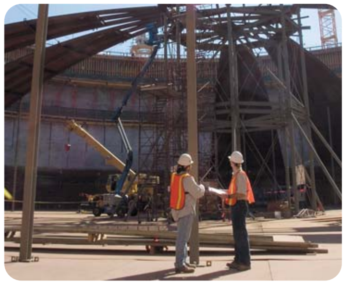
BUILDING A WORLD OF DIFFERENCE®

BLACK & VEATCH


Wind GIS Analysis For China

Prepared for the Energy Foundation
China Sustainable Energy Program

October 2009

Overview

- Analysis Assumptions
- Analysis Results
- Comparison of Results with Other Analysis

GIS Analysis Assumptions

- **Data Source**: 3Tier wind map of China
- **Regions**: Provinces
- **Exclusions**:
  - Land above 20% slope
  - Water bodies
  - Did NOT exclude urban areas, farmland, protected areas
- **Capacity Density**: 5 MW per km2
- **Capacity Factors**
  - Class 3 – 28%
  - Class 4 – 31%
  - Class 5 – 35%
  - Class 6 – 40%
  - Class 7 – 42%

Sources for GIS Data

- **Wind Power Density -** 80 meter hub height, 5km x 5km resolution, from 3Tier
- **Slope** – Derived from a digital elevation model (DEM) from the Harvard's China Historical GIS (CHGIS) dataset V3. 30 arc-second resolution. Publicly available.
- **Bodies of water** – A combination of data from the Digital Chart of the World, and land use data from CHGIS dataset. Publicly available.

