charging and rural EV usage

The eight Chinese EV industry experts interviewed for this study can be grouped into categories as follows: one academic respondent, four respondents from the EV industry, two respondents from grid companies or grid research institutes, and one respondent from the energy consulting field. Interviewees were asked about rural vehicle preferences, driving and charging patterns, use cases for smart charging and bidirectional charging, and barriers to adoption of bidirectional charging.

In contrast to Europe and North America, interviewees in China perceived major differences in EV ownership and driving patterns between urban and rural residents. As in Europe, rural areas in China were perceived as having significant ability and incentive to switch to EVs, due to wider availability of charging at home. As noted in the background section, rural Chinese vehicle preferences differ substantially from urban areas. Interviewees expressed the view that relatively low incomes, narrow rural roads, but good private charging conditions are the main factors which determine that the purchase preference in China's rural areas is for low-cost, short-range electric vehicles. Whilst migrant workers and farmers who work close to their home tend to prefer two-wheeled electric vehicles, farmer vendors of agricultural products tend to prefer three- or four-wheeled vehicles. All these groups are quite different from urban areas in terms of vehicle ownership and usage.

That said, interviewees noted that there is substantial regional variety with regard to EV purchase preferences in China's rural areas. Rural areas in more developed regions such as the Yangtze River Delta and Pearl River Delta are similar to urban areas in terms of EV adoption and EV purchase preferences.

In terms of driving patterns, Chinese EV expert interviewees believe in rural areas EVs may be used in less regular time periods than those in urban areas, because rural residents need to carry out a variety of agricultural activities, such as field farming or transportation of agricultural products. This is in contrast to cities, where EVs are mainly used for commuting to and from work or other daily travel needs, or for social and recreational activities on weekends.

> 'The median operating distance of rural private electric cars is around 20 km on weekdays and about 30 km on weekends. Urban electric vehicle owners have a wide range of activities, and their normal daily operating distance is higher than that of rural car owners on weekdays or weekends ... Large electric vehicles have longer battery life and more battery capacity. Generally speaking, the daily operating distance of large electric vehicles is longer, more than 100 km.'

Because most rural residents do not have a regular daily commute, their usage patterns are less predictable and, for some, more seasonal:

> 'The scope of use of electric vehicles in rural areas is relatively limited, rural electric vehicles are not utilised throughout the day. Two-wheeled vehicles are used more frequently to meet the daily activity needs, while three-wheeled and four-wheeled vehicles are used more frequently before and after a large number of seasonal agricultural products are put on the market and during national holidays. In addition, rural users typically seek to time their trips to avoid periods of high traffic or travelling long distances in hot or cold weather.'

In terms of frequency, the use of electric vehicles in rural areas may be somewhat low due to the relatively low demand for daily commuting, while urban owners usually use electric vehicles more frequently. To sum up, in overall, rural driving patterns are more spread out in terms of time of day and purpose. Whilst urban owners use electric vehicles mainly for daily commuting in the morning and early evening, rural owners use electric vehicles for a variety of purposes with a variety of driving frequency and times.

Urban EV owners' daily commuting mileage is also longer than that of rural EV owners on both weekdays and weekends. For rural EV owners, there is a significant difference in usage between small and large EVs: The driving range of large EVs is longer, and hence the typical trip mileage tends to be longer, reflecting owners with longer trip patterns purchasing such vehicles or using them for longer trip in the case of households with multiple vehicles, such as a single three-wheeled or four-wheeled vehicle for long trips and one or two smaller vehicles for daily use. Small EVs are mainly used for daily travel in rural areas, while large EVs are mainly used for transporting agricultural products.

Charging patterns: Reflecting the difference in vehicle types and usage patterns, interviewees in China were asked about rural EV owners' willingness to engage in four broad categories of EV charging:

Conventional charging refers to charging using portable charging equipment in the car. Power sources come from household power supply or special charging pile power supply, typically taking several hours or more to recharge the battery. In rural areas, conventional charging may be more common because charging facilities are underdeveloped and people usually charge at home.

Uncoordinated charging refers to charging whenever there is a need, regardless of the power grid load. Users can plug and unplug the charger at any time without special coordination. Uncoordinated charging may be more common in rural areas because the load on the grid is usually low and no special coordination of charging time is required.

Coordinated or smart charging involves the use of intelligent charging devices to charge when power demand is low, thereby reducing the load on the grid. This usually requires an intelligent charge management system and communication technology to coordinate the charging time. In rural areas, coordinated charging can also be achieved if there is an intelligent charging infrastructure.

In *bidirectional charging, including V2G,* electric vehicles can interact with the power grid and charge according to the needs of the power grid. This includes starting or stopping charging automatically through grid operation to ensure that the grid is not overloaded during times of peak power demand, or to optimise the dispatch of system assets such as transmission and generation. V2G usually requires advanced infrastructure and technology, which is uncommon in rural areas compared to urban areas.

However, because rural incomes are lower and households are more sensitive to electricity prices, EV users in rural areas are more likely than those in urban areas to choose to coordinate charging in order to save or make money, as long as their electric vehicles can still meet their needs. For this reason, interviewees expressed the view that bidirectional charging in rural areas has good long-term prospects, though it is not widespread at present.

Indeed, interviewees reflected the view that given the underdeveloped technical and infrastructure for smart charging or bidirectional charging, and the lack of orderly charging pricing systems in China, currently there is no significant difference between the profiles of these four charging types in urban versus rural China.

Interviewees expressed some disagreement regarding rural charging profiles in other respects, however. The majority expressed uncertainty about the choice of full-charge daily and weekly charging, stating that it mostly depends on factors such whether or not there is a daily commute, the agricultural season, the use case, and the battery capacity and driving range. Hence, for these interviewees, there would be some types of vehicles that would not necessarily be charged daily in rural areas, such as larger vehicles with more sporadic use – given that smaller vehicles tend to be used more in daily driving. However, a few respondents think daily charging is more common in rural areas as rural owners have convenient private charging facilities, and rural residents have greater concerns about the availability of public charging or running out of charge.

Interest in smart charging or bidirectional charging: The majority of Chinese interviewees estimate that more than half of rural EV owners have an interest in or the potential to participate in smart charging if offered. Three interviewees said their views were based on certain conditions: the availability of reliable equipment and infrastructure, existence of clear and supportive policy, ease of use, and whether there are economic incentives.

> ‘If we can provide comprehensive technical and infrastructure support, I estimate that more than 50% of rural electric vehicles will be willing to participate in smart charging, because their charging starting time distribution is more discrete and flexible. Compared with the 9-to-5 daily routine of urban electric car owners, the proportion of rural electric vehicle owners participating in smart charging should be significantly higher than that in urban areas – especially if subsidies or benefits are sufficient to allow participants to save money and earn money [such as through bidirectional charging].’

Others were less optimistic about bidirectional charging – often due to complexity and highly-variable daily usage requirements:

> ‘Under normal conditions, I estimate that 30% of rural electric car owners would be willing to participate in interactions given a simple adjustment of the peak-valley power consumption strategy allowing them to save electricity immediately, while for complex strategies

> [like bidirectional charging based on dynamic prices], rural electric car owners' driving patterns are constrained by several factors and vary considerably from day-to-day, and I estimate that less than 10% of users would be willing to participate.'

In addition, most interviewees believe that, if the above conditions are met and the price for smart charging or bidirectional is appropriate, or if there are subsidies or other market-based or income-based incentives for peak regulation, the uptake of smart charging or bidirectional charging will be greater in rural areas than that in cities. This relates to the availability of private charging facilities in rural areas, and greater sensitivity to economic incentives.

> 'I'd guess 70% to 80% of rural users would like to participate in smart charging if there were perfect intelligent charging conditions. For those with private charging, the proportion of participation should be larger than in cities. Although participating in V2G entails more investment costs, the two-way charge and discharge can provide flexible regulation resources for the power system, which has higher benefits than intelligent charging. For rural EV owners with private charging … if the grid companies or the government bear the investment cost, a higher proportion of EV owners – presumably 80% to 90% – would participate in the interaction.'

Reflecting the concerns expressed by international experts, one Chinese interviewee raised the topic of manufacturer warrantees for smart charging and bidirectional charging as an important consideration and potential barrier to bidirectional charging currently.

> 'With respect to V2G, it is expected that the proportion of rural private EV owners with interest or potential would be very high if the manufacturer provides a quality warranty for the battery and is clear on-grid price [for discharging into the grid at certain times]. The reasons for this are that the use intensity in rural areas is relatively low and rural users are more sensitive to short-term benefits. Given that it is difficult to provide after-sales maintenance services in rural areas, the quality warranty by the manufacturer is crucial.'

While most interviewees took an optimistic view of bidirectional charging for rural compared to urban EV users, one interviewee disagreed, estimating that due to lower awareness and lower availability of information, smart charging in rural areas is less likely than in cities.

Another interviewee, who expressed optimism about potential rural participation in smart charging and bidirectional charging, pointed out that participation may vary by season, with limited uptake during the busiest agricultural seasons.

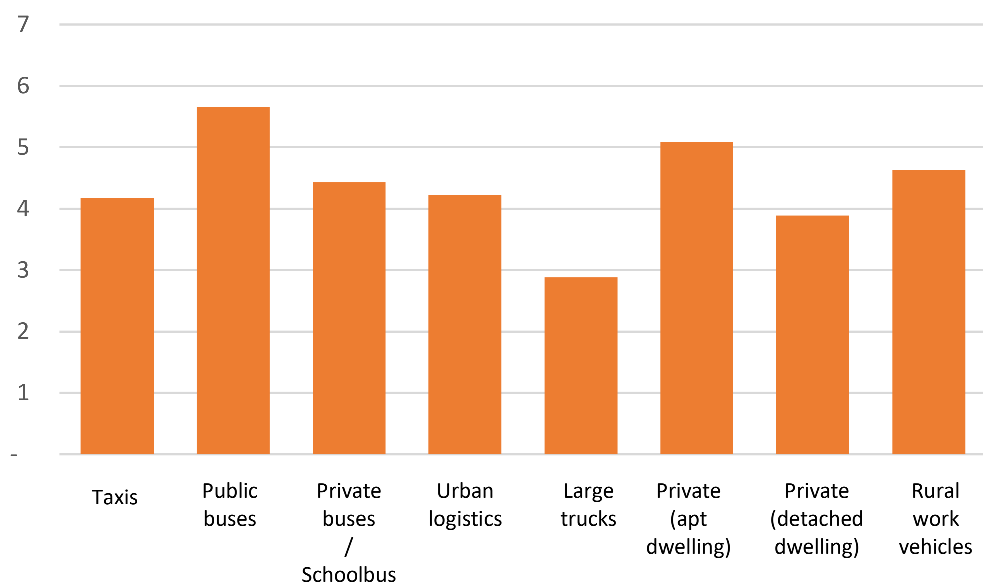
> 'People in rural areas have limited incomes and pay more attention to saving money in charging. To meet their work-related driving needs in the busy season, they have to charge when the electricity price is high, while in idle season, as long as their production work is not affected and the environment is favourable, they will certainly choose to participate in coordinated charging and V2G … I estimate

that over 90% of rural EV owners would have interest in or potential to participate in V2G or V2H, provided they can make money doing so.'

If smart charging or bidirectional charging varies on a seasonal basis, there is a possibility that its benefits in terms of reducing investment cost in distribution grid or storage resources would be significantly lower than if it could be relied upon year-round.

Use cases for bidirectional charging / V2G in China: As in the international survey, Chinese respondents offered a wide variety of opinions and estimates about which use cases appear most attractive for bidirectional charging. Perhaps surprisingly, given the lower development of wholesale power markets and absence of experience with dynamic pricing, Chinese respondents rated bidirectional charging somewhat more highly on average than international respondents, though the small number of responses and limited selection of experts likely render this distinction not meaningful. More significant is the diversity of opinions about which sector or use case would find bidirectional charging most attractive.

Figure 9: Chinese respondents' evaluation of potential for different use cases to participate in bidirectional charging, average



Source: OIES, 2023.

Overall, Chinese respondents rated public buses as most likely to participate in bidirectional charging due to their higher battery capacity and large numbers. As one respondent commented: 'Buses usually have a large charging demand and are widely operated in cities, so they have a high potential to participate in intelligent charging and V2G interaction.'

Similarly, Chinese respondents gave a higher rating than international respondents to the ability of taxis to participate in bidirectional charging. Though taxis have high utilisation during the daytime, arguably bidirectional charging overnight could be relevant in some regions with high wind capacity.

> 'The taxi fleet usually has a greater charging demand, and the charging time can be effectively optimised through the intelligent charging management system to ensure that the vehicle is available at any time. This makes them more likely to participate in smart charging and car network interaction.'

Similarly, the number and diversity of urban logistics EVs in Chinese cities is far greater than in Europe or North America, with many large vehicles restricted from delivering in some neighbourhoods during the daytime. Large and sophisticated fleet owners may also have greater incentives to engage in bidirectional charging.

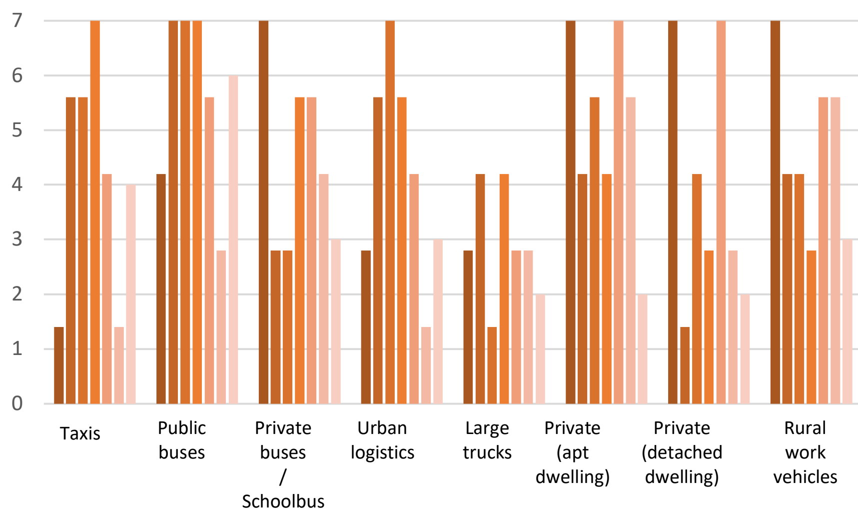
> 'Urban logistics vehicles usually need to be charged frequently, and the efficiency can be improved through intelligent charging management systems, so they have the potential to participate in intelligent charging and vehicle network interaction.'

