Potential for virtual energy storage in a wind-PV-hydropower system in Yalong River Basin, China

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Outline

1、Background

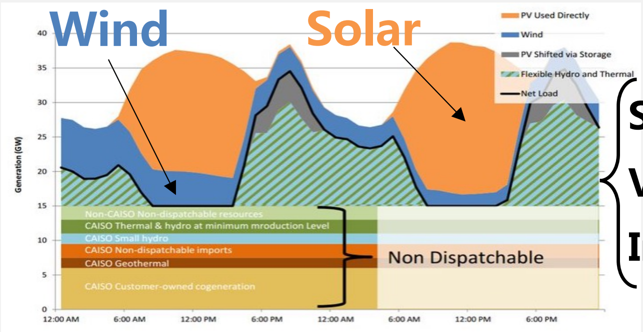
2、Methodology

3、Case Study

4、Results and discussion

New energy consumption requires flexibility resources

Wind-Solar-Hydropower multienergy system



Stochastic
Volatility
Intermittent

Need

Need

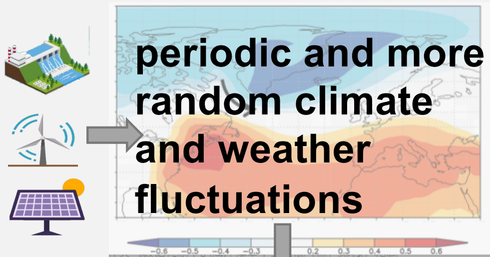
Energy Storage System

High cost of investment, operation, and maintenance

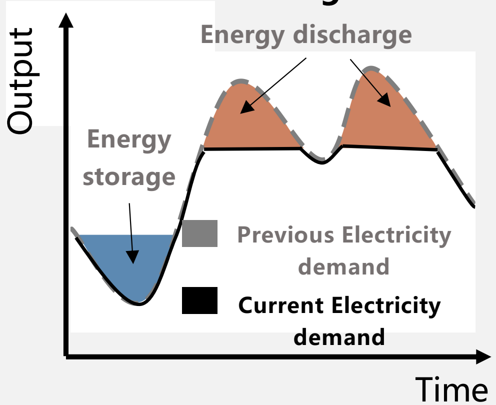
How to reduce the energy storage demand ?

Spatiotemporal characteristics of multienergy sources

① Time

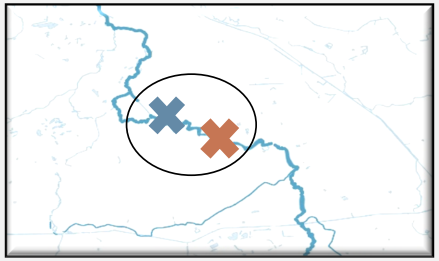


Differences in **abundance and drought**

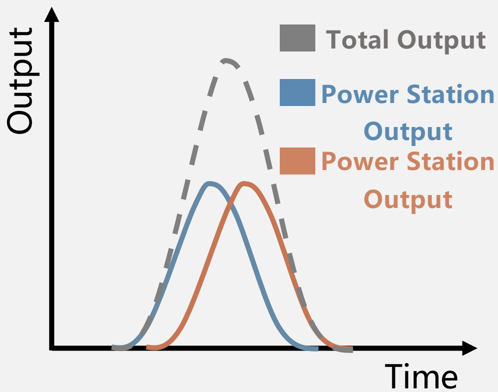


Small variance& Less energy storage demand

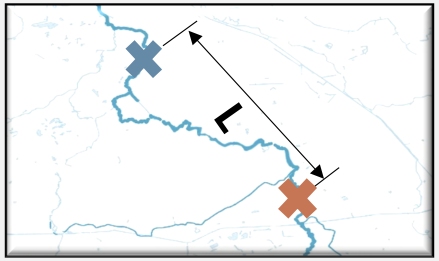
② Space



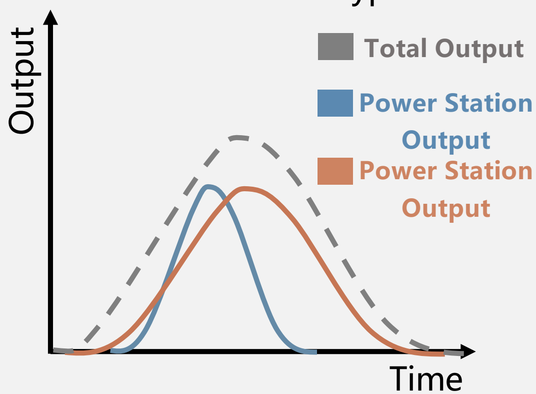
Two **close** power stations of the same type