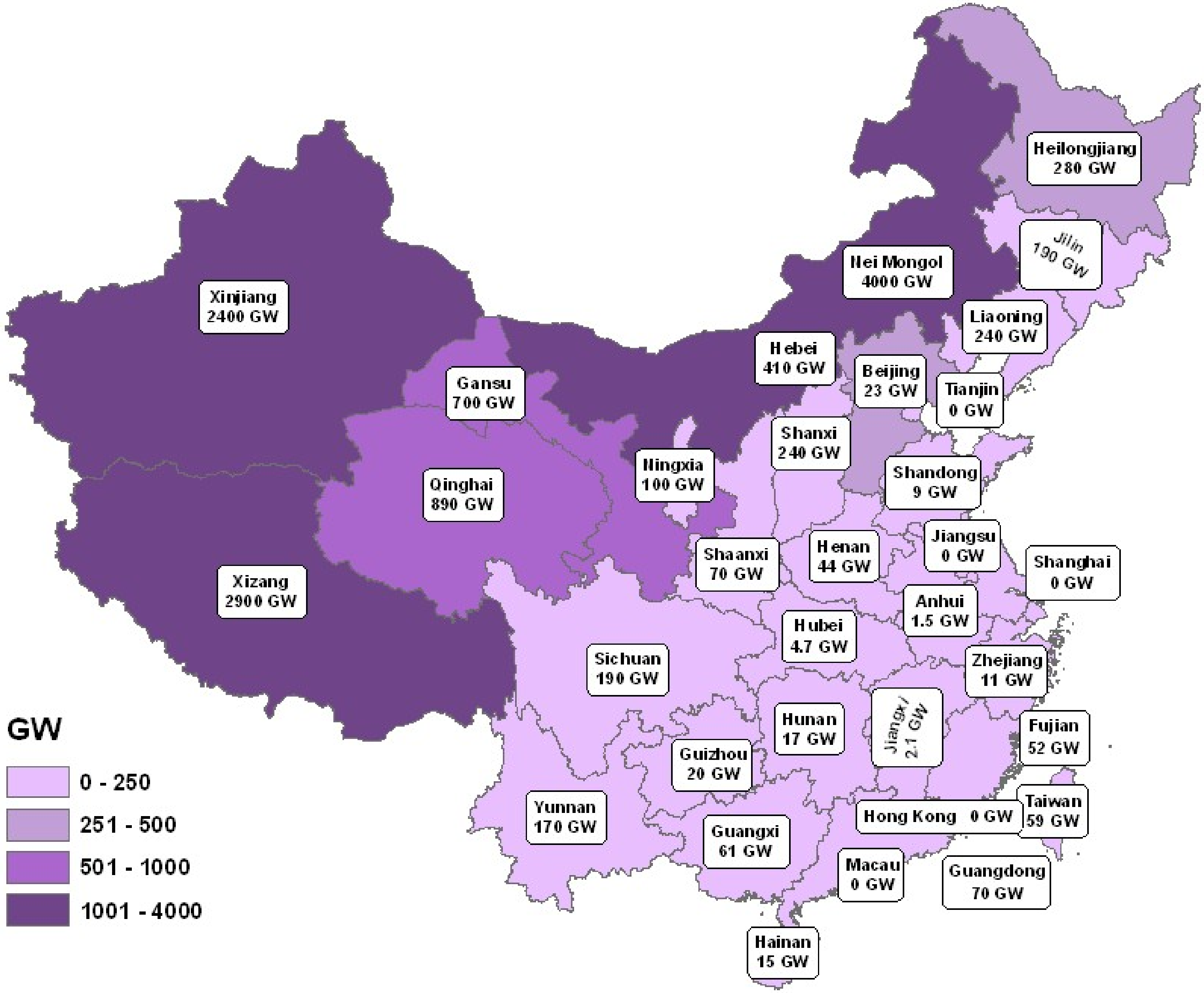
Differences with Other Analysis

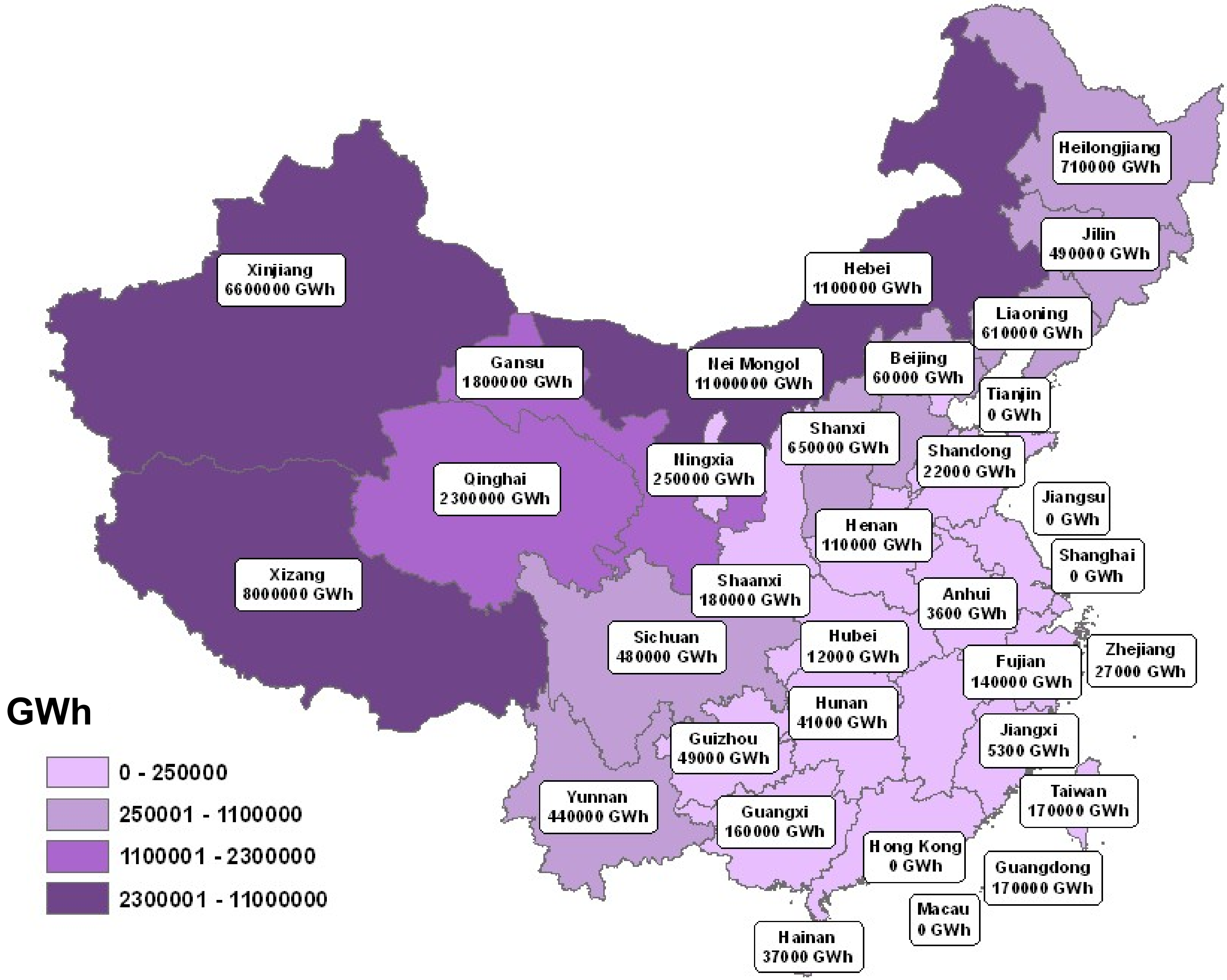
- Black & Veatch did not perform traditional supply curve analysis
  - Only reports potential GW and GWh, not costs
- Due to limited GIS layer information:
  - Black &Veatch reports all ***technical*** wind potential
  - Does not exclude land due to competing uses, except water bodies
  - Assumes a 50% discount for ***developable*** potential

Results – No Discounts, All Provinces

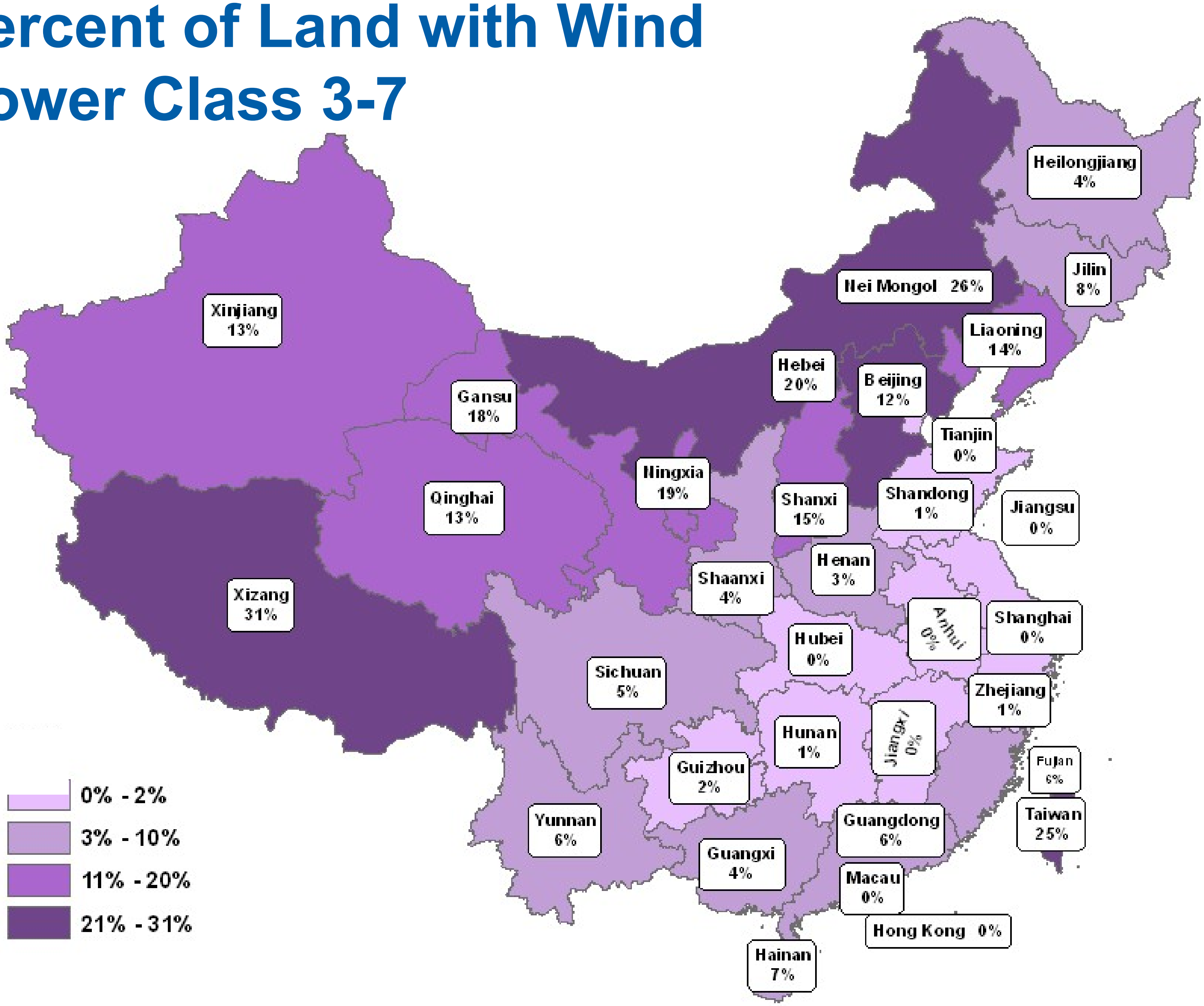
	GW Potential	GWh Potential
Class 3	7,927	19,443,811
Class 4	2,897	7,867,661
Class 5	1,216	3,728,396
Class 6	901	3,158,290
Class 7	285	1,050,097
Total	**13,227**	**35,248,256**