As in Europe and North America, large trucks were rated as least likely to participate in bidirectional charging, due to high utilisation and limited opportunities to get a full charge.

Among private vehicle owners, apartment dwellers were rated as somewhat more likely to participate than those in private dwellings, which somewhat contradicts the interview comments. Rural work vehicles were rated somewhere in the middle.

Again, there was a high degree of variation in the ratings or estimates given by the interviewees on all these points.

Figure 10: Chinese respondents' evaluation of potential for different use cases to participate in bidirectional charging, individual responses



Source: OIES, 2023.

The greatest variation in responses was seen in respect of taxis, urban logistics vehicles, and personal vehicles – all of which were rated by some as having high potential to engage in bidirectional charging, while others rated it very low. The highest agreement was on large trucks, which were unlikely to have strong potential to participate, and on public buses, which were generally seen as attractive for participation in bidirectional charging and smart charging.

Barriers: In terms of barriers to smart charging and bidirectional charging, because rural incomes are lower and rural EV owners are more sensitive to price, this restricts their interest in vehicles with larger batteries or more costly charging equipment. As mentioned above, lower average use frequency of rural EVs tends to lead to purchase of smaller batteries and implies lower fuel cost savings for those adopting EVs.

There is usually a lack of charging facilities for electric vehicles in rural areas, which does limit adoption of EVs to those with private charging access. Even when public charging stations are built, their locations may be inconvenient for rural EV owners. Installing private charging facilities poses a greater financial burden for rural electric vehicle owners. Poor roads can also lead to higher maintenance costs, also contributing to a preference for cheaper vehicles in rural areas. Inadequate local repair and maintenance services for EVs in rural areas can also contribute to a desire for smaller but more reliable vehicles.

Others barriers mentioned by interviewees include grid capacity constraints for EV charging generally (though bidirectional charging or smart charging could ameliorate such constraints), a lack of business models for smart charging or bidirectional charging given China's current power market structure, and lower awareness and knowledge of smart charging in rural areas.

> 'Currently, there is neither a mature nor widely adopted orderly charging price incentive in China, and it is mainly the electricity

> price that affects charging, including for both public and residential charging. As the electricity price of urban and rural power grid is basically the same, I don't think there is any significant difference in the charging profiles between urban and rural areas.'

As mentioned above, the availability of private charging can also help reduce barriers to both EV adoption and smart charging in rural areas compared to urban areas.

Certain regions have introduced ancillary services markets that may already begin to offer some incentive:

> 'The proportion of rural charging at the valley price under the peak-valley (time-of-use) electricity price is presumably higher in rural areas, since most households have both private parking and individual electric meters … If there are additional peak-shaving market incentives such as ancillary services markets in North China, rural EV owners are likely more willing to participate, since they are more sensitive to economic incentives.'

The same interviewee also mentioned that many low-cost EV models used in rural areas lack the technology to participate in time-of-use pricing:

> 'The limitation may be that many low-speed EVs or mini-electric models in rural areas cannot program pre-set charging times. For example, the old Wuling Hongguang model does not have this function. Newer models can support mobile phones to set charging times.'

Interviewees mentioned that provinces with the highest incomes and most well-developed charging infrastructure (public and private) are most likely to adopt smart charging or bidirectional charging in ways that would help integrate renewable energy or reduce grid capacity constraints. Rural areas of Beijing and Shanghai municipalities, as well as rural areas in Guangdong, Zhejiang and Jiangsu would fit this profile.

> 'Low-speed electric vehicles account for a relatively high proportion in Shandong, Henan, Hebei and other areas, and similarly electric minicars have a larger market there. But the Yangtze River Delta and Pearl River Delta regions will be more similar to the urban EV ownership situation.'

For residents in these regions, the key issue lies in current driving needs – which tend to encourage EV owners to minimise cost and battery size – as opposed to the economics of smart charging or bidirectional charging. If adopting a larger vehicle or a larger battery becomes more economical because of the availability of V2G, this would reduce the obstacles facing rural buyers of electric vehicles. Obtaining a lower charging price by charging from distributed solar PV could also encourage greater EV uptake in general. Hence, the present structure of rural EV ownership or driving and charging patterns should not be taken as a given, but rather as a potentially dynamic situation that could evolve as distributed energy and economic incentives for smart charging or bidirectional charging become more widespread.

> 'But because the driving patterns are so varied and heterogeneous, it is a question as to what the future will be, and whether it will be the same as in the past. Because the driving habits and needs of different groups (female or male, working versus non-working, young versus elderly) may be different, analysis based on generalisation and reasoning from the present is often problematic.'

Distribution grid limitations: Interviewees generally agree that inadequacy of charging infrastructure in rural areas is a major problem – notwithstanding greater availability of private charging – and that insufficient distribution grid capacity in many regions is one of the main obstacles or even the largest obstacle to improving charging infrastructure. That said, interviewees expressed optimism about the trend in this regard, noting that in three to five years local distribution grid issues and charging infrastructure access will improve significantly, and that orderly charging and off-peak charging can resolve many of the present issues.

However, most Chinese interviewees expressed the opinion that, to date, the poor charging conditions in rural areas such as aging and maintenance of power lines, limited charging infrastructure, slow charging speeds at those chargers that exist, the high cost of building charging facilities, and in particular unstable power supply caused by insufficient distribution grids have significantly slowed the adoption of electric vehicles in rural areas. On the flip side, the slower adoption of EVs in rural areas and the smaller size of rural EVs has substantially mitigated the importance of the distribution grid's limited capacity.

Economic barriers: In general, interviewees were split concerning the economic barriers that rural EV owners would face to adopting smart charging or bidirectional charging. Low electricity prices were one issue noted by several interviewees, though many interviewees did not consider low electricity prices as a major barrier considering the greater overall price sensitivity of rural residents. More interviewees mentioned that since the low mileage of rural electric vehicles can be satisfied by slow charging, smart charging that requires additional equipment cost may never become economically attractive.

Underdeveloped digital infrastructure in rural areas such as lack of high-speed Internet connections and the communication requirements of smart charging devices would negatively influence the remote monitoring and management of smart charging systems. Smart charging may require cloud communication to monitor the charging status and grid loads in real time. This might make it more difficult to deploy and manage intelligent charging facilities in rural areas.

To sum up, all interviewees think low electricity prices could reduce the enthusiasm of rural car owners for intelligent charging systems, but they do not present a substantial obstacle to smart charging in rural areas. As rural owners are price sensitive, they are very likely to participate in smart charging or bidirectional charging even if the revenue from participation is not very high. However, the upfront equipment cost could be a major barrier. Underdeveloped digital infrastructure such as high-speed Internet connections and the communication capabilities of smart charging devices in some rural areas would negatively influence the remote monitoring and management of smart charging systems, and as a result would impact EV adoption in rural areas.

2.5. Chinese views on international cooperation regarding integrating EV charging and renewable integration

To understand the future potential of EU-China cooperation on the topics of EV charging, and especially bidirectional charging, as a strategy for both decarbonising transport and improving integration of low-carbon renewable energy, this study also includes a series of interviews with a small number of experts currently engaged in EU-China cooperation activities, though not necessarily with the EU-China Energy Cooperation Platform. In China, there were only four respondents, all at leading government or state-owned institutions. The experts in each region were asked to evaluate the most promising areas of cooperation in light of both their theoretical potential and the need to consider various sensitive topics, such as commercial competition and the different policy environments in each region.

For example, China leads the world in manufacturing and deployment of EVs, PV, and batteries. In all of these fields, Europe is both a customer of Chinese manufacturing sectors and an industrial and commercial player in its own right. Europe has many years of experience with power market reform and renewable integration. China is currently in the midst of an ongoing power market reform, with spot markets active in many provinces and a national market design under development. Regarding EV charging and the potential for bidirectional charging, both Europe and China are focused primarily on the build-out of infrastructure to enable EV adoption, with issues such as using EVs to better integrate renewable energy still under consideration or at the pilot stage.

In this survey, we contacted Chinese experts in the electric power sector and electric power market policy space to ask in general about their views of cooperation in the fields of EV charging, power market reform, and the intersection of the two. In general, the Chinese experts contacted had various suggestions for the top areas of potential cooperation, and held extremely positive views about its potential – possibly reflecting their existing involvement in such cooperation activities.

Chinese respondents were generally most optimistic about continuing cooperation and exchange on power market reform. One Chinese expert noted that reform efforts in China have proceeded slowly due to the need to cross-subsidise various customer classes, but that China continues to pursue power market reform and study the progress of European power markets. Another expert commented on the various advantages of European power markets from which China should draw lessons:

> 'With regard to renewable energy integration, the EU has rich experience in building cross-border electricity markets, which are the most economical way to ensure renewable energy consumption, as well as developing various time scales of electricity market trading systems, and electricity market balancing mechanisms and software, all of which can provide references for China.'

Another Chinese expert with grid expertise suggested Europe should benefit from China's ultra-high voltage (UHV) power line experience:

> 'China has a lot of experience in power grid management and UHV technology, which may be utilised in the EU for importing power

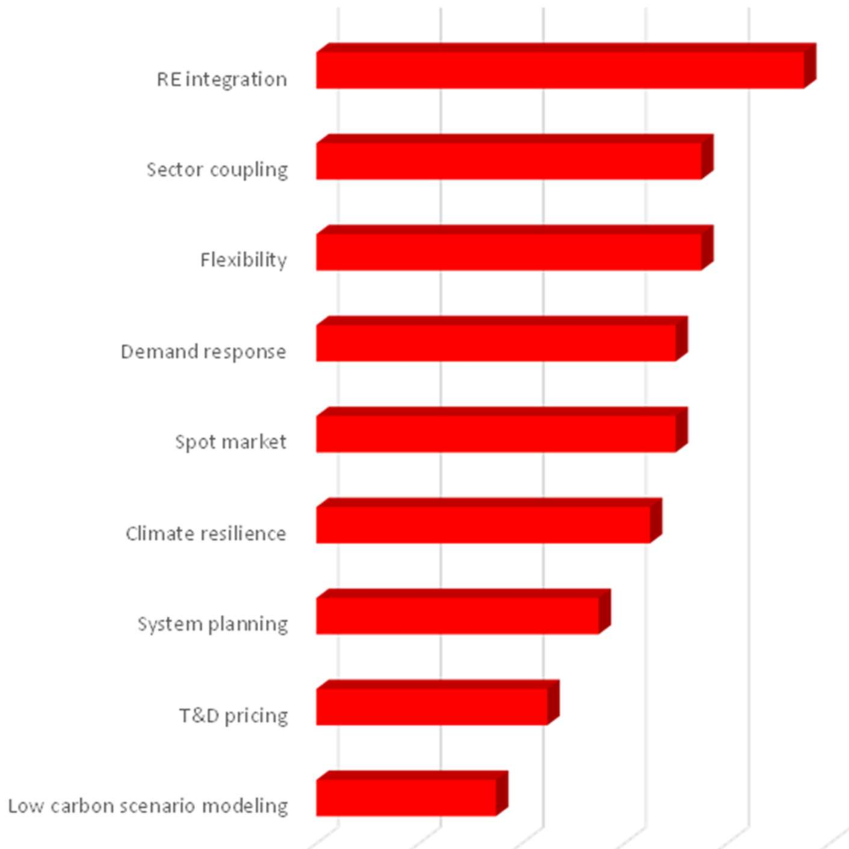
> from North Africa and the Middle East via large-scale transmission. On renewable energy, whilst China has advantages in solar PV and wind power supply chains, the EU has advantages in advanced wind and solar technology. Both sides can give full play to their advantages, for instance, in the manufacturing of super-large wind turbines for offshore wind power.'

Energy storage technology and business models were also suggested by a Chinese respondent:

> 'Wind and solar PV module manufacturing in China has reduced the cost of renewable energy in Europe and the world … China and the EU can engage in dialogue and cooperation, as well as two-way investment, with both sides benefiting from integrating the renewable energy supply chain. In addition, both China and the EU are carrying out electricity market reforms, in which energy storage is a key link. China and the EU can cooperate in energy storage: the European side can carry out technological innovation in China, and Europe also provides references for China with regard to compensation mechanism and business models.'

All respondents were positive on further cooperation on power market reforms. However, within that broad field, the experts had different topics they would prioritise:

Figure 11: Chinese expert ratings on power market-related topics for international cooperation



Source: OIES, 2023.

Notably, renewable energy integration and sector coupling (linking renewable energy to heating, transportation, and industrial energy use) received the most support, along with flexibility, where Europe is also seen as a leader. While one expert gave a high rating to transmission and distribution (T&D) pricing, most did not give a high rating to this area, cooperation on system planning and modelling, or modelling of low-carbon energy scenarios.

Regarding the current hot topic of competition between the EU and China in the field of EVs and EV charging, the experts had various opinions, but generally saw ample room for continued cooperation. In some cases, interviewees mentioned commercial cooperation and the benefits of trade. In other cases, policy cooperation was highlighted.

> 'In terms of industrial value chains, the renewables and new energy vehicle industries in China and Europe are quite complementary. This is the basis for win-win cooperation between the two sides. For example, in electric vehicles manufacturing, China has advantages in batteries and overall vehicle production capacity, while Europe has advantages in jumbo chips and popular, high-end brands.'