Large variance& More energy storage demand

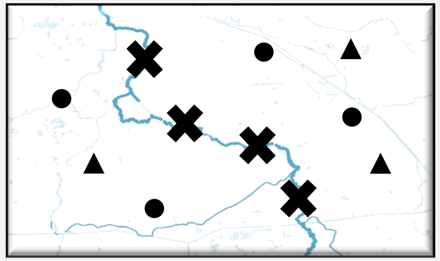


Two **distant** power stations of the same type

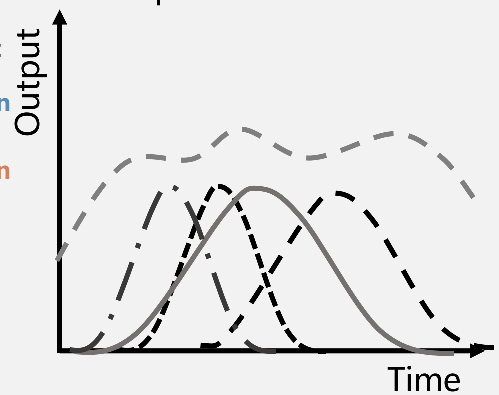


Small variance& Less energy storage demand

③ Energy source



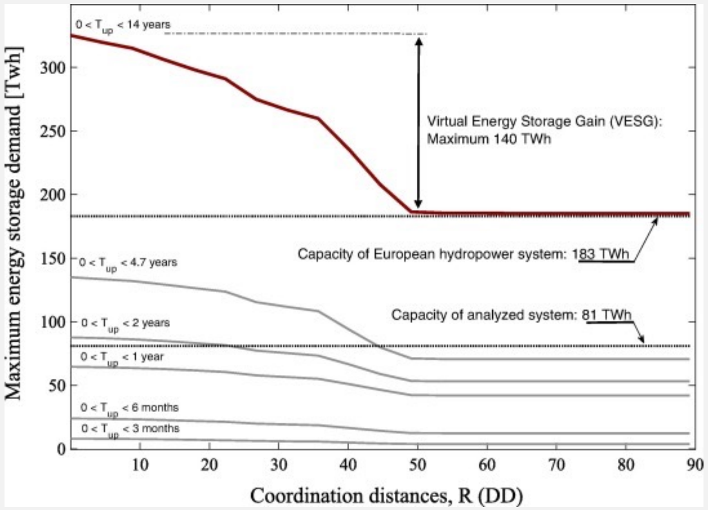
Different **types** of power stations



Smaller variance& Less energy storage demand

Spatiotemporal characteristics of multienergy sources

- Time
- Space
- Energy source



Virtual energy storage gain (VESG)

spatiotemporal coordination of multienergy

A reduction in the combined need for energy storage

Regional energy balance and energy storage demands

Energy conservation equation

Energy Storage Demand ←

$$\frac{\partial E}{\partial t} = P_c - P_d - X$$

- P_c: power production
- P_d: power demand
- X: the rate of imported and exported energy of the region

Formula Transformation

$$\frac{\partial E}{\partial t} = P_c + \varepsilon$$

Fluctuating Form

$$\Delta P_c(t) = P_c(t) - \overline{P_c}$$
$$\Delta E(t) = E(t) - \overline{E}$$
$$\Delta \varepsilon(t) = \varepsilon(t) - \overline{\varepsilon}$$