Significant wind potential in China


Heilongjiang
280 GW
Jilin
190 GW
Nei Mongol
4000 GW
Liaoning
240 GW
Xinjiang
2400 GW
Hebei
410 GW
Beijing
23 GW
Tianjin
0 GW
Gansu
700 GW
Shanxi
240 GW
Ningxia
100 GW
Qinghai
890 GW
Shandong
9 GW
Jiangsu
0 GW
Shaanxi
70 GW
Henan
44 GW
Shanghai
0 GW
Xizang
2900 GW
Anhui
1.5 GW
Hubei
4.7 GW
Sichuan
190 GW
Zhejiang
11 GW
Hunan
17 GW
Jiangxi
2.1 GW
Fujian
52 GW
Guizhou
20 GW
Taiwan
59 GW
Hong Kong 0 GW
Yunnan
170 GW
Guangxi
61 GW
Macau
0 GW
Guangdong
70 GW
Hainan
15 GW
GW
0 - 250
251 - 500
501 - 1000
1001 - 4000


Heilongjiang 710000 GWh
Jilin 490000 GWh
Xinjiang 6600000 GWh
Hebei 1100000 GWh
Liaoning 610000 GWh
Gansu 1800000 GWh
Nei Mongol 11000000 GWh
Beijing 60000 GWh
Tianjin 0 GWh
Shanxi 650000 GWh
Ningxia 250000 GWh
Qinghai 2300000 GWh
Shandong 22000 GWh
Jiangsu 0 GWh
Henan 110000 GWh
Shanghai 0 GWh
Xizang 8000000 GWh
Shaanxi 180000 GWh
Anhui 3600 GWh
Sichuan 480000 GWh
Hubei 12000 GWh
Zhejiang 27000 GWh
Fujian 140000 GWh
Hunan 41000 GWh
Guizhou 49000 GWh
Jiangxi 5300 GWh
Yunnan 440000 GWh
Guangxi 160000 GWh
Taiwan 170000 GWh
Hong Kong 0 GWh
Guangdong 170000 GWh
Macau 0 GWh
Hainan 37000 GWh
GWh
0 - 250000
250001 - 1100000
1100001 - 2300000
2300001 - 11000000

Percent of Land with Wind Power Class 3-7



Top 10 Provinces by Potential

Province	GW Potential	GWh Potential
Nei Mongol	4,020	10,547,243
Xizang	2,919	8,028,146
Xinjiang	2,419	6,607,865
Qinghai	886	2,294,301
Gansu	697	1,815,593
Hebei	412	1,127,568
Heilongjiang	279	708,812
Shanxi	243	645,330
Liaoning	240	608,117
Sichuan	191	484,284

