# Might the large-scale PV power generation be reached in China? A grid parity combined with techno-economic analysis




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# Outline

I. Introduction

II. Construction and parameter description

III. Techno-economic evaluation

IV. Grid parity estimation based on learning curve

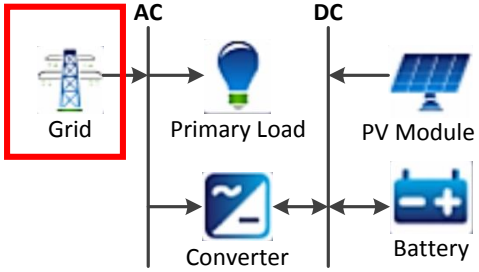
V. Conclusions and policy implications

# I. Introduction

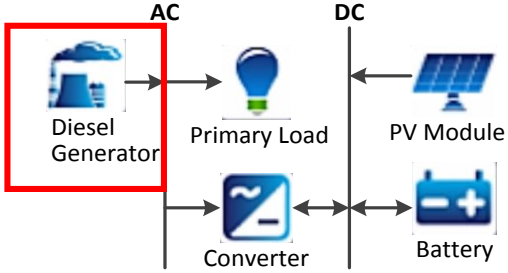
- Pressure of carbon reduction: The electricity generated from renewable energy will be reached at 9% in 2020 in the energy planning of National Energy Administration of China; But in 2013, this percentage was only 2.8%.
- The new-added installed capacity of PV solar in China: up to 10.6 GW in 2014, which accounted for about 20% of total new-added installed capacity in the world.
- The PV power generation: only 9, 000 GWh in 2013 accounting for 0.166% of the electricity generation of China. plans to be reached at 150,000GWh in 2020.
- Might this target be reached in 2020? When and What type of PV power generation (grid-connected or off-grid) can be applied in large scale? Where is more suitable to use PV power generation in China?

# II. System construction and parameter description

## 1. Grid-connected and off-grid PV power generation system




The structure of grid-connected PV system

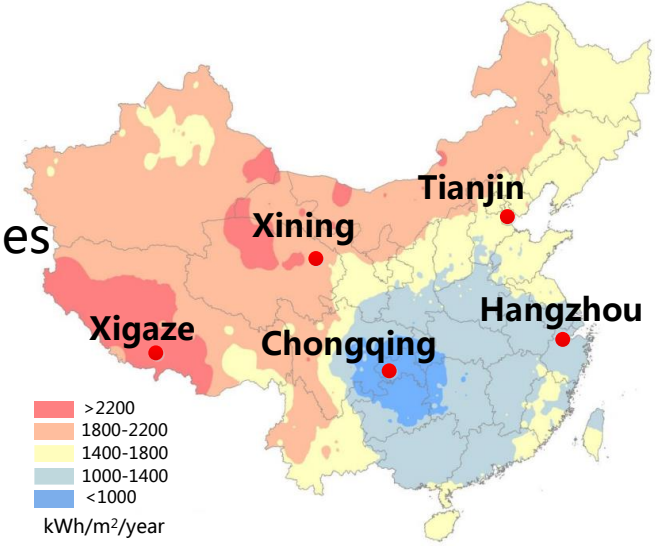



The structure of off-grid PV system

## 2. PV systems in five cities

Solar radiation (five regions):

- More solar radiation than other countries with a similar latitude;
- distributed unevenly;




The distribution of China’ s solar radiation under the optimal slope

# II. System construction and parameter description (cont'd)

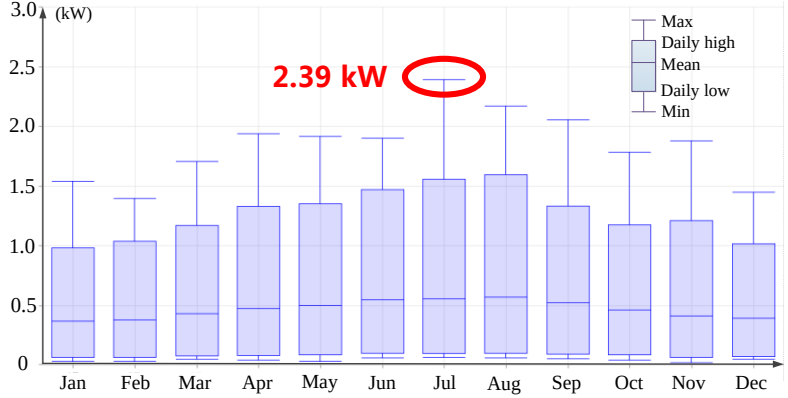
## 3. Data and Parameter description

- HOMER (Hybrid Optimization of Multiple Energy Resources), a micro-grid software developed by the HOMER Energy LLC;
- Three main functions: simulation, optimization & sensitivity analysis.