→

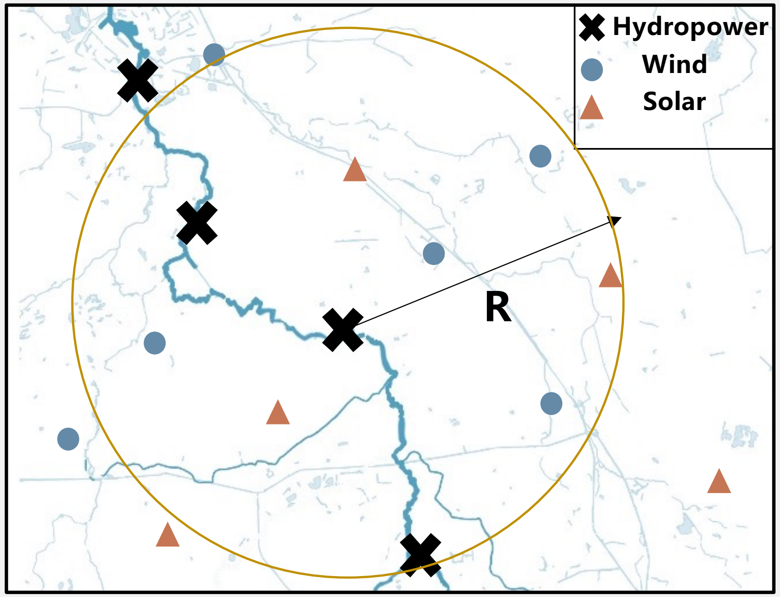
$$\frac{\partial(\Delta E)}{\partial t} = \Delta P_c + \Delta\varepsilon$$

The energy storage demand is determined by the fluctuation of the available energy.

Scenarios for coordinating hydropower production with wind and solar power

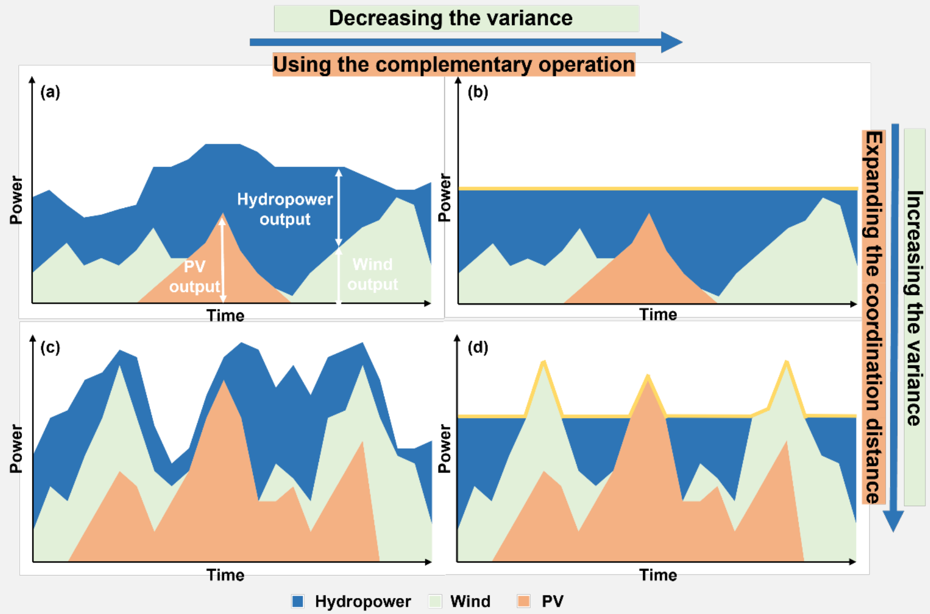
1 Unified Operations Scenario UOS

Unified operations for all power production stations within a coordination distance R



2 Hydropower Complementary Scenario HCS

Considers complementary operation between the hydropower production and the wind and PV power stations within the corresponding coordination distance R with respect to these stations.