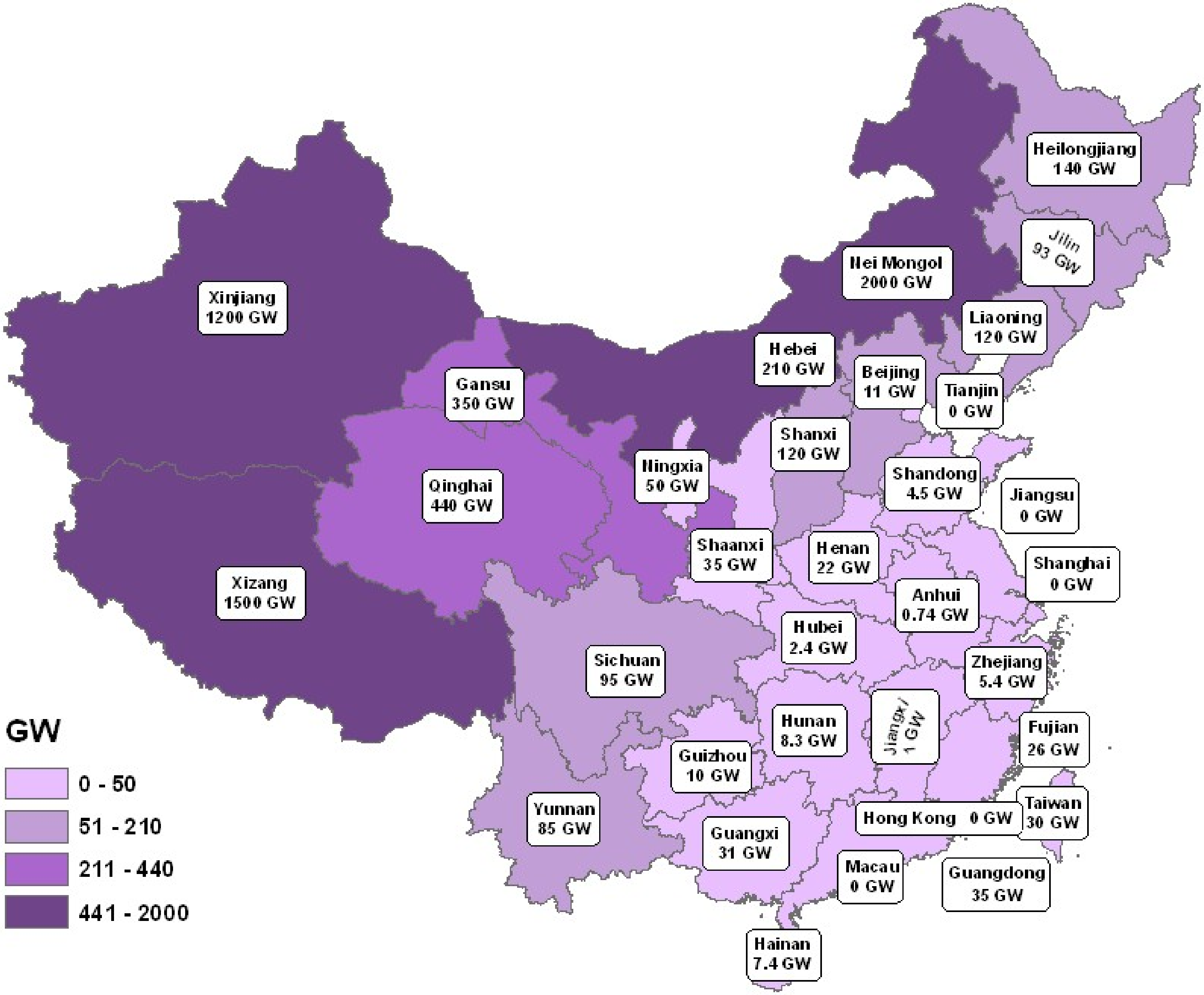
Most Potential is in Class 3

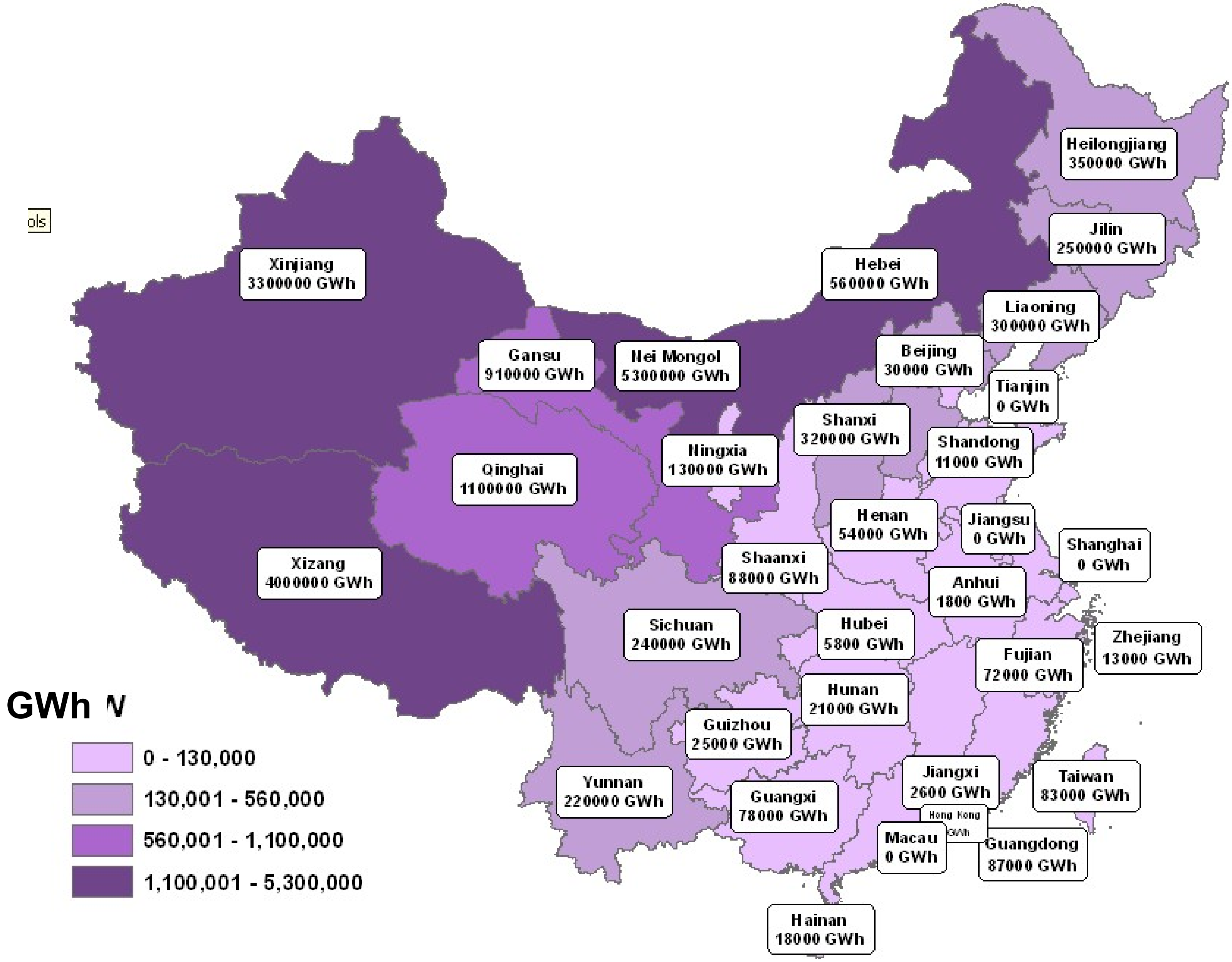
	GW Technical Potential				
Province	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**
Nei Mongol	2,683	776	277	213	71
Xizang	1,435	696	372	301	115
Xinjiang	1,239	581	279	247	73
Qinghai	598	195	66	24	3
Gansu	439	174	68	15	1
Hebei	207	102	44	44	15
Heilongjiang	215	44	17	3	-
Shanxi	139	65	22	15	2
Liaoning	180	51	8	1	-
Sichuan	145	38	4	3	0
Total	**7,279**	**2,722**	**1,158**	**867**	**281**

Assuming a 50% Developable "Discount"

	GW Potential	GWh Potential
Class 3	3,964	9,721,906
Class 4	1,449	3,933,831
Class 5	608	1,864,198
Class 6	451	1,579,145
Class 7	143	525,049
Total	**6,614**	**17,624,128**

Not all technical wind potential can be developed


Heilongjiang 140 GW
Jilin 93 GW
Nei Mongol 2000 GW
Liaoning 120 GW
Xinjiang 1200 GW
Hebei 210 GW
Beijing 11 GW
Tianjin 0 GW
Gansu 350 GW
Shanxi 120 GW
Ningxia 50 GW
Shandong 4.5 GW
Jiangsu 0 GW
Qinghai 440 GW
Shaanxi 35 GW
Henan 22 GW
Shanghai 0 GW
Xizang 1500 GW
Anhui 0.74 GW
Hubei 2.4 GW
Sichuan 95 GW
Zhejiang 5.4 GW
Hunan 8.3 GW
Jiangxi 1 GW
Fujian 26 GW
Guizhou 10 GW
Yunnan 85 GW
Hong Kong 0 GW
Taiwan 30 GW
Guangxi 31 GW
Macau 0 GW
Guangdong 35 GW
Hainan 7.4 GW
GW
0 - 50
51 - 210
211 - 440
441 - 2000


Xinjiang
3300000 GWh
Gansu
910000 GWh
Nei Mongol
5300000 GWh
Hebei
560000 GWh
Heilongjiang
350000 GWh
Jilin
250000 GWh
Liaoning
300000 GWh
Beijing
30000 GWh
Tianjin
0 GWh
Shanxi
320000 GWh
Shandong
11000 GWh
Ningxia
130000 GWh
Qinghai
1100000 GWh
Henan
54000 GWh
Jiangsu
0 GWh
Shanghai
0 GWh
Shaanxi
88000 GWh
Anhui
1800 GWh
Xizang
4000000 GWh
Sichuan
240000 GWh
Hubei
5800 GWh
Zhejiang
13000 GWh
Fujian
72000 GWh
Hunan
21000 GWh
Guizhou
25000 GWh
Jiangxi
2600 GWh
Taiwan
83000 GWh
Yunnan
220000 GWh
Guangxi
78000 GWh
Hong Kong
Macau
0 GWh
Guangdong
87000 GWh
Hainan
18000 GWh
GWh
0 - 130,000
130,001 - 560,000
560,001 - 1,100,000
1,100,001 - 5,300,000

50% "Discount" Less Tibet and Xinjiang

	GW Potential	GWh Potential
Class 3	2,627	6,442,530
Class 4	810	2,200,653
Class 5	282	865,414
Class 6	176	618,399
Class 7	49	179,126
Total	**3,944**	**10,306,122**