Another expert noted the potential for mergers and acquisitions that have already brought the regions into closer commercial integration even as rivalry and competition remain central to domestic policy discussion in both regions:

> 'China has obvious strengths in EV onboard IT systems. China's industrial policy, leveraging its enormous domestic market, has brought down the cost of renewables and laid a foundation for electric vehicle deployment. There is a virtuous cycle between the development of renewable manufacturing and EVs. The EU's strengths lie in its long automobile industry experience, well-known brands and design, as well as global services network. EU manufacturers can acquire shares in Chinese electric vehicle manufacturers via mergers and acquisitions, building joint brands. An example is the cooperation between China's BYD and Germany's Mercedes-Benz.'

Another expert agreed about the complementary nature of supply chains for EVs, and mentioned the need for more cooperation on the topic of medium and heavy-duty trucks, both in the commercial and policy fields.

> 'Although there is commercial competition in the field of electric vehicles, China and Europe have complementary advantages in some areas that can promote the healthy development of the industrial supply chain through healthy competition. For example, technological innovation and applications for medium- and heavy-duty trucks relative to passenger cars in different scenarios, and the mutual reference of industrial policies.'

As to the integration of EV charging with renewables, most of the experts did view this as a promising field, particularly if bidirectional charging or V2G becomes more widely commercialised – however uncertain that may be.

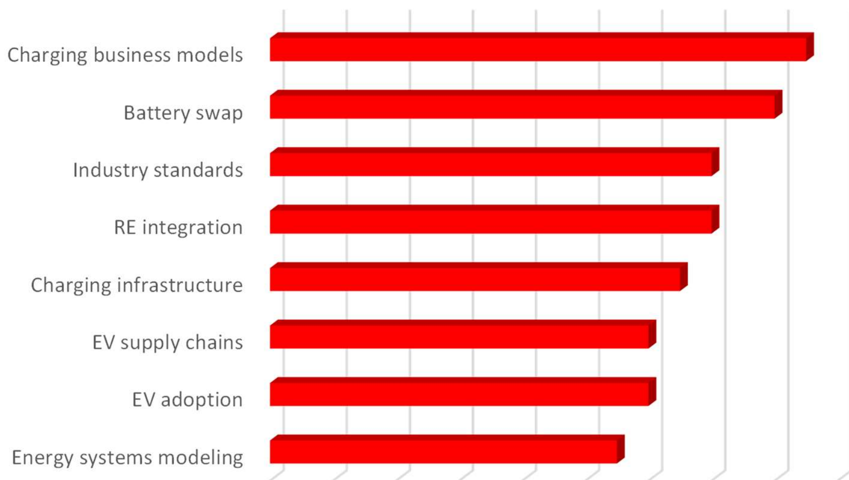
> 'The key issue for V2G is how all stakeholders can benefit from it. Car owners are concerned about its impact on their driving convenience and battery life. Power grid utilities are concerned about the controllability of electric vehicles in the power system, particularly individual electric vehicles. An exchange of ideas between EU and China on business models and market access criteria with regard to V2G would be helpful.'

The Chinese experts noted that V2G moving out of the pilot stage in China will depend on the progress and speed of changes in the power markets themselves:

> 'The integration of electric vehicles and renewable energy can focus on how electric vehicles make better use of renewable energy (such as distributed solar PV) and how to use the market mechanism to realise V2G. At present, China's V2G is still in its pilot stage. The fundamental reason is that China's power market is not well developed. Although the electricity markets in China and Europe have different national conditions and different characteristics, both sides can learn from each other with regard to power market mechanisms.'

In terms of specific priorities for cooperation, the Chinese experts rated most areas fairly highly, but gave top priority to exchange and sharing on business models for EV charging. The lack of adequate business models to drive investment in charging infrastructure is perceived as a major policy dilemma in China, notwithstanding the rapid build-out of chargers in recent years. Notably, battery swapping was also rated highly; this is a field where China has several major players, including NIO, which has invested in battery swap stations across Europe, whereas Europe has relatively little experience. Industry standards and renewable integration also rated highly.

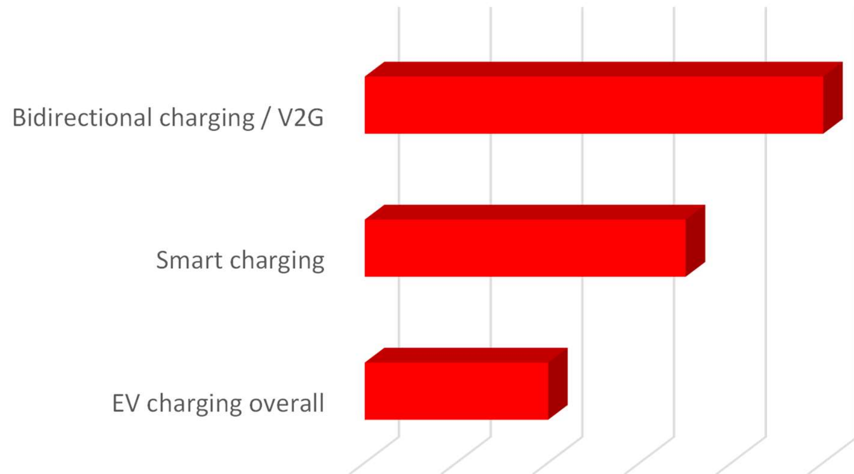
Figure 12: Chinese expert ratings on the potential for cooperation on EV-related topics



Source: OIES, 2023.

The experts were also asked to evaluate how important overall they felt EV charging, smart charging, and bidirectional charging to be for China's electricity sector. Perhaps surprisingly, they ranked bidirectional charging as very important, whereas EV charging in general they felt to be less important. This suggests overall optimism among these policy experts about the topic.

Figure 13: Chinese expert ratings on the potential importance of different EV charging types on renewable integration



Source: OIES, 2023.

Regarding cooperation on the energy transition in rural areas, the Chinese experts had various ideas and suggestions. These included integration of distributed PV (mentioned by almost all respondents), building energy efficiency, clean heating, low-carbon energy business models, and EV charging.

Several experts mentioned building energy efficiency. The following comment was typical:

> 'The efficiency of buildings in China's rural areas is low, and many buildings are built by rural residents themselves. Exchange of information and technologies on improving rural building efficiency is an appealing topic for international cooperation.'

One expert mentioned the need for experience-sharing in emerging fields related to rural energy transition, in particular the synergies between home EV charging, home energy storage, and vehicle-to-home in China's rural regions, as well as the potential for PEDF (photovoltaic energy direct current flexibility) to contribute to renewable integration in rural areas.

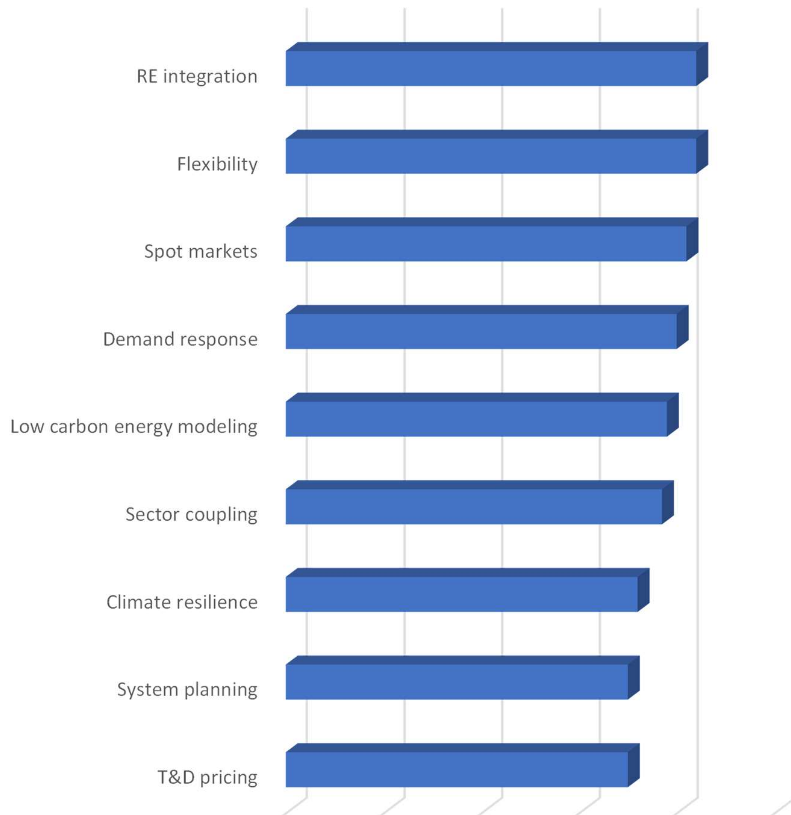
Summary of Chinese policy expert interviews: Overall, Chinese energy policy experts remained largely positive about the potential for continued policy and market cooperation between the EU and China, despite ongoing trade and commercial rivalries. The EU's advanced power market and ongoing decarbonisation efforts remain a model for China, and while China has the lead in EV and PV manufacturing and deployment, the integration of these technologies for greater decarbonisation remains valuable for an exchange of expertise at the policy level.

2.6. International policy expert views on EU-China cooperation on bidirectional charging for renewable integration

For the survey of international policy experts, nine individuals participated in a short interview or responded in writing. Most respondents were analysts at NGOs or consulting companies actively involved in the EU-China energy cooperation field. Two respondents are employed at government policy entities, and one at an industry association involved in policy dialogue on power sector and EVs. Most are focused on power sector topics, with only two focused mainly on the EV sector or sustainable transportation. All but one respondents work at European companies or government entities. Four were from Germany, two from Denmark, with the remainder from the UK, the Netherlands, and the US.

Given that most of the experts contacted for this survey are active in power sector cooperation, it is perhaps not surprising that their views on continued cooperation on this topic were positive overall. European experts gave the highest ratings to the topics of flexibility, spot markets and renewable integration, where Europe is perceived as a historic leader. Low-carbon energy system modelling, sector coupling (integration of variable renewable energy in transport, heating and industry) and demand response were also rated highly. Climate resilience of the electricity system and system planning were ranked progressively lower, with transmission and distribution (T&D) pricing receiving the lowest rating among those surveyed.

Figure 14: International policy expert ratings on power market-related topics for international cooperation



Source: OIES, 2023.

In terms of qualitative responses, several respondents mentioned the importance of continuing to exchange on power market design as an enabling factor for the low-carbon transition:

> 'If the EU and China really want to reach their 2050, 2060 net zero emission targets, there is not much time to develop the clean energy / EV technologies and non-technical expertise needed. It will take much longer if every country develops their own solutions. Exchange and cooperation between the EU and China is therefore crucial to reach the decarbonisation targets. I think the EU can share their experience with electricity markets, the integration of a high share of renewable energy, and flexibility solutions, while China is very advanced in battery technology and EVs.'

Europe's leadership in integrating large percentages of wind and solar was cited by several experts as a topic which China should draw upon in its own power market design efforts:

> 'A key challenge remains how to integrate renewable distributed energy resources and ensure system adequacy. In discussion with Chinese grid experts, they mentioned several times that they are very concerned about the strong growth of distributed energy and how to handle adjustable loads versus non-adjustable loads. I think this is a topic where both EU and China have collected some experience and some cooperation has happened, but more exchange on best practices could be useful. A big topic here is also the role of market mechanisms and prices, and how markets function together.'

However, one international expert at an NGO with long experience in exchange on power markets noted that the differences in market design and contentious internal issues at stake might make exchange on power market design challenging:

> 'While there is a need to deepen [power market] reform, the issues that need to be addressed such as pricing are very thorny, so I am not sure if there is much appetite for exchange. It may be easier to engage in areas that are more technical such as flexibility or issues of increasing importance such as climate resilience.'

Several experts mentioned flexibility as a major priority for ongoing cooperation, given Europe's relatively long experience improving system flexibility in terms of both generation and transmission, as well as ongoing efforts to improve the flexibility of the demand side.

> 'Flexibility is key in the integration of renewable energy into the power system. Its activation can take many forms. in Germany, the activation of stationary batteries and demand-side management has begun with distribution network operators contracting home batteries from consumers. More regulatory change to spur the development is on its way. With more and more variable renewable energy going online, China could well benefit from German experiences. Policy makers also discuss harnessing flexibility of EVs in Germany, but this clearly entails many challenges. One of them is upgrading grids, and here China could provide useful insights to Germany, given its much faster EV growth. Moreover, both countries could engage in a discussion of the other challenges, exchanging research results and insights from regulation.'

While most of the experts contacted for this aspect of the study were not experts in EV-related topics, several felt that EVs remain an important topic for ongoing exchange related to the low-carbon transition in the power sector:

> 'I think that China can learn from the European efforts to connect what's happening on the wholesale power market with retail activities such as EV charging (and V2G). I think that the power market reform in China, particularly as relates to spot markets and short-term pricing, is pretty much understood at an expert level, but there is a long way between that and the practitioners who will build the services and business models for managing charging.
> Conversely, I believe that European players can benefit from the rapid business innovation of the Chinese tech companies who are

> getting into this space. I think that both the EU and China can benefit from developing solutions that are not miles apart, to ensure that [EV and EV charging] products and services rely on similar standards and communications protocols.'

A number of respondents mentioned that EV charging could play a larger role in decarbonising the power sector as a whole, not just in better coordination with the needs of the grid or renewables:

> 'One topic that I currently find very interesting is the role smart charging and particularly V2G can play in displacing the need to keep coal power plants online to ensure power supply adequacy as the bulk of power generation becomes wind and solar. We are doing an exercise with 20 years of weather data to see how much wind and solar in different net-zero generation capacity portfolios enable supply adequacy.'