Analysis of the regional maximum energy storage demand

Maximum energy storage demand → $E_{max} = \sqrt{2} std(P_c) T/\pi$

Std of the sum of the power output of all power stations in the region → $Std\left(\left(\sum_{i=1}^{N}(P_{c,i})\right)\right) = \sqrt{\sum_{i=1}^{N} Var(P_{c,i}) + \sum_{i\neq j=1}^{N} Cov(P_{c,i}; P_{c,j})}$

Unified Operations Scenario

$$Std\left(\left(\sum_{i=1}^{N}(P_{c,i})\right)\right) = \sqrt{\left.\sum_{i=1}^{N} Var(P_{c,i}) + \sum_{i\neq j=1}^{N} Cov(P_{c,i}; P_{c,j})\right|_{r_{i,j}<R} + \left.\sum_{i\neq j=1}^{N} std(P_{c,i}) std(P_{c,j})\right|_{r_{i,j}>R}}$$

$$\left.Std\left(\sum_{i=1}^{N}(P_{c,i})\right)\right|_{r_{HP,i}<R} \leq \left.\sum_{i=1}^{N} Std(P_{c,i})\right|_{r_{HP,i}>R}$$

Hydropower Complementary Scenario

$$Std\left(\left(\sum_{i=1}^{N}(P_{c,i})\right)\right) = \sqrt{\left.\sum_{i=1}^{N} Var(P_{c,i}) + \sum_{i\neq j=1}^{N} Cov(P_{c,i}; P_{c,j})\right|_{r_{i,j}<R}}$$

$$Std\left(\left(\sum_{i=1}^{N}(P_{c,i})\right)\right) = \sqrt{\left.Var\left(\left(\sum_{HP=1}^{M_{HP}} \sum_{i_{HP}=1}^{N_{HP}} (P_{c,i})\right)\right)\right|_{r_{HP,i_{HP}}<R}}$$

Energy storage demand calculation based on power spectra

The relationship between energy fluctuations and energy storage E in the basin

$$\frac{\partial(\Delta E)}{\partial t} - \sum_{i=1}^{N} \Delta P_{c,i} = 0$$

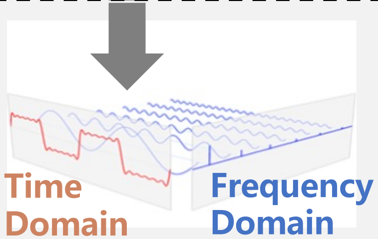
Definition of power spectrum

$$(2\pi f)^2 S(E(f)) = S\left(\sum_{i=1}^{N} P_{c,i}(f)\right)$$

$$Var(E) = 2\int_{f_1}^{f_2} S(E(f))\,df$$

Fourier transform

$$Var(E) = 2\int_{f_1}^{f_2} \frac{S\left(\sum_{i=1}^{N} P_{c,i}(f)\right)}{(2\pi f)^2}\,df$$



Time Domain

Frequency Domain

the total variance of the time series = the integral of the power spectrum

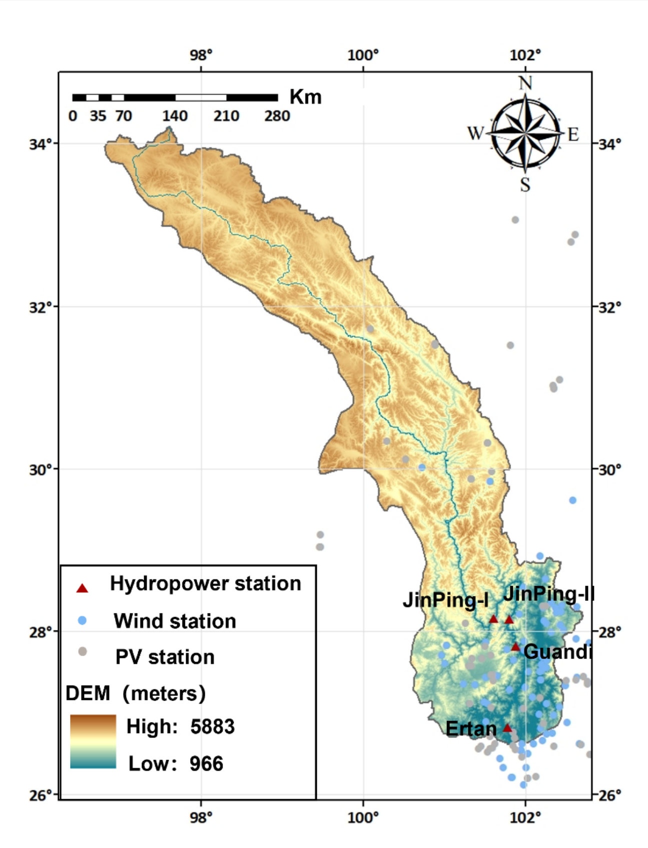
Maximum energy storage demand

$$E_{max} = \sqrt{a * Var(E)}$$

Power spectrum form of the variance of the coordination distance

$$S\left(\sum_{i=1}^{N} P_{c,i}\right) = \left(\sum_{i=1}^{N} S(P_{c,i}) + \sum_{i\neq j}^{N} Re\{S(P_{c,i}; P_{c,j})\}\right)$$