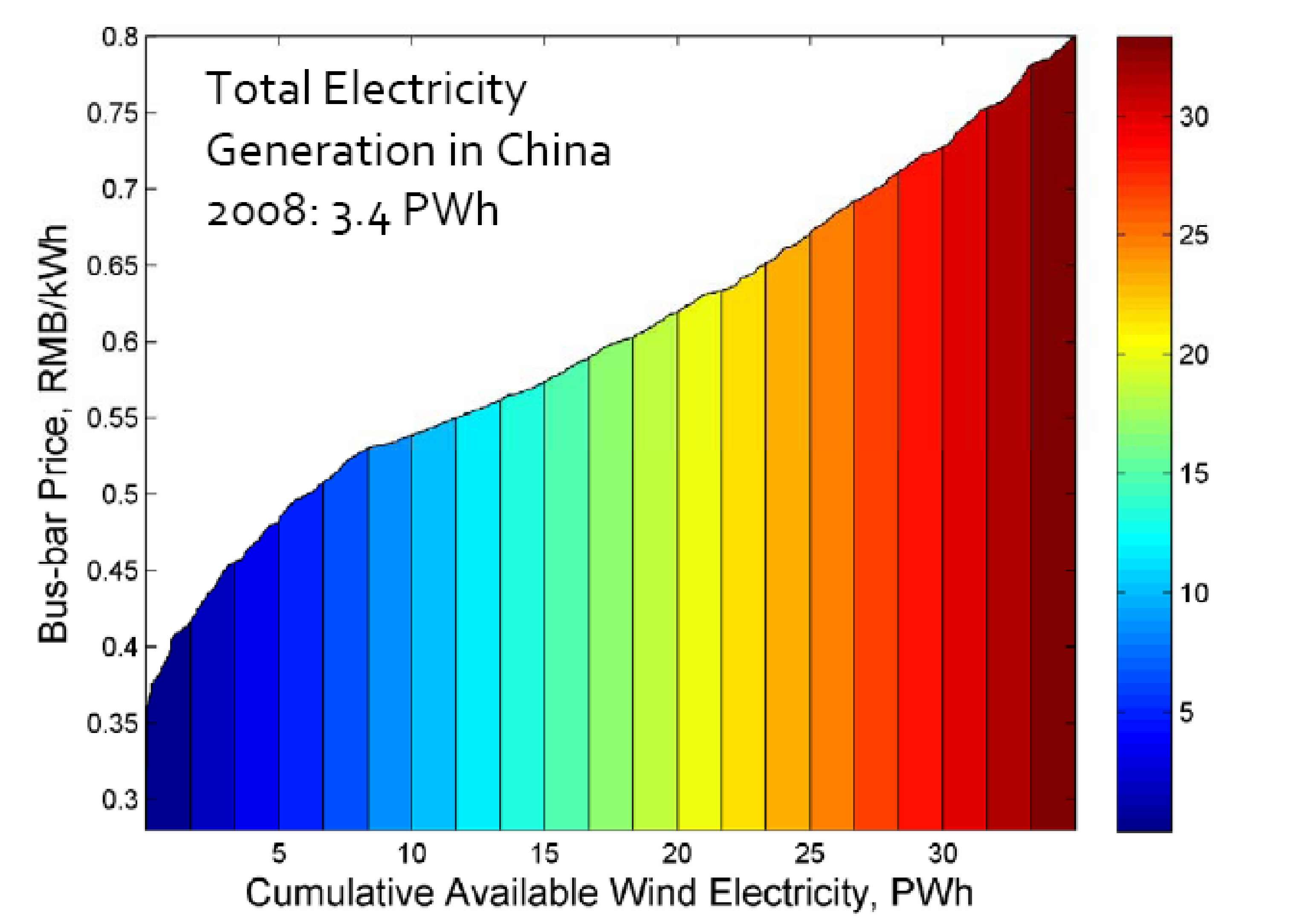
Two provinces distant from load centers have significant potential

Comparison with CHECC Analysis (GW)

	CHECC (GW less than 0.6 RMB/kWh)	CHECC (Total GW)	Black & Veatch (GW)	Black & Veatch with 50% Discount (GW)
Inner Mongolia	850	900	4,020	2,010
NorthEast China	160	187	705	353
Hebei	115	143	412	206
Xinjiang	190	311	2,419	1,210
Gansu	160	197	697	349
Ningxia	37	41	100	50
Total	**1,512**	**1,781**	**8,354**	**4,177**

CHECC appears to be assuming 25% developable potential; 95% correlation, using same data source

Harvard China Wind Assessment



Harvard China Wind Assessment

Comparison with Harvard Wind Assessment (GWh)

	Harvard	Black & Veatch
China Total	39,000,000	35,248,256
Tibet	6,486,000	8,028,146
North West	3,350,000	10,894,603
North	5,364,000	12,665,993
North East	9,051,000	1,809,540
East	284,000	171,251
Central	89,000	657,462
South	59,000	856,102
Total	24,683,000	35,083,097

Total reported GWh match relatively closely; many differences are based on how regions are defined (Harvard splits New Mongolia into North and Northeast).

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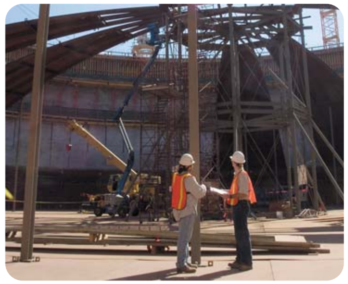