Another expert agreed, pointing out that China's rapid EV adoption could offer significant insights for Europe and other regions that have yet to deal with large increases in power demand associated with EV adoption:

> 'The EU and China have much to share and learn from each other on EV and RE integration and power market reform … China is the biggest global EV market, and thereby can offer insights into technical and policy challenges that European countries are yet to face, such as responses to the rapid increase in charging demand, smart charging systems, V2G and storage technology options for flexibility. Exchanges focusing on technical areas such as these, with a view to achieving broader decarbonisation goals, could allow for continued interactions and mutual learning, despite growing commercial competition.

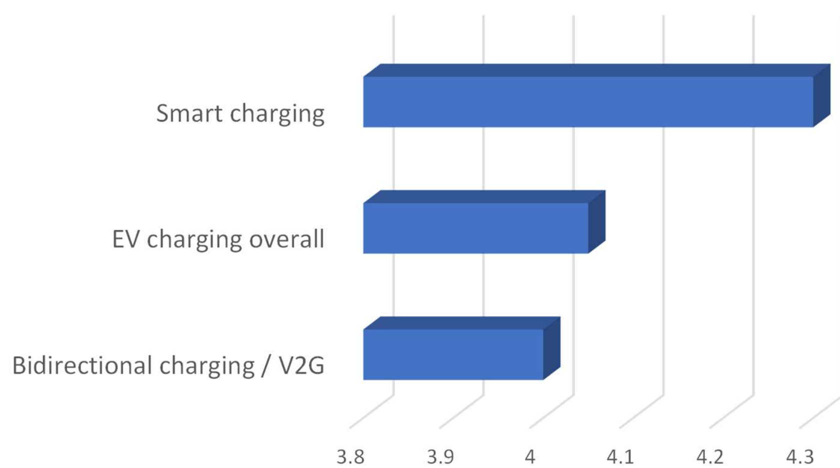
Importantly, the European experts believe that efficient power markets – particularly spot markets – are a necessary enabling factor to allowing EV charging or bidirectional charging to play a role in decarbonising the grid. Notably, this does not imply that Europe's power market reforms are already at this stage:

> 'I see clear benefits both for the EU and China in continuing the cooperation and exchange on experience and ideas and also joint research on these issues regarding the role of EV integration and renewable integration. For me, the main enabler for dynamic EV charging is dynamic electricity pricing, and this requires greater transparency in the wholesale power market … I think you've identified a serious issue of using EVs to solve the problem of distribution investment costs. In Denmark we have semi-dynamic pricing that helps, but it is based on a fixed hour duration which does not necessarily reflect use of grid, but we decided not to make it more complicated. Basically we should do as you do with the spot market, but that is not the case at the moment.'

In comparison with the Chinese policy experts, the international experts made fewer mentions of commercial and industrial cooperation and placed more emphasis on policy and technical market design cooperation. However, a couple of international experts made passing references to the need for the two markets to continue to remain connected, to reduce the cost of the clean energy transition and accelerate progress towards climate goals:

> ‘China can gain a deeper understanding of the EU's power and spot markets from the exchanges and optimise its own market design. The EU can … attract Chinese enterprises to invest and produce in Europe, which will reduce its dependence on imports from China, while expanding employment and strengthening local automobile and renewable energy production capacity. European enterprises could also benefit from the upscaling in Chinese market and get early market feedback and refinancing for the R&D for technology iteration.’

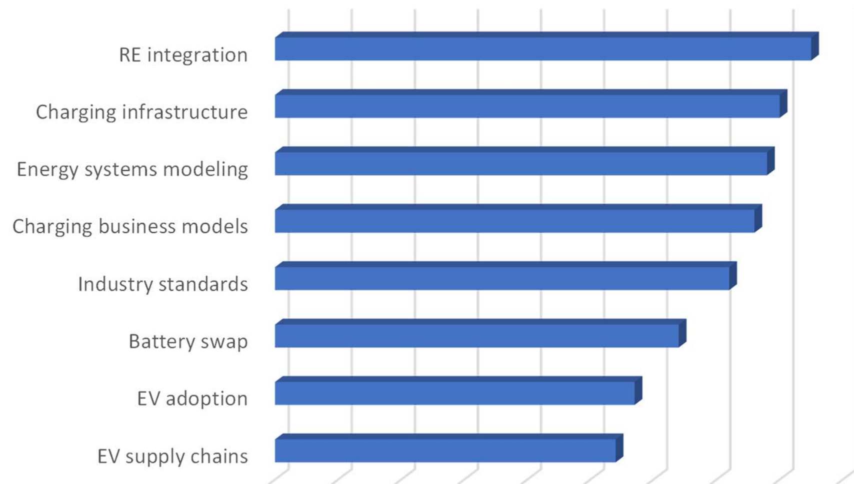
Figure 15: International policy expert ratings on the potential importance of different EV charging types on renewable integration



Source: OIES, 2023.

In general, international experts took similarly optimistic overall views of the impact of smart charging and bidirectional charging on the electricity sector. However, in contrast to the Chinese interviews, European respondents generally rated smart charging as more likely to affect the electricity sector than bidirectional charging – possibly reflecting greater optimism regarding the role of smart charging in Europe given present market designs as opposed to less optimism regarding bidirectional V2G specifically. International experts were not asked to give a separate evaluation of the barriers to bidirectional charging, but as we have seen, these are likely to be significant. The lower rating on bidirectional charging’s impact may reflect this.

Figure 16: International policy expert ratings on the potential for cooperation on EV-related topics



Source: OIES, 2023.

As for the need for EU-China cooperation on specific topics related to EVs, international experts were similarly positive with regard to cooperation on power sector topics. Notably, renewable integration was rated most highly by this group. Relatively speaking, international experts placed more emphasis on infrastructure and energy systems modelling, whereas Chinese experts tended to rate charging business models and battery swaps more highly. This likely reflects the relative emphasis on these topics in each region, with China leading on battery swaps, for example, whereas many European organisations are actively conducting system modelling studies that contribute to policy debates.

In terms of qualitative answers, European experts suggested a wide variety of fields where the two regions can cooperate. These included interoperability and functionality of EV batteries for V2G and flexibility provision and developing technical protocols and standards. While there exists considerable concern about commercial competition in the EV and battery spaces, these experts felt that Europe should continue to integrate with the Chinese manufacturing sector in this space to drive down costs:

> ‘The EU can certainly take advantage of China’s scale to drive down costs in order to pull adoption closer to the present. [In the EU] there’s some hesitancy with regards to allowing too many imports to enter their markets. Overall, the EU should concede that they need help and that China provides the best possible and most affordable solutions that could quickly put them on a path to faster integration of renewable energy. The issue is more political than technical or commercial.’

Lastly, in terms of the rural energy transition, international experts provided a variety of suggested topics for future discussion and mutual benefit. Many experts specifically mentioned the need to improve integration of EV charging with distributed renewable energy:

> '[Topics I would prioritise include] the limited grid capacity of rural distribution grids in face or new loads such as e-mobility and heat pumps and renewable generation and how to make flexibility happen at the local scale. [Similarly, I would prioritise the topics of] local flexibility markets, how to integrate local flexibility into power market, and how to incentivise flexibility with adaptable grid fees at certain times.'

Most of the respondents also mentioned building energy efficiency and rural distribution grids as policy priorities in China for the renewable energy transition. One international expert pointed out the need to place more emphasis on the energy transition in smaller cities and rural areas instead of just the largest cities, where efficiency is relatively high:

> 'Building efficiency, clean heating/cooling are two of the major concerns I would have but also grid readiness. The real focus in China has been to upgrade and push forward the tier 1 and 2 cities with regards to EV adoption and grid readiness … It's even more of an issue in the lower tier cities but hasn't been highlighted … That's good and bad because the lower tiered cities are less efficient and don't seem to be as aligned with central government policy than their larger, higher-tiered city counterparts.

To summarise, international policy experts retain a favourable view of EU-China cooperation on the topics of power market reform and EV charging. While Chinese policy experts appeared to focus more on commercial and industrial cooperation and trade, international experts appeared to agree that commercial rivalry should not stand in the way of integrating the two regions, which each have advantages and areas of specialisation that can benefit the other. On policy, European experts placed greater emphasis on spot market cooperation and energy modeling as topics of cooperation, but given the overall high ratings assigned by these experts to all topics, it does not appear there are any fields of relative interest where differences would prevent fruitful exchange via existing policy cooperation platforms.

2.7. Overall summary of Chapter 2

Given the relatively recent growth in EV adoption and the limited availability of vehicles with bidirectional charging capability, the expert interview process confirmed widespread uncertainty and disagreement about the potential of EVs to help integrate renewable energy. The main finding of this chapter is that there is little consensus on which use cases will be most attractive for bidirectional charging or which barriers will prove most important to resolve.

Several of the international EV charging experts interviewed have direct experience of bidirectional charging pilots or products, and were able to discuss barriers in great detail. The main barriers in the international context included the cost of equipment, the inadequate availability of dynamic pricing, too few bidirectional-capable vehicle models, and regulatory barriers such as taxes or fees, insufficient grid codes, or lack of standards. Interviewees disagreed about the extent to which these barriers may be resolved in the next two years. Similarly, international experts disagreed about consumer interest and policy maker interest in bidirectional charging. In China, by contrast, bidirectional charging is a relatively new technology and not widely available, therefore interviewees could mainly speak in general about the relative attractiveness of the concept for rural residents. Most felt that rural residents would be both interested and able to participate, though unpredictable driving and charging patterns and low awareness could be major barriers.

As for international cooperation, the experts consulted in this research expressed a high degree of optimism and expressed favourable views on the value of cooperation in the fields of electric power market reform and EV charging. Among policy experts – many of whom are directly involved in both policy making in their home countries as well as in international cooperation projects between the EU and China – several mentioned the importance of continuing to learn from one another on the topic of EV charging as a technique for increasing renewable integration. As one European expert noted, if the EU and China are to meet their climate goals, such learning is critical, and charting separate paths can only slow and weaken the clean energy transition.

3. Modelling and Analysis of Combining V2H with PV and Heat Pumps

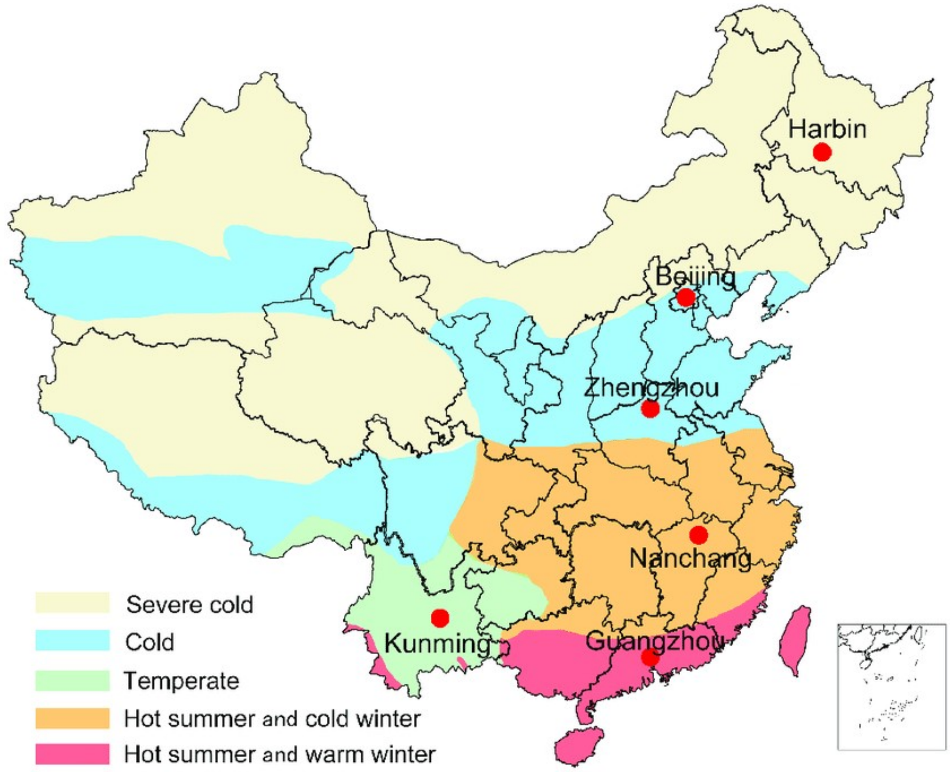
Chapter Summary:

- This chapter uses a model of hourly solar and climate data for the county level to evaluate the economic benefits of combining PV with EV charging in vehicle-to-home (V2H) mode.
- The purpose of bidirectional charging in this case is both to increase self-consumption of PV electricity, thereby reducing the need to upgrade local distribution grids, and to produce electricity cost savings for the household.
- The analysis finds that under the base case scenario a household would receive modest electricity cost savings of around CNY 300 per year (EUR 39 per year) from adopting V2H bidirectional charging.
- If the price paid for surplus PV output sent to the grid is set to zero, savings rise to CNY 600 per year.
- On a regional basis, the largest savings from adopting V2H are available in the provinces where the Whole County PV Programme is most active, in north-central China provinces such as Shandong, Hebei, Henan and Jiangsu.
- V2H produces more benefits in regions with reasonable winter solar output and higher winter heating load, and produces fewer benefits in regions with high cooling loads and lower heating loads.

3.1. Introduction

This study builds on prior quantitative analysis that found a strong synergy between China's Whole County PV Programme and the use of electric air-source heat pumps for heating and cooling in the provinces of East China where the Whole County PV Programme is most active. Generally, the provinces of East China fall into either the Hot Summer Cold Winter climate zone or the Cold climate zone. The analysis found that heat pumps offered attractive payback periods for homes built to Chinese building standards with PV already installed.