Study area



Yalong River basin in China

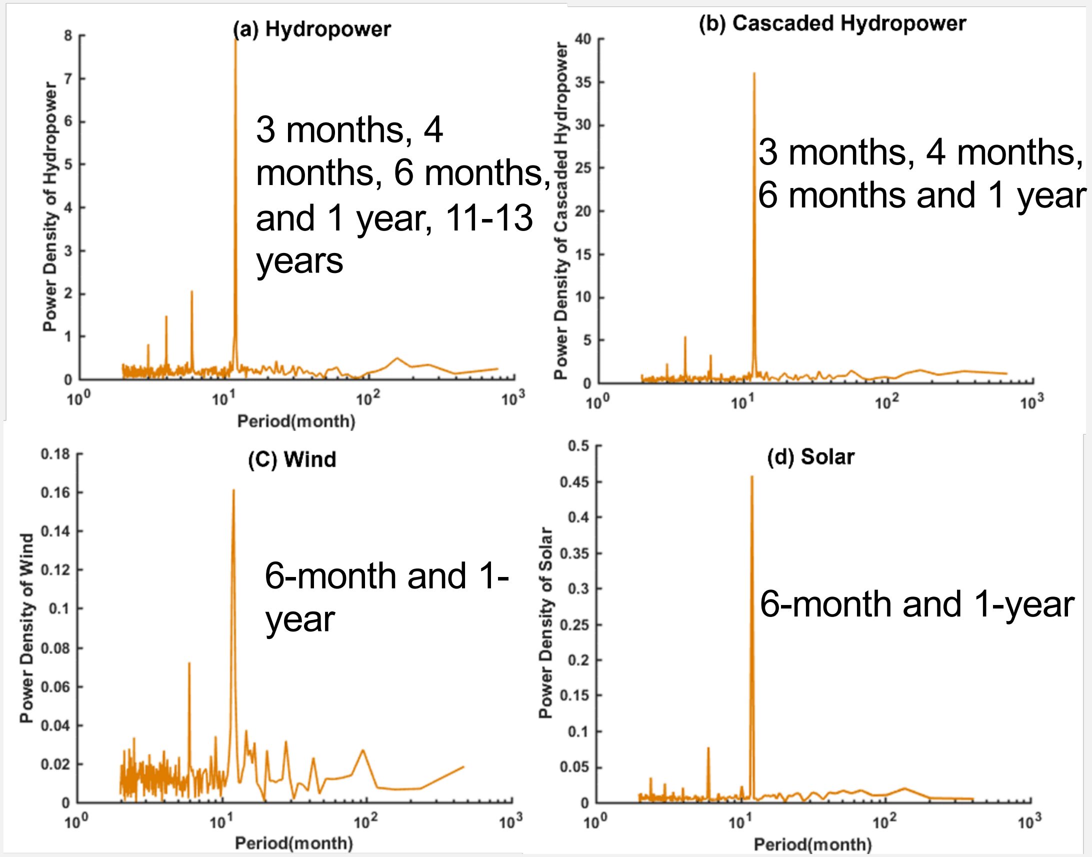
Scheme — Management scenarios considered for multienergy power coordination

1. **UOS-S**
   unified operation- single station scenario
2. **HCS-S**
   hydropower complementary- single station scenario
3. **UOS-M**
   unified operation- multiple station scenario
4. **HCS-M**
   hydropower complementary-multiple station scenario

