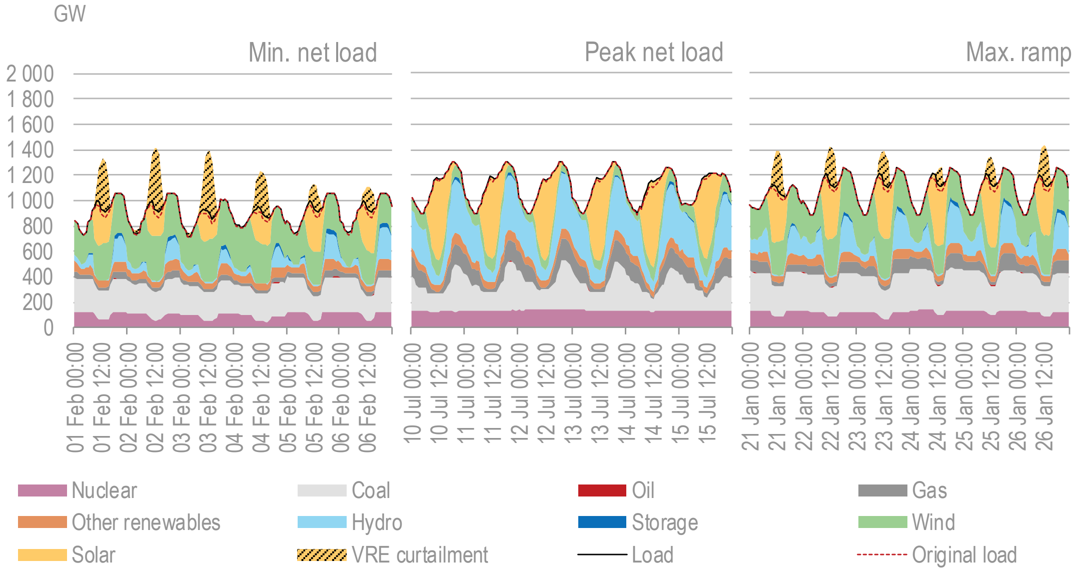
this baseline case the modelling results show that wind and solar PV contribute around 35% to total power generation, which is significantly higher than the 21% VRE penetration in the NPS. Power system flexibility, already an important characteristic, therefore becomes increasingly critical to the cost-effective operation of the power system and accommodation of VRE.

With limited flexibility options available, annual average curtailment is around 5% nationally, with regional curtailment levels for NCR, NER and NWR reaching between 3% and 15%. Power plants of all technologies, including nuclear, are required to provide a substantial amount of operational flexibility (Figure 40). Importantly, VRE curtailment occurs despite the significant operational flexibility that can be provided by dispatchable generation, improved system operations and greater regional transmission interconnectivity.

In summary, the SDS-Inflex case demonstrates the paramount importance of power system flexibility in a decarbonising Chinese power system in 2035. This case is now used as a basis for comparison of cases in which various flexibility measures are deployed. All reported savings are expressed relative to this baseline.

Figure 40. Generation patterns and the demand profiles during high stress periods with limited flexibility options, SDS-Inflex case



Notes: Max. = maximum; Min. = minimum.

Without additional flexibility options available, the Chinese power system experiences increased VRE curtailment during minimum load and maximum ramp periods.