Figure 17: Map of China climate zones

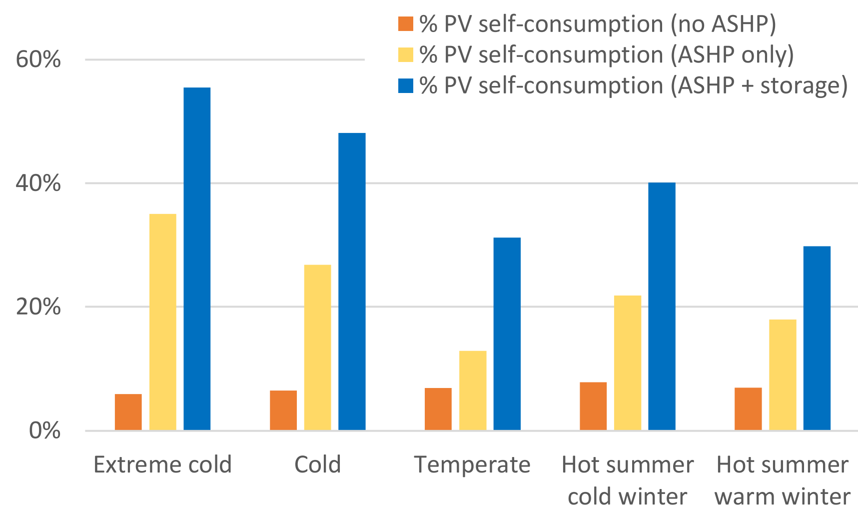


Source: Fan Xinying et al., *Energies*, 2020 (CC).

The addition of an electric heat pump to a home with rooftop PV already installed can help absorb more of the electricity produced by the PV panel than would otherwise be the case. Because most of China has more balanced winter and summer PV output than other countries – such as the US or Europe – PV can be used for relatively more winter heating load than elsewhere. In the climate regions mentioned, heating load far exceeds cooling load.

Although the combination of an electric air source heat pump (ASHP) can help improve the integration of electricity produced by distributed rooftop PV systems under the Whole County PV Programme, the analysis also showed that self-consumption rates only showed modest improvement. For all climate zones, home energy storage was required to improve PV self-consumption beyond 30% of the electricity produced by PV. For the Hot Summer Cold Winter climate zone, as well as the Hot Summer Warm Winter climate zone, self-consumption rates with an ASHP and no storage hovered around just 20%. In short, the vast majority of electricity produced by PV would still need to be absorbed by the grid. Further, since energy storage systems would roughly double the cost of the installation of a heat pump, the payback periods appeared unattractive.

Figure 18: Percentage of PV self-consumption in three cases: (1) PV only, (2) PV and ASHP, and (3) PV, ASHP, storage



Source: OIES, 2023.

This study attempts to resolve this problem by modelling the addition of an electric vehicle battery with or without the ability to operate in vehicle-to-home (V2H) mode – in other words, with or without bidirectional charging capability. If an EV charges at home without V2H, it will still help absorb output from the home PV system, potentially increasing the PV self-consumption rate. This will reduce the share of electricity the PV system can provide, but potentially improve its economics, depending on when the vehicle charges and the time-of-use electricity prices for both electricity consumed and, for solar, injecting electricity from PV into the grid at times of surplus production.

If the EV and home charging system have the ability to charge bidirectionally, the EV can also serve as a battery to store surplus PV output, in place of a home energy storage system. As we have seen in Chapter 1, electric vehicles are already commonplace in rural China, although most are two- and three-wheeled vehicles with batteries too small to be readily used for bidirectional charging. However, based on interviews, we believe most areas of rural China would have at least some households with four-wheeled electric vehicles. Further, interviewees suggested that households with four-wheeled EVs may use them more sporadically than urban residents with a regular commute. Many rural residents may use their two- or three-wheeled vehicles for shorter trips and daily tasks, for example. On the other hand, during agricultural season (mid-May and also October), larger EVs may be away from home charging for extended periods, especially during the daytime when surplus PV is available. On balance, however, the usage pattern described here is relatively favourable for combining PV with V2H compared to an urban or suburban commuter who is rarely parked at home at midday – even assuming that the urban resident has dedicated parking and rooftop solar, which is likely limited to wealthier residents of villa homes on the outskirts of cities.

The practicality of pairing V2H with a heat pump and PV depends on multiple factors, however. These include residential electricity prices, the structure of time-of-use prices and prices for injecting surplus PV electricity into the grid at midday, the cost premium of a bidirectional home charger, the battery capacity of the EV available for V2H at different times, and the travel patterns and driving distances of the EV.

Unfortunately, there is little reliable data available to inform generalisations about a typical household with regard to any of these factors. Further, assuming there is considerable variation in EV usage across households and among regions, the resulting analysis may produce radically different results depending on the household's circumstances. Therefore, the analysis presented here must be considered as only an initial indicator of the potential economic attractiveness of pairing PV and ASHPs with EV charging and V2H. Moreover, by using a consistent set of assumptions across regions, and then using sensitivity analysis for the case of a single location (inland Shandong province), this analysis can help identify the key variables that will help determine the most attractive locations and household situations for such a pairing.

The following represent some of the major assumptions used in this analysis:

- **PV and heat pumps:** As with the prior analysis of combining PV and ASHPs, the analysis assumes a fixed-tilt 5kW rooftop PV system with no home energy storage, combined with a 5kW home heat pump. The home is assumed to have 100 m^2 of climate-controlled area and to be insulated to China's present standards for the Hot Summer Cold Winter climate zone. Temperature set points are assumed as 16 degrees for the winter and 26 degrees for the summer. Hourly PV output and temperature data are from PVWatts.[126]
- **Electricity prices:** Residential electricity prices are based on a time-of-use tariff with five price periods.[127] For PV electricity injected into the grid, the net price paid is CNY 0.35/kWh for most periods, similar to the present level of compensation,[128] but is assumed to be cut to CNY 0.175/kWh during midday hours (10am to 2pm).
- **EV base case:** The modelled household has one EV with a 30kWh battery back. The daily driving distance averages 50 km, with a maximum of 100 km. The vehicle efficiency is 0.2kWh/km, leading to a total electricity consumption for EV charging of 3 100kWh per year (8kWh per day).[129] All vehicle charging takes place at home from off-peak electricity, unless a trip cannot be completed with the battery capacity available, in which case the vehicle is

[126] See methodology section of the PV-heat pump paper for more details.

[127] Although residential electricity prices are currently insulated from time-of-use pricing in most of China, the adoption of time-of-use for reducing peak loads is a long-term trend, and national officials have encouraged provinces to shift to more granular time-of-use structures with at least five price periods. See '国家发展改革委有关负责同志就 《关于进一步完善分时电价机制的通知》答记者问 [NDRC officials reply to journalist questions regarding notice on further improving time-of-use electricity pricing],' National Development and Reform Commission, August 2021, at https://www.ndrc.gov.cn/xxgk/jd/jd/202108/t20210802_1292769.html; '全国各地最新销售电价表一览 [National listing of latest retail electricity prices],' Beijixing, 31 May 2021, at https://news.bjx.com.cn/html/20210531/1155249.shtml.

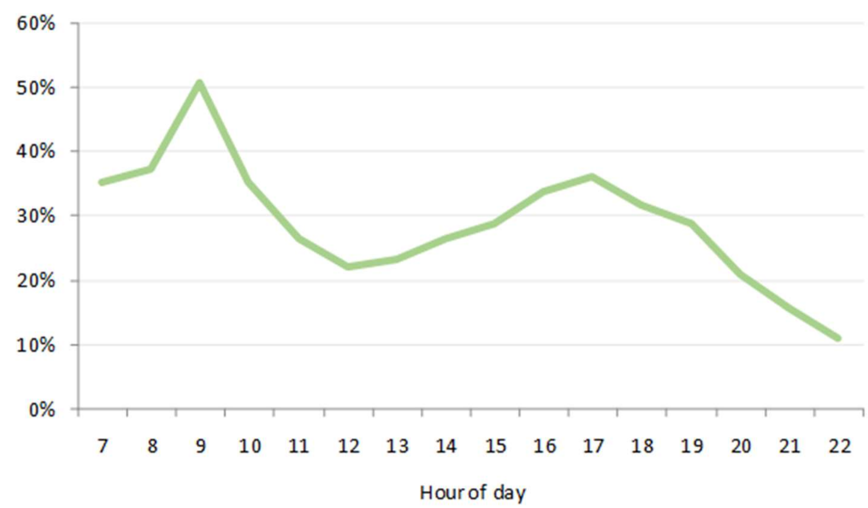
[128] See '户用光伏建设运行百问百答,' National Energy Administration and China Solar PV Industry Association, 31 August 2022, at https://www.nea.gov.cn/2022-08/31/c_1310657941.htm.

[129] Additional electricity use for climate control or other loads is excluded from the analysis.

assumed to charge away from home – but only to a level sufficient to complete the trip and return home.

- **Driving patterns:** Daily travel distance varies randomly throughout the year, with a uniform daily distribution from zero to the maximum daily distance (100 km, in the base case).[130] Further, the household is assumed to make between zero and two trips per day, depending on distance travelled. The model assumes a random daily split of distance between trips (if more than one). Trips are assumed to begin either in the morning (from 7am to 11am) or afternoon and evening (from 12am to 10pm). Driving speed is assumed to average 30 km per hour. Morning trips are assumed to require activities away from home averaging 1 hour with a maximum of 2 hours, while afternoon/evening trips are assumed to entail activities averaging 3.5 hours, with a maximum of 7 hours. All trips are assumed to be completed by 11pm, and the vehicle is therefore parked at home overnight all year. In the base case, the vehicle is away from home for just under 5 hours per day.[131] The average usage pattern (times away from home) can be seen as follows:

Figure 19: Percentage of time EV away from home in base case



Source: OIES, 2023.

- **V2H base case:** For the base case of a 30kWh EV battery capacity, 10kWh is assumed to be available for bidirectional charging for those engaged in V2H – in other words, users will not discharge electricity from the EV battery for home use beyond a 20kWh (66%) state-of-charge. The home is equipped with a 7kW bidirectional home charging system. The vehicle will recharge only

[130] This reflects a much higher variation in daily usage than in the case of a normal distribution. Interviewees emphasised the high variation in EV usage, and that EVs would not be used at all on many days, or might not be the primary vehicle for many activities.

[131] In the maximum 200 km daily travel case, this rises to 7 hours per day away from home.

from off-peak electricity, and will leave a buffer of 20% (6kWh, in the base case) to enable some midday charging from surplus midday PV output. The battery will discharge into the home only at peak times, and will not discharge at off-peak times to restore the buffer. (In other words, if the EV charges from solar at midday and charges fully to 30kWh, this will not discharge back to the home during off-peak times.)[132]

3.2. Results: savings from V2H

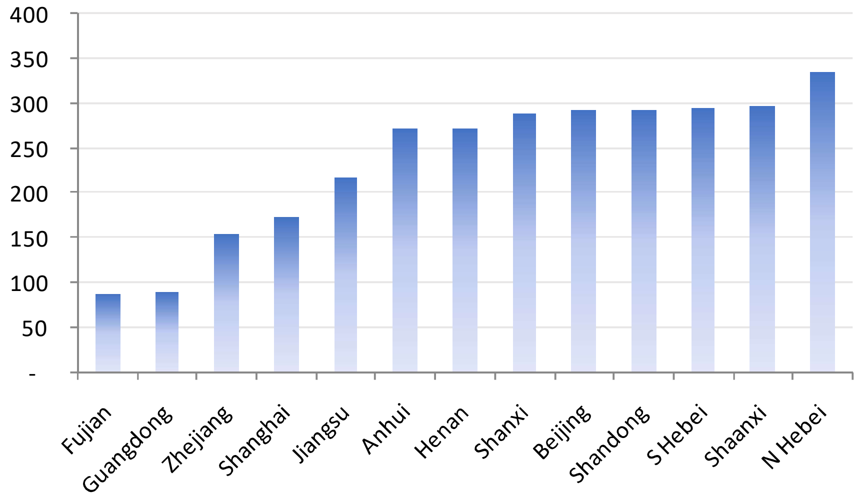
The results of the analysis show that V2H offers those with existing PV and ASHP modest but significant electricity savings compared with owning an EV without V2H capability. Savings from V2H averaged CNY 236 per year across the 13 provinces considered. Further, EV ownership can substantially increase the percentage of self-consumption of electricity from rooftop PV, with or without V2H.

The sensitivity analysis shows that the benefit of V2H for either electricity savings or improving the ratio of PV self-consumption varies by region, and depends on daily driving patterns, battery size, amount of battery used for V2H, and the amount of buffer left overnight for storing midday surplus PV.

For the base case, the average annual electricity saved by adopting V2H versus EV charging with no V2H was CNY 236 (EUR 30) per year. Of the 13 provinces considered, savings ranged from just CNY 87 (EUR 11) to as high as CNY 335 (EUR 43) per year for the base case; however, over half the regions experienced savings between CNY 250 and CNY 300 per (EUR 32-38). Even if the cost of purchasing a bidirectional charger falls significantly over the coming years, this cost saving is quite modest and inadequate to recover the upfront costs of the charging equipment.

[132] Other research has studied minimum state-of-charge for users engaged in V2G. See R. Somya and V. Sankaranarayanan, 'Optimal vehicle-to-grid and grid-to-vehicle scheduling strategy with uncertainty management using improved marine predator algorithm,' Computers and Electrical Engineering, 100, May 2022, at https://doi.org/10.1016/j.compeleceng.2022.107949. Optimal maximum charging levels are discussed in Emmanouil D. Kostopoulos et al., 'Real-world study for the optimal charging of electric vehicles,' Energy Reports, 6, November 2020, at https://doi.org/10.1016/j.egyr.2019.12.008.

Figure 20: Base case electricity cost savings (RMB per year) from V2H versus off-peak charging



Source: OIES, 2023.