Intraregional energy power spectral density analysis

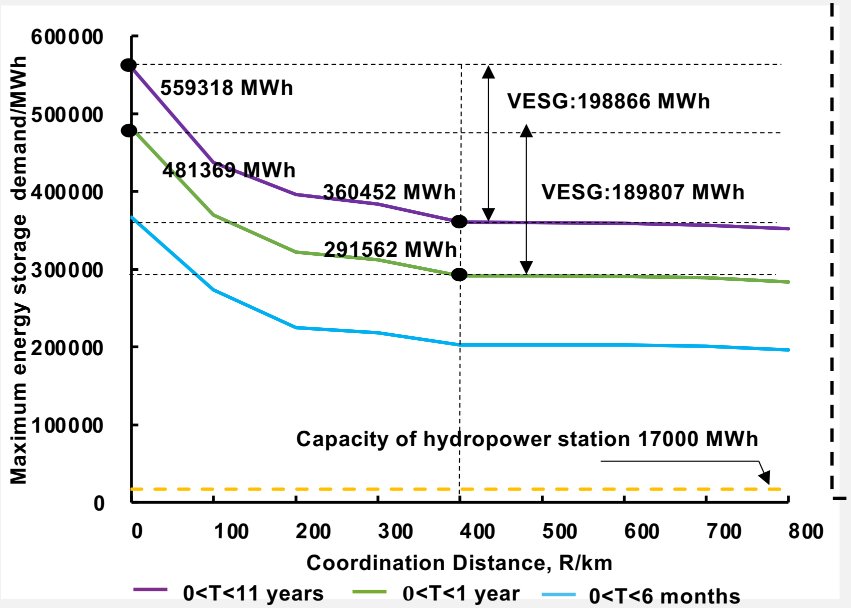
The spectral density of different energy in the region

Three different periods of 6 months, 1 year, and 11 years were chosen to analyse the energy storage demand under each period and the optimal coordination range.



Single-station scenarios for the spatial and temporal coordination

(a) UOS-S Scenario



0<T<1 year 481369 MW → 291562 MW

- Coordination distance is small
  →poor complementarity → large energy storage demand

- Coordination distance is large
  → the complementarity increases
  since multiple energies coordinate spatially and temporally
  → reduce the energy storage demand

- VESG 189807MW= 11.17 * Capacity of hydropower station:17000MWh

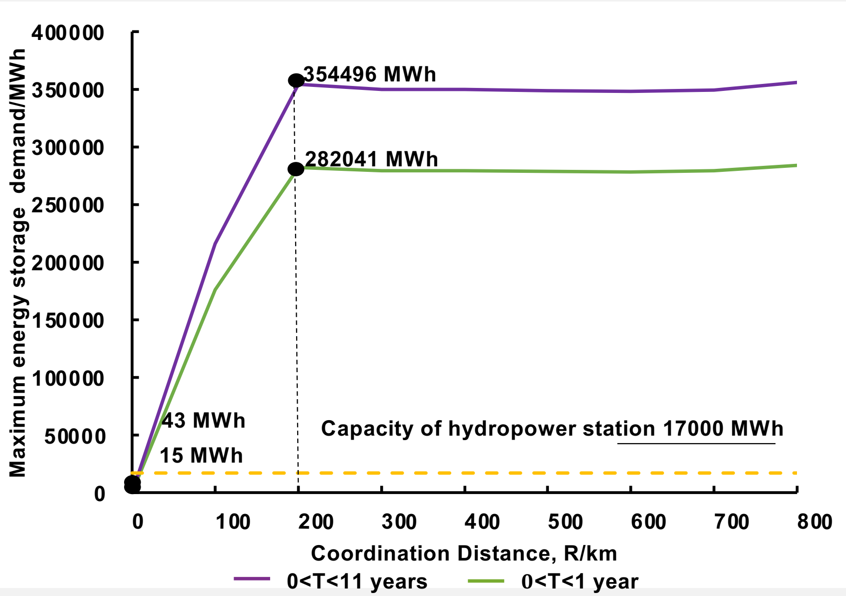
0<T<11 year 559318 MW → 360452 MW

Larger regulation period → Larger VESG （198866MW > 189807MW）

- The complementary effect on the larger time scale is mainly due to the difference in hydropower output in wet years and dry years.