**The cost of each component in PV system**

| Components | Capital | Replacement | O&M | Lifetime |
|---|---|---|---|---|
| PV module (1kW) | 3640 | 3640 | 36.4 | 20 years |
| Converter (1kW) | 800 | 800 | 0 | 15 years |
| Battery | 600 | 600 | 0 | 10 years |
| Diesel generator (1kW) | 1300 | 1300 | 0 | 15000 h |

**Collected from: Annual Review and Outlook for China Solar PV industry, 2013; www.solarzoom.com; www.1688.com**




**The synthesized data of load profile of residential houses**

**The picture resource comes from the HOMER software**

# III. Techno-economic evaluation

## 1. Technical feasibility analysis

Objective function: $min$ NPC (Net Present Cost)

s.t.

the electricity generated from each component in a PV system ≥ the electricity demand

**The optimal system configurations of grid-connected and off-grid PV systems in five cities**

| | Cities | PV capacity (kW) | Battery (quantity) | Converter capacity (kW) | Generator capacity (kW) |
|---|---|---|---|---|---|
| Grid-connected | All five cities | 3 | 1 | 1 | / |
| Off-grid | Chongqing | 10 | 30 | 3 | 5 |
| | Hangzhou | 7 | 35 | 3 | 5 |
| | Tianjin | 5 | 35 | 3 | 5 |
| | Xining | 5 | 30 | 3 | 5 |
| | Xigaze | 5 | 25 | 3 | 5 |

# III. Techno-economic evaluation (cont'd)

## 1. Technical feasibility analysis

Grid-connected:

PV production: more than 50%;

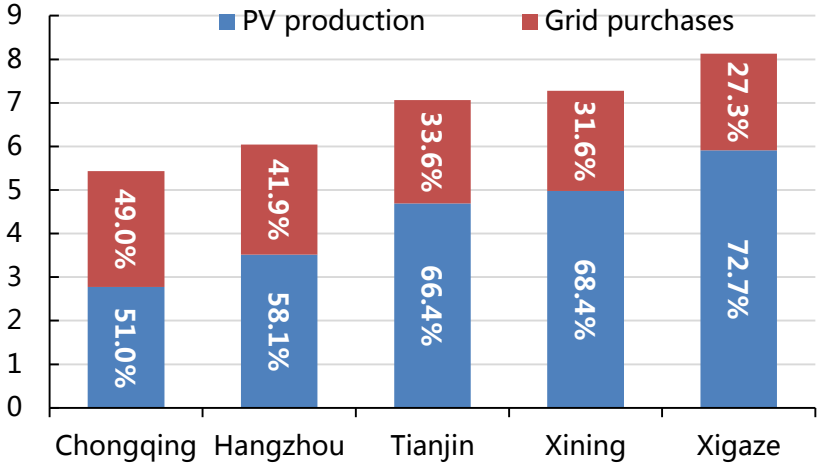
Xigaze: PV 5913 kWh (72.7%);

Chongqing: PV 2771 kWh (51%).