As can be seen at a glance, the regions with the greatest cost savings are clustered towards the regions with higher heating load. Higher heating load translates to greater ability to utilise surplus midday solar by adopting V2H. The correlation between heating load and annual electricity cost savings was + 0.81, and the correlation between average winter temperature and annual savings was - 0.93. By contrast, there was a small negative correlation with cooling load and annual savings. Cooling load is not only far smaller than heating load for most of China – including even the warmer provinces shown above – but also has a closer match to daily PV output. Both of these factors reduce the value of V2H for reducing peak electricity consumption.

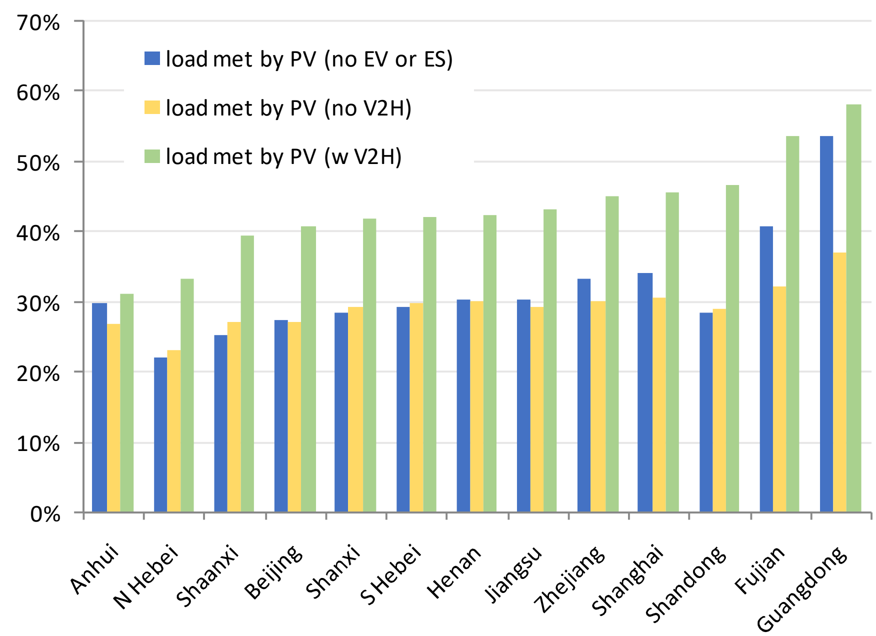
3.3. Regional differences in savings from V2H

Adding V2H capability substantially boosts self-consumption of PV output. In contrast to the topic of electricity cost savings, where northern regions are more favoured, self-consumption percentages tend to show better results in provinces with lower winter heating load. Further, with V2H, the proportion of household electricity load met by PV rises substantially, and in some cases more than with stationary energy storage, despite the frequent daily periods when the EV is not at home at times of peak PV output.

Figure 21 displays three cases: The first case consists of an PV paired with an electric ASHP with no EV; the second consists of PV paired with an ASHP and an EV that charges with off-peak electricity or surplus PV output; and the third consists of PV with an ASHP and an EV that operates in V2H mode when available. Although an EV substantially increases the total household electricity consumption, even without V2H the proportion of household load met by PV is similar to that without the EV, with the exception of warmer regions that begin with a high proportion of household load that can be met by PV due to the overlap between cooling loads and PV output.

In colder regions, adding the EV with V2H capability substantially increases the proportion of household load (including EV charging) met by solar PV. In warmer regions, adding V2H capability also results in a major improvement in the proportion of load met by PV. In Guangdong, this proportion reaches almost 60% in the V2H case.

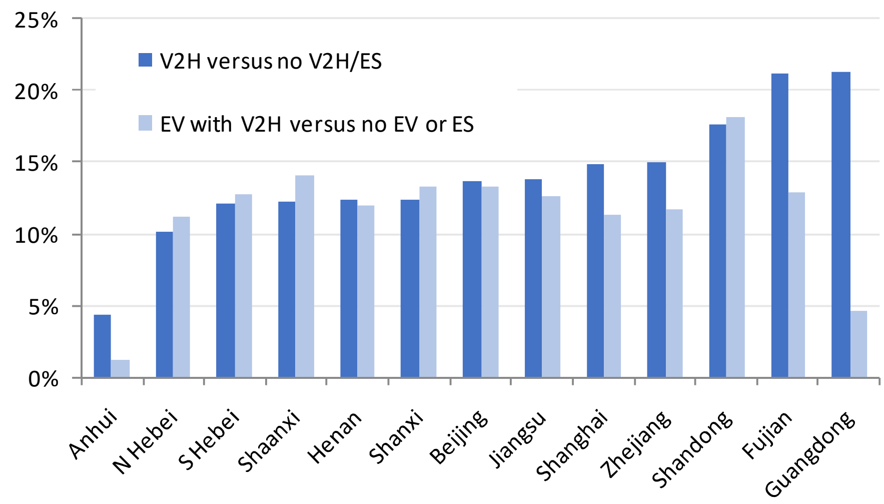
Figure 21: Proportion of PV self-consumption by region, base case



Source: OIES, 2023.

As the chart below demonstrates, the warmer regions such as Fujian and Guangdong see a large benefit from adopting V2H versus the non-V2H case (an EV charging from off-peak power or surplus PV output only). Most other provinces would see a 10% boost to the PV share of household load in the V2H case versus the non-V2H case.

Figure 22: Differences in proportion of PV self-consumption between cases, by province



Source: OIES, 2023.

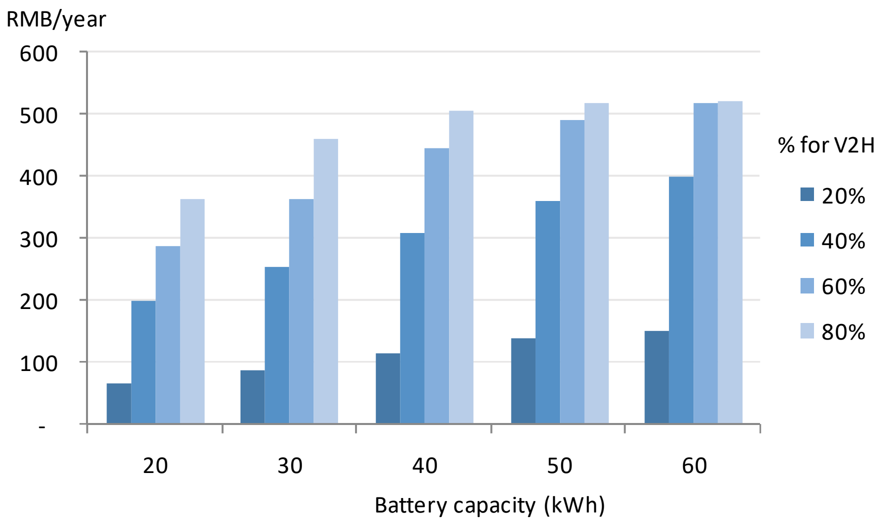
3.4. Sensitivity analysis of battery and V2H characteristics

V2H involves multiple trade-offs. A larger battery not only gives more driving range, but potentially more battery capacity that could be used to store surplus PV electricity. However, a larger battery costs more, and if the extra capacity is rarely used for driving or V2H, it may not be worth the extra expenditure. Interviewees emphasised low purchase price as a central consideration for rural EV buyers, not necessarily driving range.

Several international EV experts noted that most EV owners want mainly to use their EV for transportation, with V2H benefits as a far lower priority than completing trips with maximum convenience. By contrast, Chinese experts suggested that rural residents would be motivated to sacrifice some convenience to save or make money through smart charging or V2H – particularly if the upfront costs could be handled by the grid company or another third party. It is possible that in certain villages the grid company or a solar PV service provider would subsidise the extra cost of bidirectional charging equipment in exchange for greater control over charging times.

As Figure 23 demonstrates, for the base case household with a 5kW rooftop PV system and a maximum daily driving distance of 100 km, the economic savings from V2H are only moderately sensitive to battery size. For the base case, in which a household uses between 20% and 30% of the battery capacity for V2H, electricity cost savings approximately double in the case of a 20kW versus a 40kW battery size. However, if a larger proportion of the battery is used for storing midday PV output, more savings are possible, though a larger battery does not greatly improve the savings potential. This is because the surplus electricity from the 5kW rooftop system is already fully stored with 30kW of useable battery capacity. Of course, using more battery capacity to consume more surplus PV at peak electricity price periods implies greater likelihood of not being able to complete trips without an outside charge (either in the morning prior to when surplus PV output is available, or in the afternoon and evening if surplus PV was unavailable that day), which could negate the economic benefit – even aside from the inconvenience.

Figure 23: Annual electricity savings (RMB) for given battery capacity (kW) versus percentage of battery used for V2H



Source: OIES, 2023.

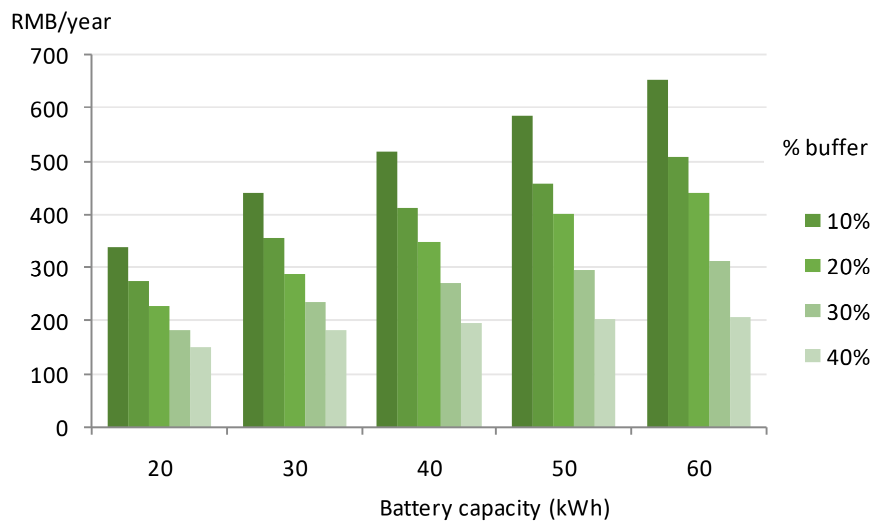
A second major consideration for maximising the electricity cost savings is the home charging buffer. In the absence of V2H, many EV owners prefer to charge fully on a daily basis, or to the manufacturer's recommended charging amount, such as 80% state-of-charge. If the battery is charged fully every night using off peak power, this leaves no battery capacity available the following day for storing midday PV, unless the timing of trips happens to open up some spare capacity. However, leaving too large a buffer opens up the possibility of needing to charge the vehicle at peak electricity time periods, depending on trip length.

Another factor determining the value of saving a buffer to absorb daytime PV output is the relative price of night-time charging compared to the price paid for excess solar PV output. The base case uses an assumption that PV is paid a value similar to the on-grid tariff for coal, or CNY 0.35/kWh, except for midday hours when this price is discounted by 50%.[133] However, the overnight charging tariff under the time-of-use pricing scenario is around CNY 0.20/kWh, so that for most days excess PV output sent to the grid will earn more money for the household than would be saved by reducing overnight charging to arbitrage peak prices with midday solar output.

[133] This assumption was also used in the analysis pairing heat pumps with PV, and was used for the base case here for consistency.

Hence, in the base case, maintaining an overnight buffer to maximise self-consumption of PV does not produce any savings, as the figure below shows.

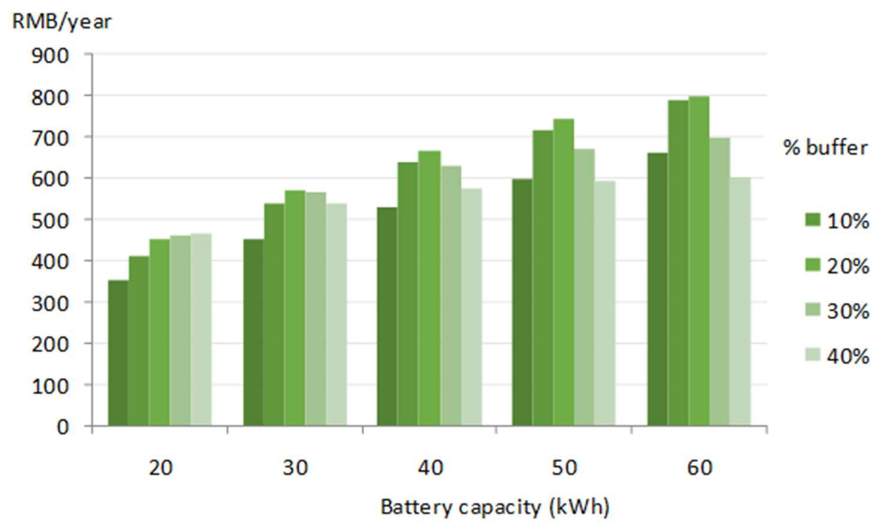
Figure 24: Annual electricity savings (RMB), given battery capacity (kW) versus percentage of battery left as buffer (percent), assuming high prices (RMB 0.18 to RMB 0.35/kWh) for PV output sent to grid



Source: OIES, 2023.