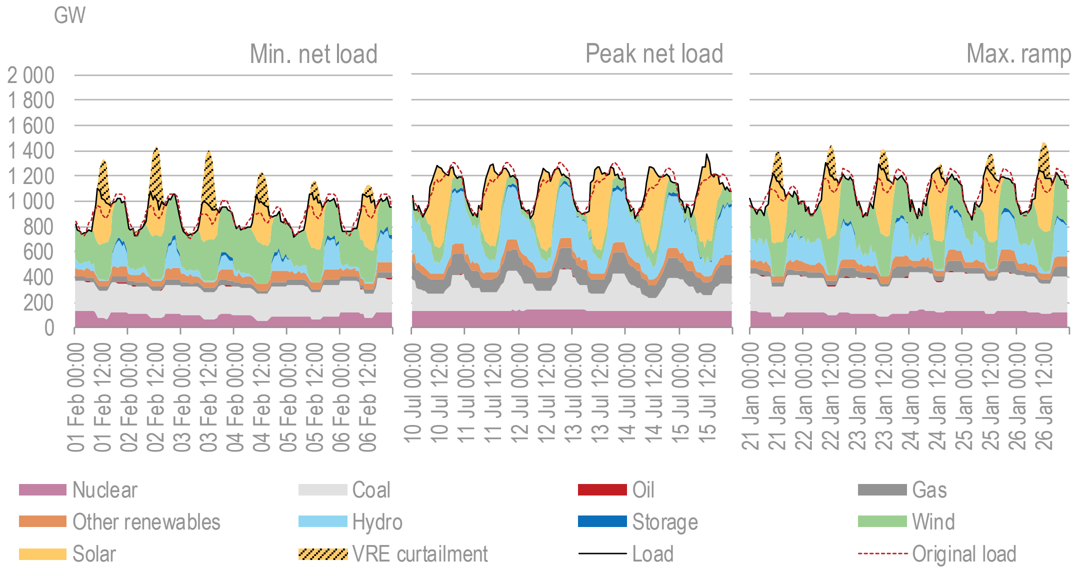
Assessing individual flexibility options

Understanding the value of DSR deployment: SDS-DSR

The SDS-DSR case is used to understand the value of DSR options. It considers 300 GW of residential, commercial, agricultural and industrial load contributing to DSR programmes in 2035, with enrolled resources spanning space heating and cooling, water heating, refrigeration and cleaning appliances. Smart EV charging is assessed in a separate case.

Comparing results from the SDS-DSR case against the SDS-Inflex case is instructive in understanding the costs, benefits and operational impacts of these DSR options in a decarbonising 2035 Chinese power system. Operational costs in the DSR case are approximately 3% lower, which is equivalent to a saving of approximately USD 7 billion per year. These savings are driven primarily by increased utilisation of VRE enabled by flexibility, which reduces fossil fuel consumption in the system. In addition, DSR leads to a flatter demand profile, which enhances the utilisation of resources with low fuel costs (including nuclear power) at the expense of more costly peaking generation (Figure 41). Total CO_2 emissions in the SDS-DSR case are 4% lower than the SDS-Inflex case.

Figure 41. Generation patterns and demand profiles during high-stress periods, SDS-DSR



DSR measures lead to increased utilisation of low marginal cost resources such as nuclear and VRE, while reducing the stringency of operational requirements during high-stress periods.

Importantly, the modelled flexibility measures also deliver a reduction in peak net demand of 71 GW compared to the SDS-Inflex case, which translates into a potential annualised investment cost saving of approximately USD 9 billion per year (driven by reduced investment in low-utilisation generation infrastructure). Combined savings (OPEX and CAPEX) are USD 16 billion per year.

Enrolling these resources tends to have negligible investment-related cost to the power system, as participating DSR resources (or their aggregators) typically finance the modest infrastructure upgrades to become a DSR resource (e.g. power electronics upgrades, new information and communication systems). They receive compensation based on their participation in the market (and this compensation is captured within the operational modelling framework).

Options are also available that do require additional investment in retrofits. The example of adding flexibility to existing aluminium smelters has been analysed in detail as a separate option in addition to the DSR programmes (Box 25).

Box 25. Boosting the flexibility of aluminium smelters in China

Aluminium production in China accounts for up to 85 GW of demand and 593 TWh (7%) of electricity consumption in 2035. Globally, aluminium smelters account for nearly 5% of electricity consumption. Aluminium plants traditionally require a very stable level of supply to keep the electrochemical process running, as well as to maintain a critical heat balance in the reduction cells (known as "pots").

Recent innovations in the active temperature management of pots provides smelters with the ability to modulate power consumption both up and down by as much as +/- 30%. This is accomplished by retrofitting pots with an external temperature management system, which allows variations in electricity consumption while maintaining the critical heat balance of the pots and without affecting the electrochemical process in any way.