China Concentrating Solar Thermal Electric Resource Assessment

A Spatial Analysis

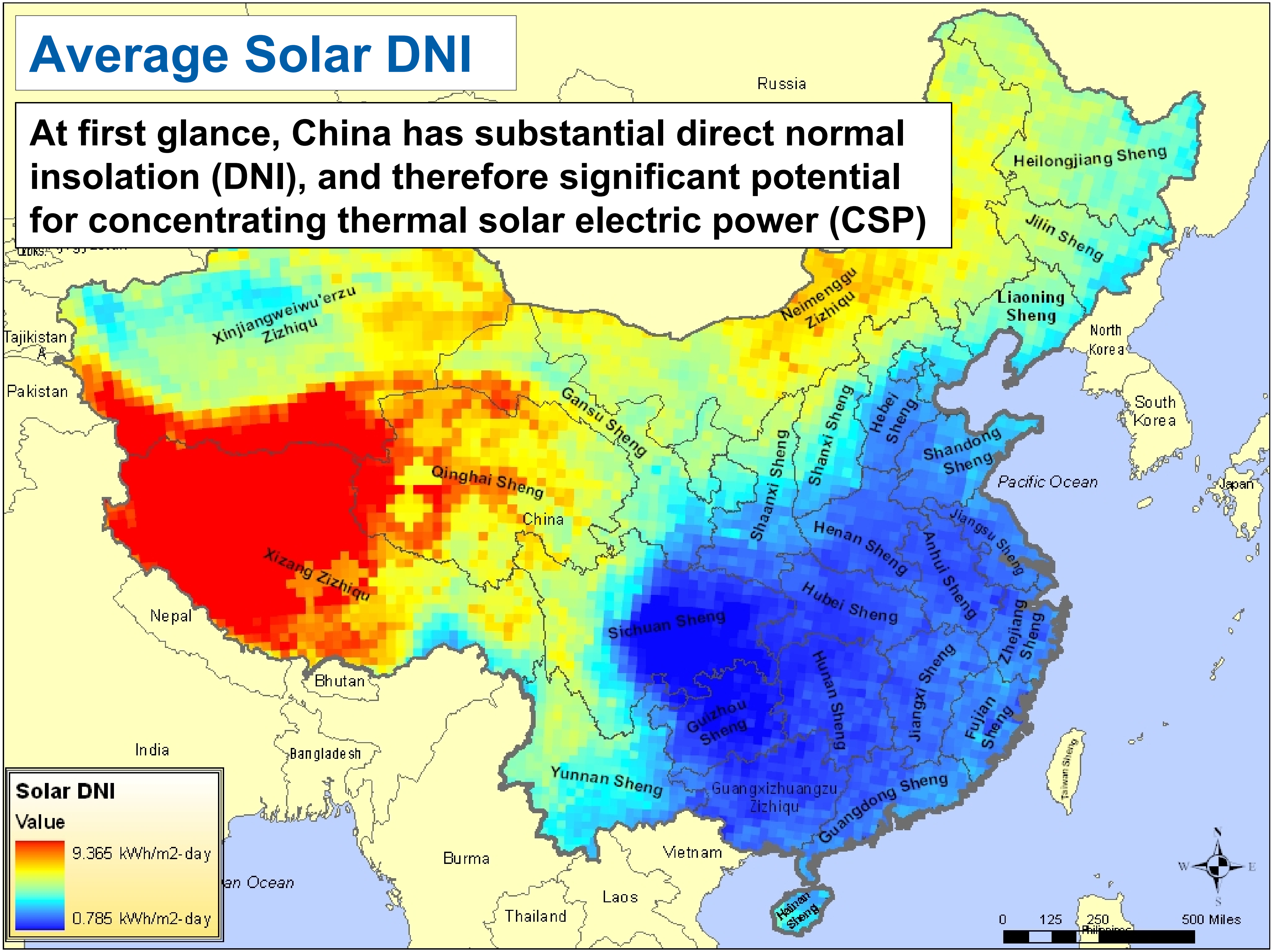
Ric O'Connell, Sally Maki, Ryan Wiser

Prepared for the Energy Foundation's China Sustainable Energy Program

December 23, 2009

Average Solar DNI

At first glance, China has substantial direct normal insolation (DNI), and therefore significant potential for concentrating thermal solar electric power (CSP)



Potential Barriers to Developing CSP

- Technological/Economic Reasons
  - Insufficient solar direct normal insolation (DNI)
  - Steep slopes make development challenging / expensive
  - Distance from and need for transmission and road access
  - Bodies of water that preclude development
  - Increased population density can increase costs
- Political or Land Use Reasons
  - Urban areas
  - Protected areas
  - Mining areas
  - Other competing land uses
  - Cooling water availability
- Many, but not all, of these barriers are addressed in the present assessment of China’s CSP resource potential

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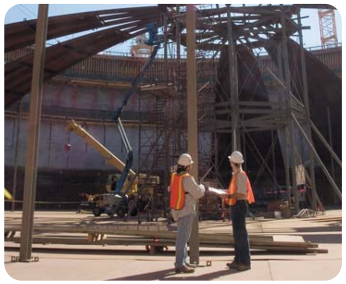


Methodology

Analysis Steps to Determine Resource Potential

1. Define necessary information
2. Procure relevant GIS data
3. Identify and define assumptions
4. Determine the area available for potential development in each province, by resource class
5. Perform calculations based on assumptions

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Information for Our Analysis

- Solar DNI
- Bodies of water
- Land slope
- Urban areas
- Protected areas
- Mining areas
- Other land use
- **Present analysis does not include distance to roads and transmission, cooling water availability, population density**

Analysis Steps to Determine Resource Potential

1. Define necessary information
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3. Identify and define assumptions
4. Determine the area available for potential development in each province, by resource class
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GIS Data - Sources

- **Insolation –** Solar DNI, National Renewable Energy Laboratory (NREL), 40 km resolution
- **Slope** – Derived from a DEM from Harvard's China Historical GIS (CHGIS) dataset V3, 30 arc-second resolution
- **Land use** – China: The Environment / ERIM International, Inc., 1999, ~10 km resolution
- **Bodies of water** – A combination of data from the Digital Chart of the World (DCW), and land use data (mentioned above)
- **Urban areas** – A combination of Center for International Earth Science Information Network (CEISIN) GRUMP Urban Extents data, data from the DCW, and land use data
- **Protected areas** – The World Database of Protected Areas

GIS Data – More About the Solar DNI Data

From NREL:

These data provide monthly average and annual average daily total solar resource averaged over surface cells of approximately 40 km by 40 km in size. The solar resource value is represented as watt-hours per square meter per day for each month. The data were developed from NREL's Climatological Solar Radiation (CSR) Model. This model uses information on cloud cover, atmospheric water vapor and trace gases, and the amount of aerosols in the atmosphere to calculate the monthly average daily total insolation (sun and sky) falling on a horizontal surface. Existing ground measurement stations are used to validate the data where possible. The modeled values are accurate to approximately 10% of a true measured value within the grid cell due to the uncertainties associated with meteorological input to the model. The local cloud cover can vary significantly even within a single grid cell as a result of terrain effects and other microclimate influences. Furthermore, the uncertainty of the modeled estimates increase with distance from reliable measurement sources and with the complexity of the terrain.