However, when the price paid for PV output sent to the grid is reduced, the relationship changes to a non-linear one, in which a small buffer to enable greater uptake of midday PV results in cost savings versus no buffer. This is shown in Figure 25 below:

Figure 25: Annual electricity savings (RMB), given battery capacity (kW) versus percentage of battery left as buffer (percent), assuming low prices (RMB 0.05 to RMB 0.10/kWh) for PV output sent to grid



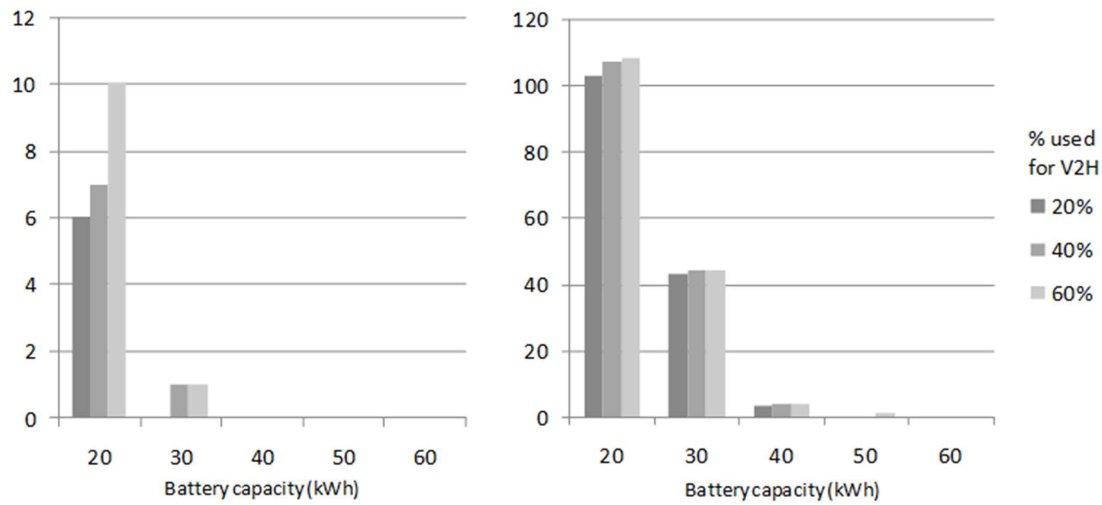
Source: OIES, 2023.

Given the size of the home PV system, an overnight capacity buffer of around 6kW for a 30kW battery appears to offer good uptake of midday PV output compared to a larger or smaller buffer percentage. The relationship holds for larger battery sizes as well, which is unsurprising given the point noted previously about larger capacity not necessarily being needed for absorbing midday PV output.

Completing most or all trips with home charging is likely a major priority for the majority of rural EV users, even in China. The two figures below consider the base case of an EV in Shandong province, with a 5kW PV system, an electric ASHP, and 20% overnight charging buffer. The graph on the left shows that for a household that uses the EV for a maximum trip length of 100 km, almost all trips can be completed with home charging using a 30kW EV battery, with only a single day where a charge is needed away from home if the V2H capacity percentage was 40% or 60%. For a 20kW battery, however, an outside charge would be needed on six to ten days .

For a household with a 200 km maximum daily travel distance, a 40kW battery is sufficient to complete most trips using home charging. However, for this case, a 20kW battery would imply over 100 days where a charge is required away from home to complete travel, using over 300kWh from public chargers during trips, which would negate or significantly reduce the incentive to adopt V2H. A 30kW battery would also require external charging on more than 40 days.

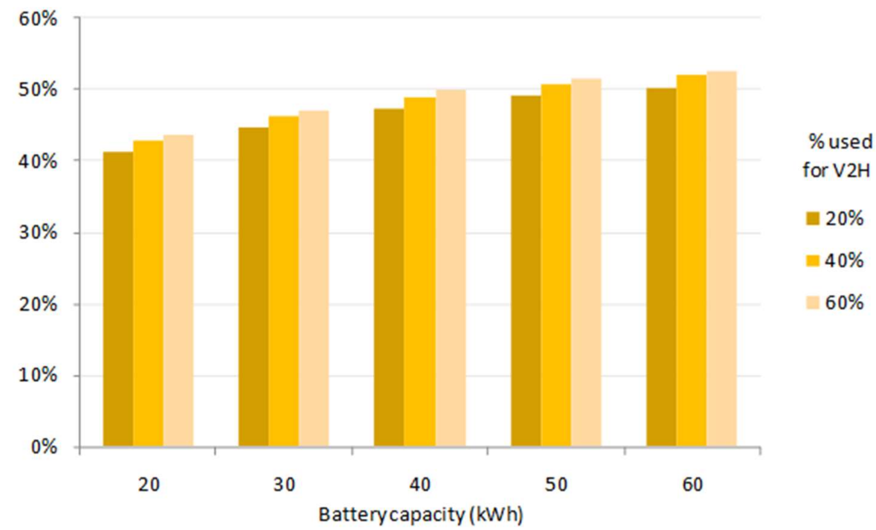
Figure 26: Days requiring charging away from home for maximum daily travel of 100 km (left) or 200 km (right), depending on battery size (kW) and percentage of battery used for V2H



Source: OIES, 2023.

A larger battery and a larger proportion of battery capacity utilised for V2H can each contribute to boosting the self-sufficiency of a home with rooftop PV and an ASHP. The most important factor is clearly the battery capacity, not the proportion made available for V2H. For a 20kW battery, the household in rural Shandong province can meet over 40% of its electricity consumption with PV and the EV battery in V2H mode. Increasing the battery size to 60kW and boosting the proportion of the battery employed for V2H can bring this self-sufficiency ratio up to 55%. For each given battery capacity, increasing the proportion used in V2H mode can boost self-sufficiency by around 5%.

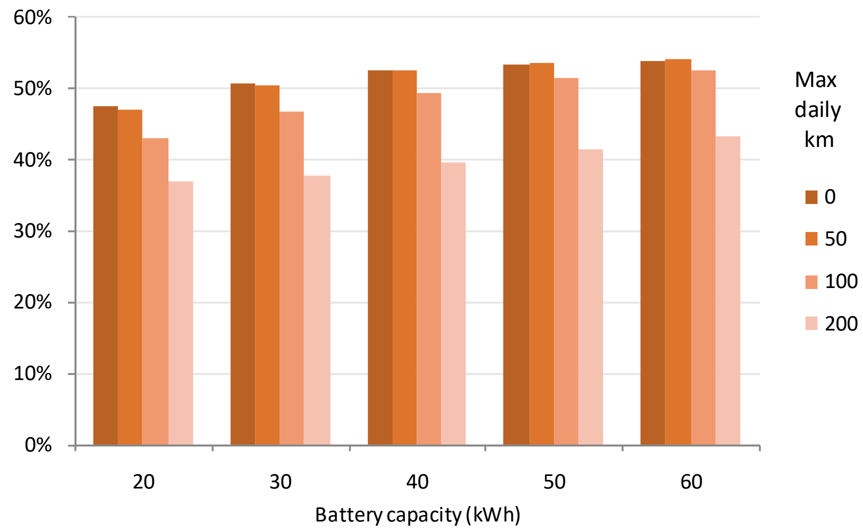
Figure 27: Percentage of household electricity load met from PV, depending on battery size (kW) and proportion of battery capacity used for V2H



Source: OIES, 2023.

As already noted, for the base case of a household with maximum daily driving distances of 100 km, almost all trips can be completed from a home charge, with V2H substantially improving PV self-consumption and household electricity self-sufficiency. Figure 28 shows that for households with daily travel under 100 km, self-sufficiency is not highly sensitive to EV battery capacity. Indeed, even comparing the case of a vehicle that never leaves home (maximum daily driving distance of zero km, and no time spent away from home – in other words, the vehicle is only serving as a home storage battery), there is almost no difference in self-sufficiency as compared with a household with a maximum daily driving distance of 50 km. However, beyond 100 km the percentage of self-sufficiency begins to decline sharply. This is due to higher electricity consumption for EV charging, as well as less vehicle time at home for storing midday peak PV output. The decline is largest for the smaller battery capacity vehicles. Of these two factors, EV electricity consumption for travel is the most sensitive.

Figure 28: Household self-sufficiency (percentage) as compared to EV battery capacity (kW) and maximum daily driving distance (km)

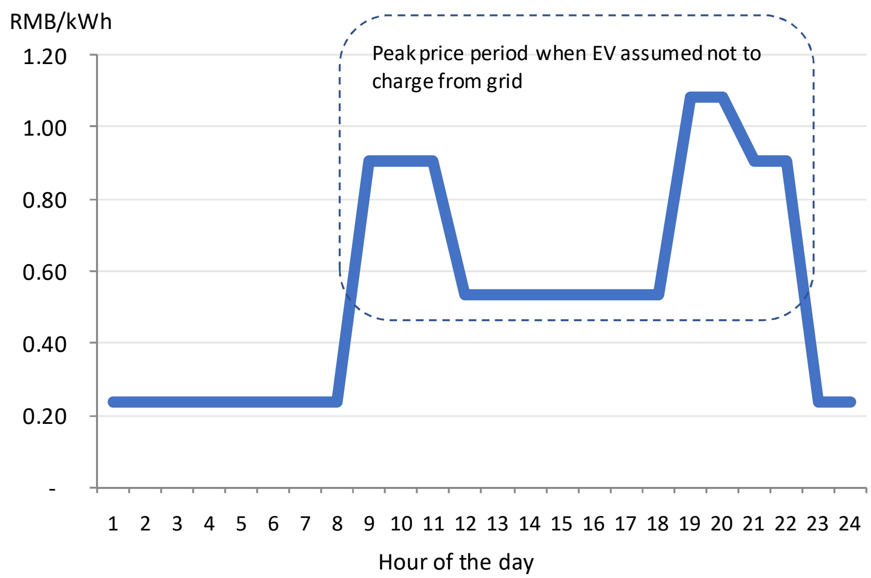


Source: OIES, 2023.

Electricity prices are another important consideration. In China, residential electricity prices are lower than commercial or industrial electricity prices, and time-of-use pricing is most common for industrial and commercial customers. While there is a super-premium residential electricity tariff for households that consume the most electricity,[134] rural residents are unlikely to consume sufficient electricity to be offered these premium tariffs. In the future, however, time-of-use pricing is likely to become more common, in China and worldwide, particularly for households with EVs or solar PV. The base case in this model assumes time-of-use pricing is in effect for all such households, as shown below.

[134] Known as ladder pricing, this tariff charges a higher price per kWh above a certain threshold of monthly or annual consumption, and is generally only applicable to households in the top fifth of local electricity consumption. There is no time-of-use element to ladder pricing.

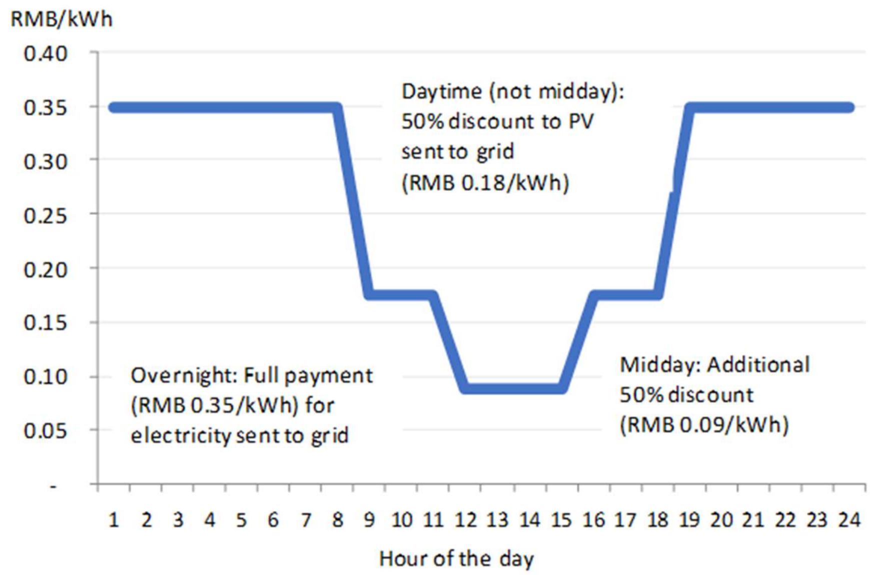
Figure 29: Base case residential time-of-use tariff and EV charging time



Source: OIES, 2023.

As already mentioned, the base case also assumes solar output sent to the grid is compensated at CNY 0.35/kWh, except for midday solar PV sent into the grid, which is valued at only 50% of the price offered at times other than the midday peak. As midday solar PV overproduction becomes more common in provinces with large amounts of rooftop solar, it is likely that grid companies will increasingly discount the per-kWh price paid to households with excess solar output, especially at peak times. A full price could still be offered at other times, such as during the evening peak, to households with energy storage. The following sensitivity analysis considers such a scenario, with three separate time components for payments for electricity sent back to the grid: a night-time price, a daytime price, and a midday price. The daytime price (8am to 6pm) and the midday price (11am to 2pm) can each be discounted by a certain proportion.

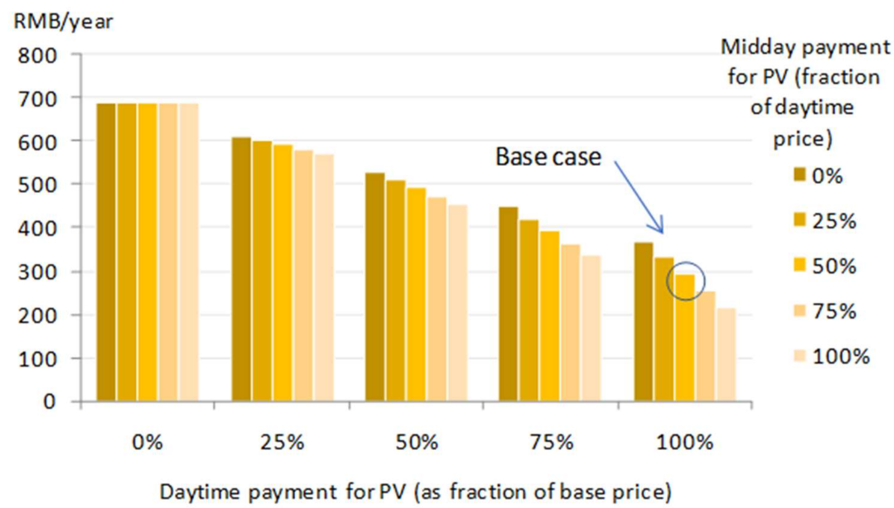
Figure 30: Hypothetical time-of-day payment schedule for surplus rooftop PV output sent to grid, RMB/kWh



Source: OIES, 2023.