Single-station scenarios for the spatial and temporal coordination

(b) HCS-S Scenario



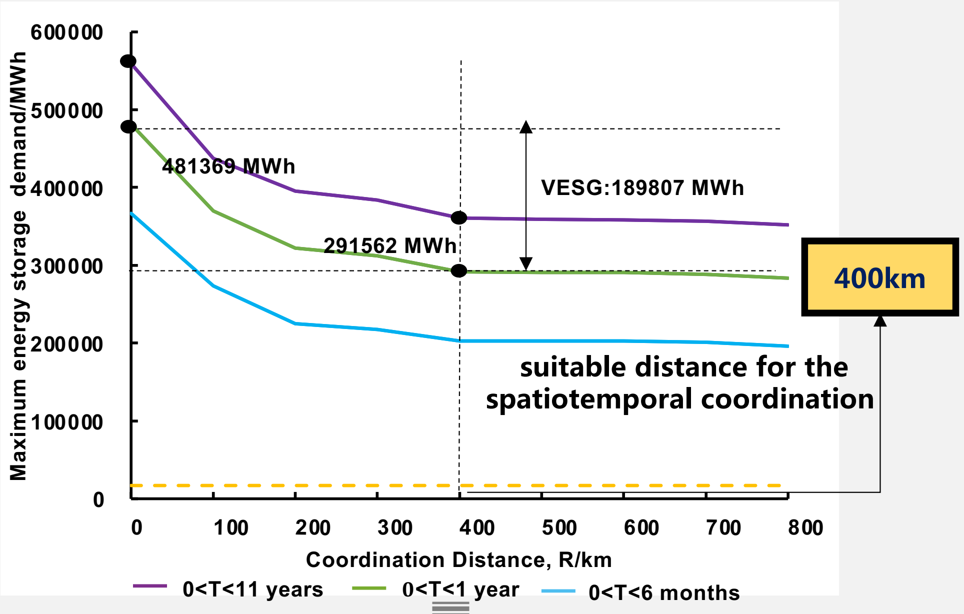
0<T<1 year 15 MW → 282041 MW

- the hydropower regulation ability decrease
  →storage demand ↑
- spatial-temporal coordination
  → storage demand ↓
  Small coordination distance,
  hydropower regulation ability > spatial-temporal coordination
  Large coordination distance,
  hydropower regulation ability< spatial-temporal coordination

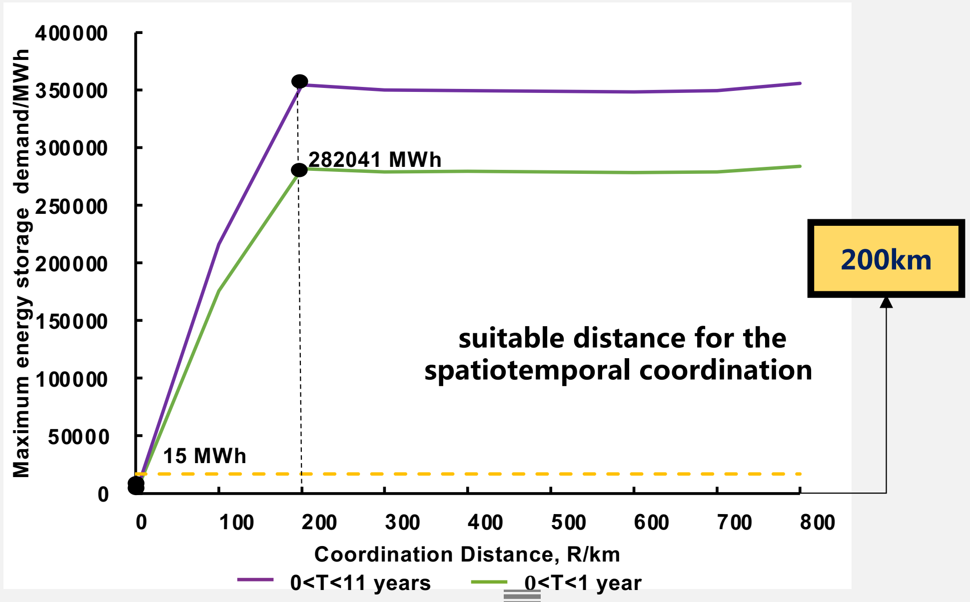
0<T<11 year 43 MW → 354496 MW → **Upward tendency**