Data from 1985-1991

Analysis Steps to Determine Resource Potential

1. Define necessary information
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3. **Identify and define assumptions**
4. Determine the area available for potential development in each province, by resource class
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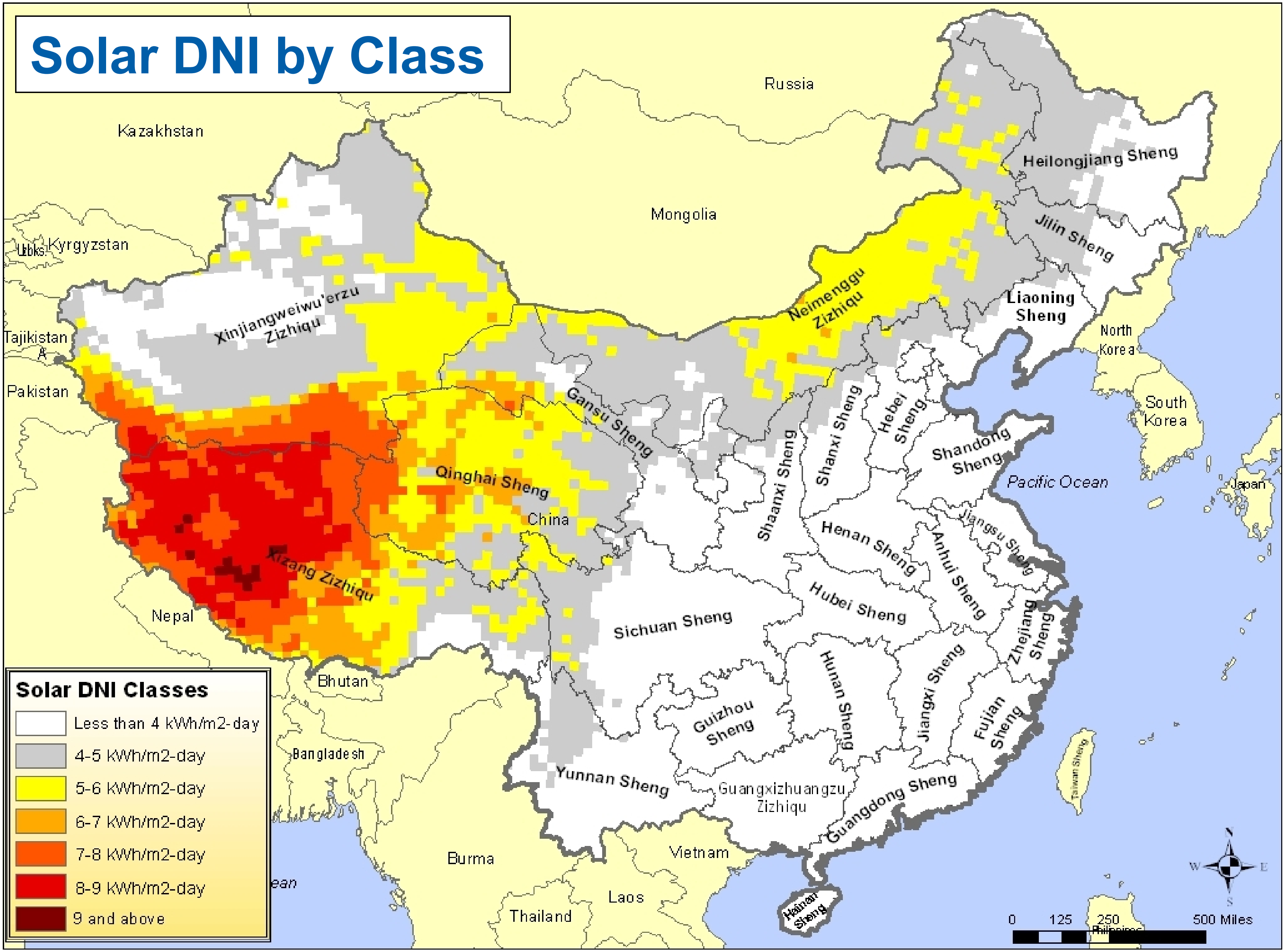
Power Plant Assumptions

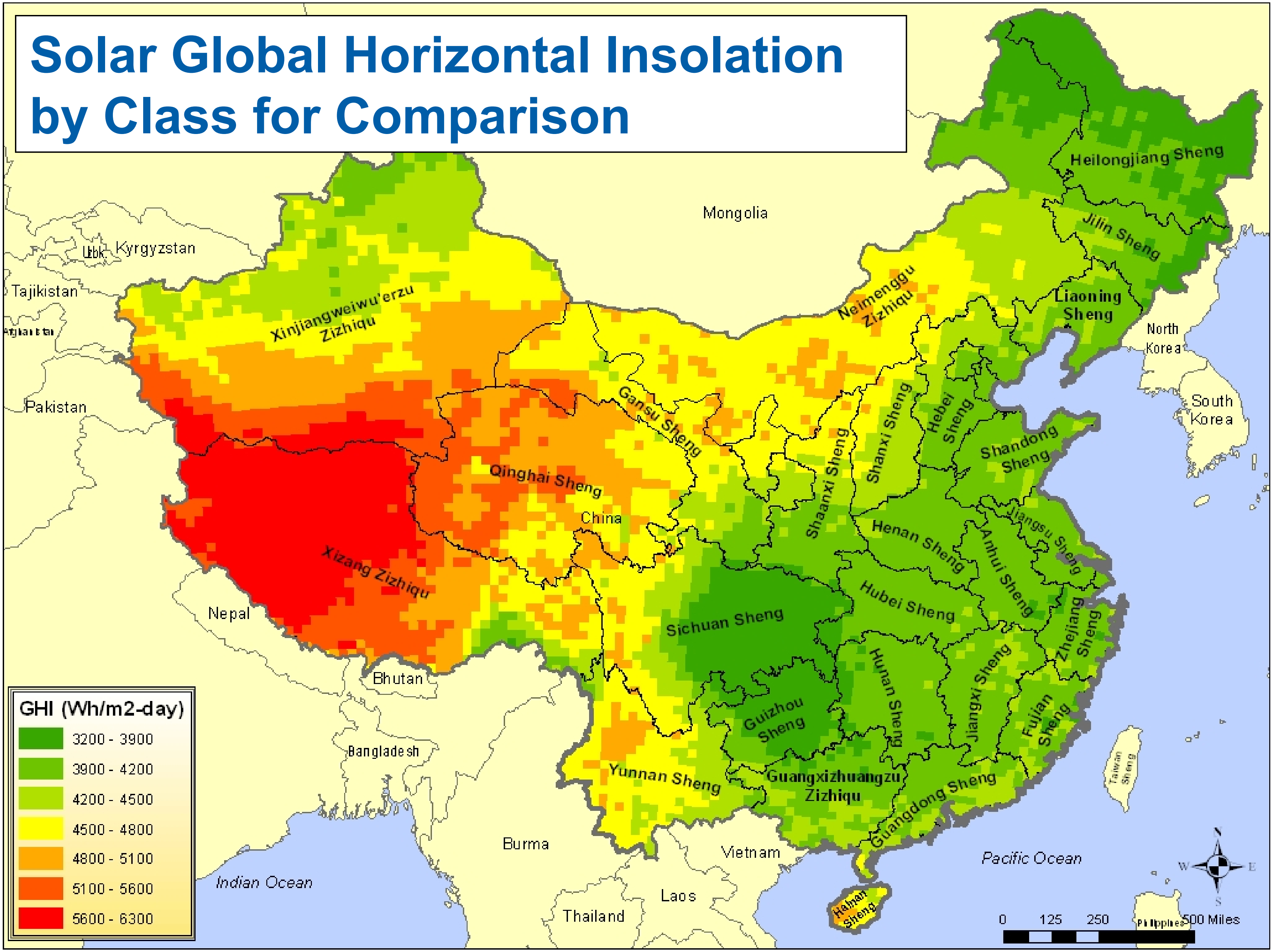
- Assumptions are for current *Parabolic Trough Technology*, without storage, and a Solar Multiple of 1.5:
  - Power Plant Solar to Electric Efficiency: 15%
  - Area: 30 MW/km^2
  - Collector area to land area Ratio: 25%
- Technology assumptions can easily be modified for other CSP technologies.
  - Trough with storage would have less MW per km2
  - CLFR would have higher collector area to land area ratio