As Figure 31 shows, the savings generated by using V2H in the base case are clearly and linearly inversely proportional to the price paid for PV electricity sent back to the grid – in other words, as the price paid for PV falls, the savings from V2H rise. The bars on the left show savings of nearly CNY 700 (EUR 90) per year in the case where daytime electricity is not compensated at all (that is, compensated at 0% of the base rate). The percentages in the legend at right show the discount applied to the midday peak of PV output. The midday peak covers fewer hours than the full daytime period, so the savings resulting from variation in this payment is correspondingly lower. The base case is circled: 100% payment for daytime solar outside of the midday peak, and 50% payment for midday peak solar.

Figure 31: Annual savings depending on percent payment for daytime solar sent to the grid (bottom axis) and for midday solar sent to the grid (percentages in legend)



Source: OIES, 2023.

The sensitivity of annual electricity cost savings is more sensitive to this one factor – price paid for surplus PV sent to the grid – than any other variable. Given the rapid deployment of rooftop solar in local areas with weak distribution grids, this circumstance could well take place even before V2H or home storage become widely commercialized in China. Indeed, there are undoubtedly places where midday surplus solar output cannot be accepted by the grid at all. For households with rooftop PV and an EV, this factor could become a major motivator for adopting V2H to store solar output.

3.5. Conclusions: V2H offers solar and EV households modest savings at little cost to convenience

The main result of the modelling analysis from this study shows that bidirectional charging offers modest electricity cost savings for solar PV households in those regions where the Whole County PV Programme is most active – namely, North and Central China. This is because these provinces combine relatively good solar resources, fairly balanced solar PV output in winter compared to summer, and high heating load compared to midday cooling load. With these characteristics, V2H can offer annual electricity cost savings of CNY 250 to CNY 300 in most of this area. These savings would be insufficient to enable recovery of the current upfront cost of adopting V2H for most users,[135] at least in the absence of equipment cost subsidies or additional subsidies for participating in V2H, such as might be offered by the grid companies. Savings are significantly smaller in warmer provinces that can use

[135] As noted in Chapter 1, a bidirectional home charger in China could cost up to RMB 20,000.

midday solar for cooling in the summertime and have less need for heating in the winter.

Two changes would be necessary to make V2H more economically attractive: the upfront cost of charging equipment would need to fall, and the time-of-use price structure would need to provide greater savings opportunities for absorbing surplus solar output. In particular, this analysis shows that adjusting or removing the payment for sending power back to the grid at midday would more than double annual savings. Further adjustment to time-of-use power prices to increase the peak-trough price differential would likely provide further incentive. However, any of these changes on their own would be insufficient to make V2H attractive on its own.

The second finding relates to trip lengths and durations. Although the analysis necessitates several simplifying assumptions, it nevertheless demonstrates that for a hypothetical household with two EV trips per day and several hours of activity time per trip, the amount of time spent parked at home is sufficient to make V2H worthwhile as a method to boost self-consumption of surplus midday solar electricity. For an urban household with a uniform daily commute on weekdays and some daytime travel on weekends as well, there would be comparatively little opportunity to use V2H for absorbing midday solar output.

The third major finding relates to self-consumption of PV and household self-sufficiency. Although V2H could offer an economic way to increase self-consumption of surplus PV, it would not suffice to make a household entirely self-sufficient. Nor would V2H entirely eliminate the problem of midday overproduction at the local level. Instead, self-consumption of PV rises to around 60%, while self-sufficiency rises to 50% to 60%. This implies that households and villages participating in the Whole County PV Programme may be able to moderate their need for distribution grid upgrades, but some upgrades and potentially central utility-scale storage will still be needed to absorb surplus solar PV production.

An open question arising from this analysis is whether localised sharing or trading of surplus PV, such as through community V2G charging facilities, could do a better job of absorbing midday solar PV than a single vehicle owned by an individual household. For villages in the Whole County PV Programme, the number of households with four-wheeled EVs capable of bidirectional charging is likely to be far smaller than the number of households with rooftop PV. Nevertheless, by smoothing out parking and trip times by aggregating multiple vehicles, some storage capacity would always be available at midday – which is not the case at the household level for V2H. As we have seen, with a rooftop solar capacity of 5kW, a small amount of storage goes a long way to boosting self-consumption of PV.

A second question not analysed here involves increasing the use of night-time charging for V2H price arbitrage. In the base case of this analysis, the EV mainly engages in smart charging, charging at night and then only occasionally discharges extra energy from solar into the household at peak electricity price periods. Using a larger amount of battery capacity to engage in daily price arbitrage could result in larger savings – but also requires a larger number of simplifying assumptions – for example, the future structure and level of household time-of-use prices.

As more bidirectional-charging-capable vehicles come on the market, and more customers begin to experiment with V2H around the world, we can expect more data on the cost savings and grid benefits to become available. In some cases, data from

Chinese bidirectional charging pilots may be published, giving more information on trip patterns and charging habits. New policies on residential electricity tariffs will also help clarify the economics of bidirectional charging in some regions. Many of the questions raised in this analysis will then be ripe for reappraisal.

4. Conclusions and Lessons for EU-China Cooperation on EV Charging and V2G

Electrification of personal transportation is a critical aspect of the global low-carbon energy transition, and both Europe and China are leading in adoption of electric vehicles. Meanwhile, China's rural areas, especially in eastern China, have begun to rapidly scale up rooftop solar, offering potential synergies with other strategies to electrify household energy consumption, such as for heating and transportation. For many years, V2G and bidirectional charging have appeared to offer an eventual solution to the problem of variable output of local solar PV, and this is especially relevant in China, given weaknesses in local distribution grids.

As the modelling in this study shows, however, bidirectional home charging faces major challenges, both in terms of upfront cost and in the economics of charging. These barriers are present even for a hypothetical rural household with existing rooftop solar, an electric heat pump, and a variable driving and charging profile that would provide time for the vehicle to help absorb midday solar. Adjustments to rural household electricity prices, as well as lower cost bidirectional charging equipment, are necessary to make bidirectional charging a viable strategy. Possible solutions include sharing of charging equipment, and encouraging grid companies to subsidise and coordinate bidirectional charging, possibly by optimising charging for the wider grid, instead of for a single household as studied here.

Although the modelling analysis presented here has not included Europe, the situation in most European countries has some similarities to that in China. The upfront cost of charging equipment and lack of bidirectional-charging-capable vehicles present the most daunting challenges to adoption of V2H or V2G. In addition, most countries have inadequate time-of-use or dynamic electricity pricing options for personal EV users, though there are several exceptions. Still, until more vehicles and cheaper equipment options are available, V2G and V2H may be limited to pilot projects.

While the challenges to employing bidirectional charging as a strategy for integrating renewable energy may seem overwhelming, the interviews conducted for this study present arguments for optimism – both about the future importance of bidirectional charging, and about the prospects for EU-China cooperation on this topic. At the broadest level, the most intriguing finding from the interviews in both Europe and China was that the industry and policy analysts working on EV charging or bidirectional charging – the experts most optimistic about V2G and bidirectional charging – lack consensus on the major barriers to their adoption and, therefore, on how best to overcome them. This presents an opportunity for productive and fruitful discussion and exchange, to enable the various parties to learn from experiences and perspectives different from their own.

Second, both EV charging experts and experts working on international cooperation remain optimistic about the potential for cooperation between Europe and China in the field of EVs and renewable integration. Experts acknowledge the commercial and industrial rivalry between the EU and China on EV and battery manufacturing, which affects national EV policy and could restrict which topics are most attractive for cooperation. However, most also feel that Europe and China have complementary experiences and advantages that make cooperation in the EV and low-carbon transition fields both productive and essential to achieving national climate goals.

In the field of policy cooperation, there is interest on both sides in continued exchange on the topic of electric power markets, especially on the topics of flexibility and renewable integration, where Europe is seen as having valuable technical and policy experiences that China can continue to learn from. Within the field of EVs, however, the topics for cooperation are broader than policy. Notably, experts from both sides expressed the view that commercial and industrial integration between China and Europe will be necessary to speed the adoption of EVs and enable a more rapid clean energy transition than would otherwise be possible. Further, experts in both regions are interested in learning about their counterparts' experiences in the fields of EV charging, managed/smart charging, and V2G.

Within V2G specifically, experts similarly believe each region has complementary advantages. Resolving the problem of high upfront costs will require scaling up of manufacturing for both charging equipment and vehicles capable of bidirectional charging. This process will be facilitated if common standards and communications protocols are discussed and developed in a cooperative fashion, rather than in isolation as has often happened with EV charging standards in the past.

On the topic of policy, while V2G and bidirectional charging remain at an early stage in both China and Europe, there are many European companies working actively on offering various smart charging and bidirectional charging services in regions where electricity prices make these practices advantageous. These include aggregators of EV loads that manage charging to bid into electricity markets, charging providers that offer dynamic charging tariffs, and charging managers that help companies minimise electricity and equipment costs by managing fleet charging operations.

As V2G becomes more common, these companies will be well placed to offer similar services in more geographical areas, including potentially in partnership with Chinese players such as car manufacturers and charging equipment providers. In interviews, both Chinese and European experts expressed openness to such direct commercial cooperation within the EV field, especially in those areas such as bidirectional charging that have yet to reach commercial scale and require additional basic research and experience before they can be proven in the market and accepted by customers and policy makers.

Summary: As China's rural clean energy transition accelerates, there is an urgent need to improve integration of distributed renewable energy, especially rooftop solar, at the household and village level, both to reduce grid investment cost and prevent curtailment of distributed renewables at periods of peak output. V2G and bidirectional charging offer a potential solution, but face many barriers – including high costs, unclear revenue models, and regulatory barriers. This study shows that bidirectional charging at the household level in places that already have rooftop solar could offer modest electricity cost savings, but these would be insufficient to incentivise adoption of bidirectional charging without significant changes in both equipment costs and electricity tariffs in China.

There are reasons for optimism, however. First, costs are expected to fall rapidly, and electricity tariffs are also the focus of efforts to increase variable pricing to encourage better matching of loads with generation. Second, as more vehicles with bidirectional charging capability come to the market, new products and services are likely to follow. Third, policy makers and consumers worldwide have high interest in bidirectional charging as a solution to various issues, including but not limited to integration of renewable or low-carbon energy, making this field ripe for new commercial innovations and services. In this study, experts in both Europe and China have agreed that cooperation and exchange at both the policy and commercial levels can accelerate adoption of bidirectional charging as a solution to renewable integration, ultimately helping to facilitate the clean energy transition and achieve national climate goals.

5. List of Figures

Figure 1: China's total installed solar capacity by category 11

Figure 2: Household PV additions by province, 2022, in GW 12

Figure 3: Household PV additions by province, 1H 2023, in GW 13

Figure 4: China's Whole County PV programme by total county population covered, in millions 14

Figure 5: China sales of New Energy Vehicles, as share of passenger vehicle market, 2017-23 18

Figure 6: Timeline of key 2023 policies on charging infrastructure relating to rural areas or power markets 35

Figure 7.1 : Attractiveness of bidirectional charging for different vehicle use cases (response average) 45

Figure 7.2: Attractiveness of bidirectional charging for different vehicle use cases (by respondent) 46

Figure 8.1: Importance of varies categories of barriers to bidirectional charging (response average) 50

Figure 8.2: Importance of varies categories of barriers to bidirectional charging (by respondent) 51

Figure 9: Chinese respondents' evaluation of potential for different use cases to participate in bidirectional charging, average 62

Figure 10: Chinese respondents' evaluation of potential for different use cases to participate in bidirectional charging, individual responses 64

Figure 11: Chinese expert ratings on power market-related topics for international cooperation 69

Figure 12: Chinese expert ratings on the potential for cooperation on EV-related topics 71

Figure 13: Chinese expert ratings on the potential importance of different EV charging types on renewable integration 72

Figure 14: International policy expert ratings on power market-related topics for international cooperation 74

Figure 15: International policy expert ratings on the potential importance of different EV charging types on renewable integration 77

Figure 16: International policy expert ratings on the potential for cooperation on EV-related topics 78

Figure 17: Map of China climate zones 82

Figure 18: Percentage of PV self-consumption in three cases: (1) PV only, (2) PV and ASHP, and (3) PV, ASHP, storage 83

Figure 19: Percentage of time EV away from home in base case 85

Figure 20: Base case electricity cost savings (RMB per year) from V2H versus off-peak charging 87

Figure 21: Proportion of PV self-consumption by region, base case 88

Figure 22: Differences in proportion of PV self-consumption between cases, by province 89

Figure 23: Annual electricity savings (RMB) for given battery capacity (kW) versus percentage of battery used for V2H 90

Figure 24: Annual electricity savings (RMB), given battery capacity (kW) versus percentage of battery left as buffer (percent), assuming high prices (RMB 0.18 to RMB 0.35/kWh) for PV output sent to grid 91

Figure 25: Annual electricity savings (RMB), given battery capacity (kW) versus percentage of battery left as buffer (percent), assuming low prices (RMB 0.05 to RMB 0.10/kWh) for PV output sent to grid 92

Figure 26: Days requiring charging away from home for maximum daily travel of 100 km (left) or 200 km (right), depending on battery size (kW) and percentage of battery used for V2H 93

Figure 27: Percentage of household electricity load met from PV, depending on battery size (kW) and proportion of battery capacity used for V2H 94

Figure 28: Household self-sufficiency (percentage) as compared to EV battery capacity (kW) and maximum daily driving distance (km) 95

Figure 29: Base case residential time-of-use tariff and EV charging time 96

Figure 30: Hypothetical time-of-day payment schedule for surplus rooftop PV output sent to grid, RMB/kWh 97

Figure 31: Annual savings depending on percent payment for daytime solar sent to the grid (bottom axis) and for midday solar sent to the grid (percentages in legend) 98

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