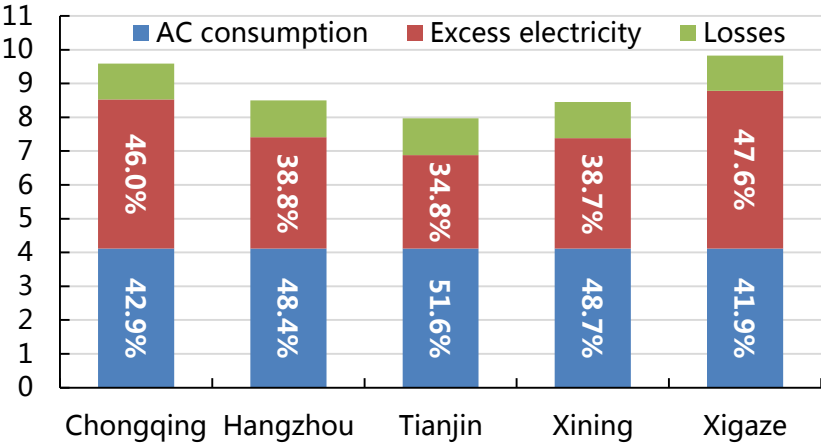
Off-grid:

The same electricity consumption: 4113 kWh/year;

The excess electricity of Tianjin is the lowest; (the most cost-effective)




**The electricity generation of grid-connected PV systems**




**The electricity generation of off-grid PV systems**

# III. Techno-economic evaluation (cont'd)

## 2. Cost-effectiveness analysis

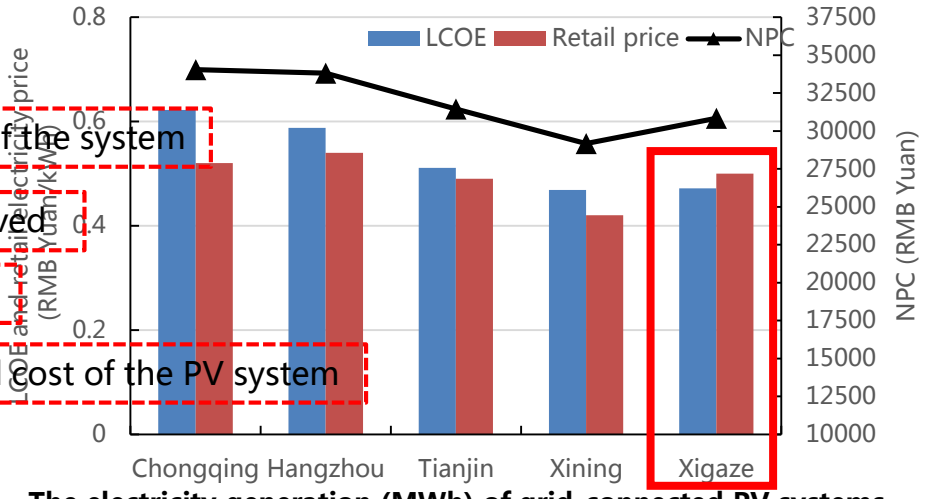
$$LCOE = \frac{C_{\text{ann}}}{E_{\text{served}}}$$

Levelized cost of energy

- $C_{\text{ann}}$: the total annualized cost of the system
- $E_{\text{served}}$: the total electrical load served

$$C_{\text{ann}} = CRF(i, N) * C_{\text{NPC}}$$

- $CRF(i, N)$: capital recovery factor
- $C_{\text{NPC}}$: the total net presented cost of the PV system



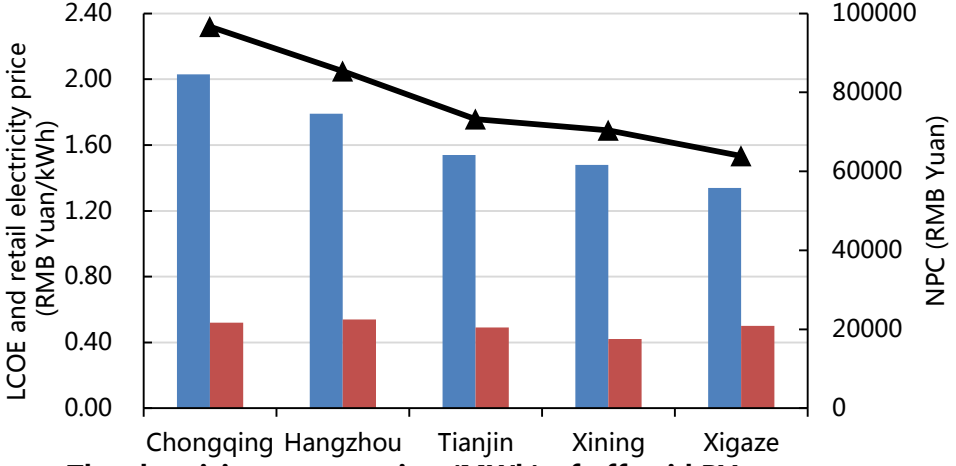

**The electricity generation (MWh) of grid-connected PV systems**

Grid-connected:

- LCOE: 0.469-0.622 RMB Yuan/kWh;
- Xigaze: the only region, LCOE<retail price;

Off-grid:

- LCOE: 1.34-2.03 RMB Yuan/kWh;
- NPC: much more than grid-connected systems (more energy storage batteries).




**The electricity consumption (MWh) of off-grid PV system**

# III. Techno-economic evaluation (cont'd)

## 3. Environmental performance

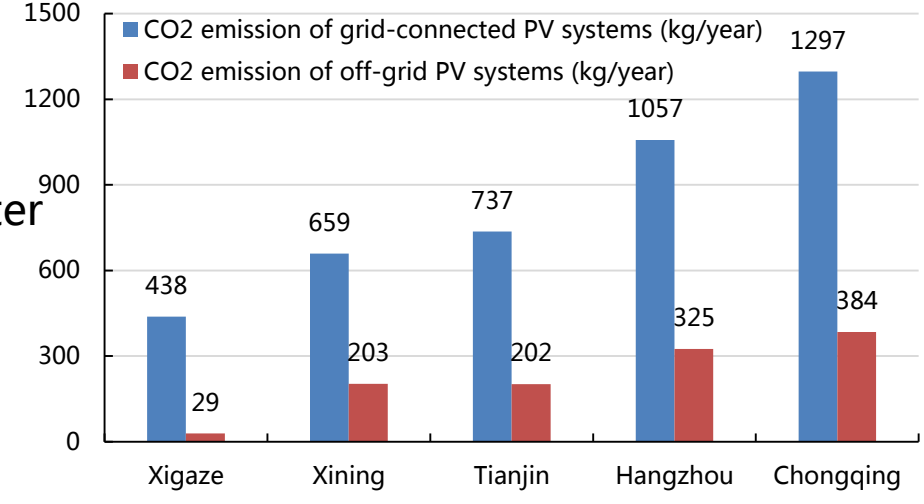
$M_i = E_p * EF_i$

$M_i$: the emissions of pollutant i (kg)

$E_p$: the net grid purchases (kWh) or the consumption of fuel p (kg)