Single-station scenarios for the spatial and temporal coordination

(a) UOS-S Scenario



(b) HCS-S Scenario

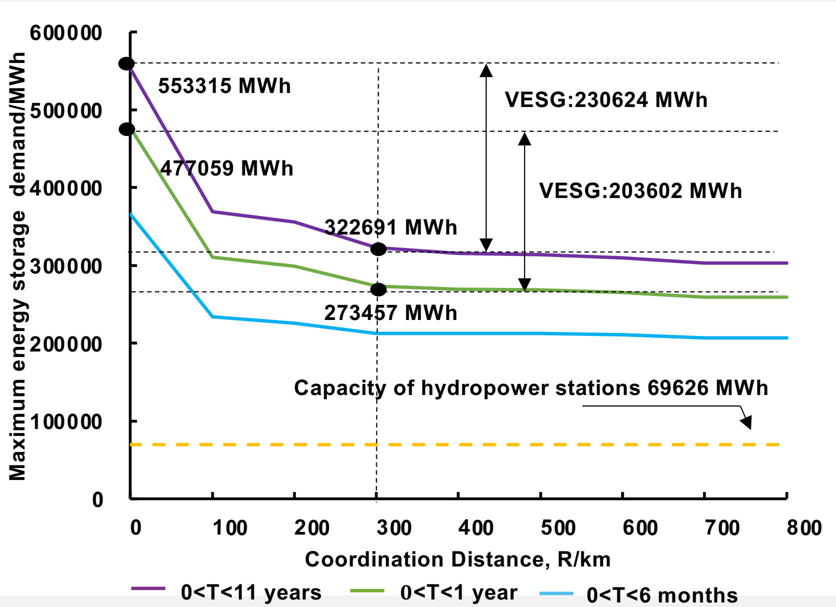


Storage demand is 360452 MWh with 400 km of coordination > **Storage demand is 354496 MWh with 200 km of coordination**

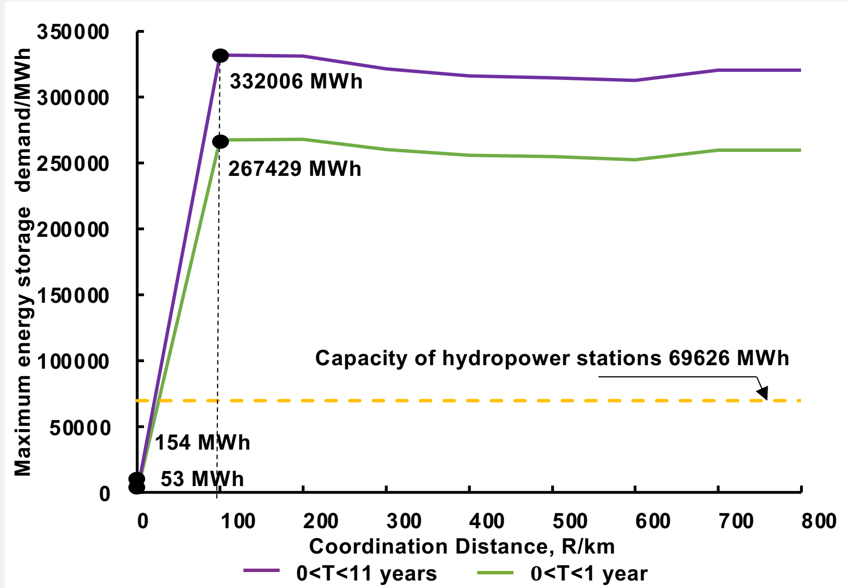
Reflect the advantages of the coordinated operation of hydropower, wind and PV power compared to the operation that only considers its own optimal levels

Multiple-station scenarios for the spatial and temporal coordination

(a) UOS-M Scenario



(b) HCS-M Scenario



VESG: 203602 MWh → Capacity of hydropower station:17000MWh (2.92 times)

300km → suitable distance for the spatiotemporal coordination

100km → suitable distance for the spatiotemporal coordination

Thank You !