To increase energy use (which correspondingly produces more metal), additional cooling of the pot is required. The temperature management system achieves such cooling by drawing large volumes of ambient air past the external shell of the pot and into a ducting system, which is (usually) externally vented. The negative pressure to run the system is provided by a large external fan connected to the ducting, which is the only moving part. To achieve a decrease in energy use (which correspondingly produces less metal), the pot needs to be insulated to stop it from cooling. In this situation, the heat exchangers act as an insulating blanket when the fan speed is either reduced or stopped altogether.

An initial analysis of the latent flexibility potential from China's fleet of aluminium smelters indicates a potential of around 25 GW. Critically, the load-smoothing capacity that modulating aluminium smelters provide is not only from hour to hour and day to day, but from season to season as well. This can help mitigate supply disruption caused through the variability of generation, especially through extended seasonal periods of low generation.

The total cost of retrofitting smelters in China is estimated to be in the order of USD 10 billion, with the cost assumptions provided by industry (approximately USD 50 per kilowatt [kW] for downward flexibility and USD 100 million per smelter for upward) (EnPot, 2019). This compares to operational cost savings of USD 3.5 billion per year compared to the SDS-Inflex option. Assuming a contribution to peak net load reduction of 10 GW, this would imply a simple investment payback period of 1.5 years from a power system perspective, assuming that all retrofits are ratepayer financed.

It is important to note that the flexible use of aluminium smelters for seasonal load shifting will influence the production profile of the plant (while maintaining the same annual output). Costs associated with increased storage requirements for aluminium at the plant have not been taken into account in the analysis. However, the relatively short payback period points to substantial possible savings that merit a more detailed analysis.

Source: Information provided by Energia Potior and available on the website, How EnPot Works, https://www.energiapotior.com/how-enpot-works/.

DSR has already been recognised as a key system flexibility measure by Chinese policy makers (NDRC, 2017), and this case demonstrates the significant operational value that DSR programmes can potentially deliver to a largely decarbonised Chinese power system in 2035.

Policy makers can consider a variety of actions to realise the various benefits offered by widescale DSR deployment. First is the commissioning of economy-wide studies of DSR potential to better understand the opportunity and where best to direct efforts. Next, once promising market segments for DSR have been identified, specific government interventions may be necessary to enrol particular larger-scale load resources (e.g. aluminium smelters), including the design of financial incentives for retrofits and/or participation requirements. Once enrolment costs have been well established for specific classes of larger-scale DSR resources, potential estimates and associated costs can be included in long-term planning exercises to provide specific deployment targets and guidance to implementing policy-making agencies.

As increasing amounts of competition are introduced into the power system, upgraded market framework rules can also allow for the participation of demand aggregation entities who have the ability to stack DSR potential across regions, customer classes and devices. The market for small-scale DSR aggregation can be further supported by upgrading device manufacturing standards to encourage or mandate the inclusion of information and communications technology (ICT) systems that streamline secure communication with aggregators and grid operators.

Understanding the value of electricity storage: SDS-Storage

In the SDS-Storage case developed for this report, an additional approx. 70 GW of PSH and over 50 GW of battery energy storage are deployed. The main differences between these two forms of storage, from the standpoint of short-term operational flexibility, lies in the round-trip efficiency of the two technologies (75% for PSH and 81% for lithium-ion batteries) and the size of the storage. PSH resources are assumed to have as many as 10 hours of storage, whereas battery energy storage resources are deployed with an equal split of one-hour and four-hour storage capability.

Immediate operational and economic benefits result from adding storage to the SDS power system, as these resources allow pumping/charging loads to be shifted into periods of high VRE output, producing operational cost reductions. The additional storage resources reduce annual operational costs by around 3%, or approximately USD 8 billion per year, which is equivalent to the required annualised investment cost of the storage assets. The storage options bring a further benefit of a peak net demand reduction of 42 GW, which would result in avoided generation investment of USD 6 billion per year.

Storage also reduces VRE curtailment levels in every region compared to the SDS-Inflex case (Figure 42).

Storage options are primarily used during periods of highest and lowest net demand, storing energy during low-demand periods and discharging energy during peak periods. The result is lower peak demand and higher minimum demand (Figure 43). In doing so, storage provides flexibility for the system to reduce reliance on peaking generation while also reducing coal- and gas-fired generation levels, which have relatively high operational costs for fuel and emissions.