$EF_i$: the emissions factor of pollutant i

- $CO_2$, $SO_2$, $NO_X$ , CO and particulate matter
- Grid-connected > off-grid




**The CO2 emissions produced by grid-connected and off-grid systems in five cities**

# IV. Grid parity estimation based on learning curve

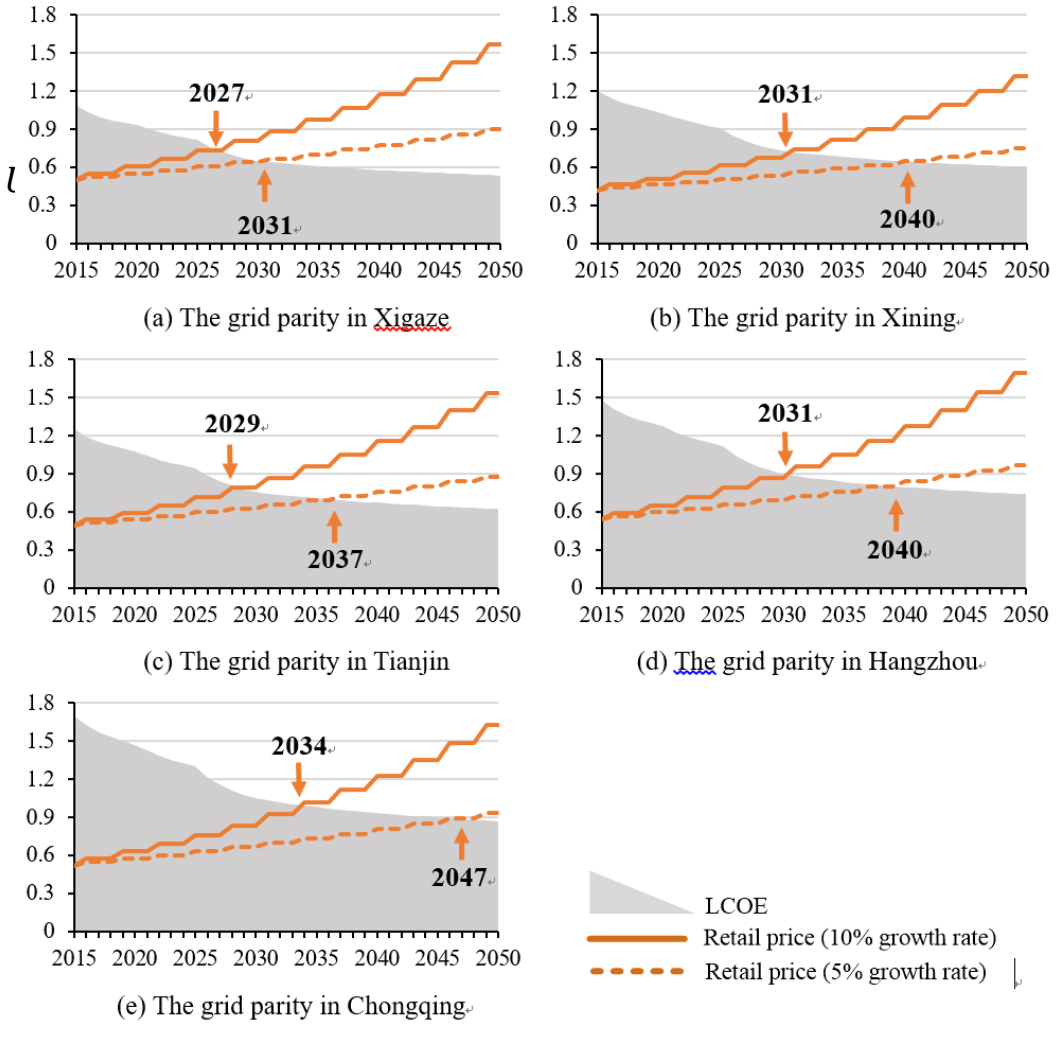
## 1. The learning curve in five cities

| Model | Formula |
|---|---|
| One-factor | $SC = a \times (CC^{-b})$ |
| Two-factor | $SC = a \times (CC^{-b}) \times (KS^{-c})$ |
| Three-factor | $SC^{inflation} = a \times (CC^{-b}) \times (KS^{-c})Q^{d}$ |
| Four-factor | $SC = a \times (CC^{-b}) \times (KS^{-c})Q^{d}(\prod_{i=1}^{n} p_i^{e^i})$ |

## 2. Grid parity in five cities

Grid parity in future 30 years;

Xigaze: the first region (2027-2031).




(a) The grid parity in Xigaze

(b) The grid parity in Xining

(c) The grid parity in Tianjin

(d) The grid parity in Hangzhou

(e) The grid parity in Chongqing

# Conclusions and policy implications

The LCOE of grid-connected PV systems is close to the retail electricity price (RMB Yuan/kWh).

| | Chongqing | Hangzhou | Tianjin | Xining | Xigaze |
|---|---|---|---|---|---|
| LCOE | 0.622 | 0.588 | 0.511 | 0.469 | 0.472 |
| Retail price | 0.520 | 0.540 | 0.489 | 0.420 | 0.500 |

**1. The diversified development of the user market**

(1) Courtyard house and single houses;
(2) High-tech industrial parks.

Xigaze has the best solar radiation and the earliest grid parity (2027-2031).

Tianjin has the high retail electricity price and the average solar radiation.

**2. Market deployment of PV power generation will vary across regions**

(1) Remote areas in Tibei —— off-grid PV system;
(2) North China —— grid-connected PV system.

The LCOE of off-grid PV systems will drop to be 0.536 -0.870 RMB Yuan/kWh in 2050.

Grid parity will be reached in the future 30 years.

**3. The subsidy-change strategy of PV power generation**

China's benchmark price is reducing to 0.80, 0.88 & 0.98 RMB Yuan/kWh in 2017.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