Solar Potential Assumptions

- Solar DNI aggregated into classes:
  - Below 5 kWh/m^2-day → Excluded, or 0 kWh/m^2-day
  - 5-6 kWh/m^2-day → 5.5 kWh/m^2-day
  - 6-7 kWh/m^2-day → 6.5 kWh/m^2-day
  - 7-8 kWh/m^2-day → 7.5 kWh/m^2-day
  - 8-9 kWh/m^2-day → 8.5 kWh/m^2-day
  - Above 9 kWh/m^2-day → 9 kWh/m^2-day


Solar DNI by Class
Solar DNI Classes
Less than 4 kWh/m2-day
4-5 kWh/m2-day
5-6 kWh/m2-day
6-7 kWh/m2-day
7-8 kWh/m2-day
8-9 kWh/m2-day
9 and above
Russia
Kazakhstan
Mongolia
Kyrgyzstan
Uzbks.
Tajikistan
Pakistan
Nepal
Bhutan
Bangladesh
Burma
Thailand
Laos
Vietnam
North Korea
South Korea
Japan
Pacific Ocean
China
Xinjiangweiwu'erzu Zizhiqu
Xizang Zizhiqu
Qinghai Sheng
Gansu Sheng
Neimenggu Zizhiqu
Heilongjiang Sheng
Jilin Sheng
Liaoning Sheng
Hebei Sheng
Shanxi Sheng
Shaanxi Sheng
Shandong Sheng
Henan Sheng
Jiangsu Sheng
Anhui Sheng
Hubei Sheng
Sichuan Sheng
Zhejiang Sheng
Hunan Sheng
Jiangxi Sheng
Fujian Sheng
Guizhou Sheng
Yunnan Sheng
Guangxizhuangzu Zizhiqu
Guangdong Sheng
Hainan Sheng
Taiwan Sheng
0 125 250 500 Miles
N
S
E
W

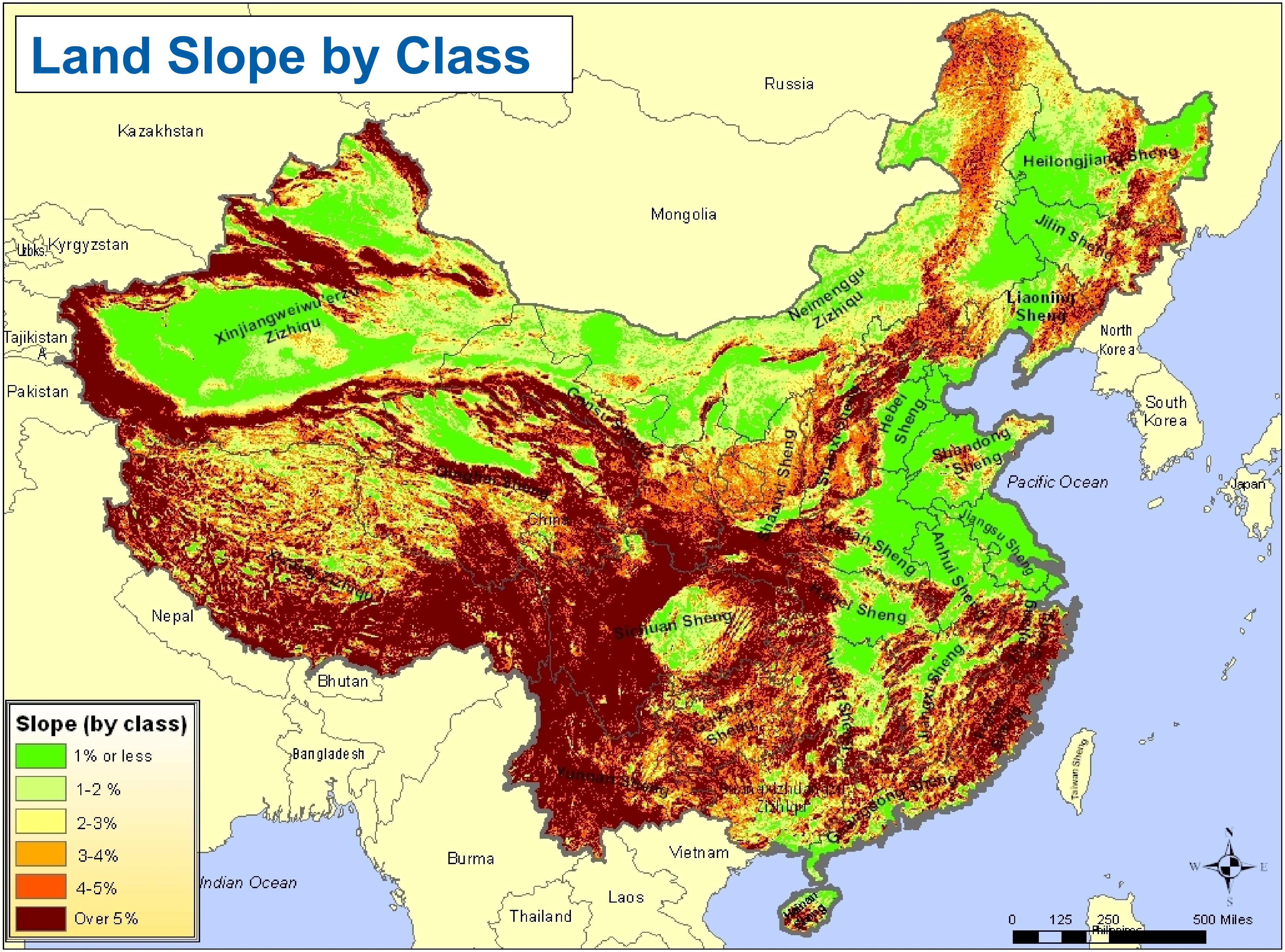
Solar Global Horizontal Insolation by Class for Comparison



Assumptions: Land Slope

- Two methods:
  - Everything less than a given slope is included 100%, and everything above is excluded
  - The areas can also be “discounted” based on slope
- Our assumption
  - Land with a 3% slope and less is included 100%
  - Land with a slope greater than 3% is excluded

Land Slope by Class

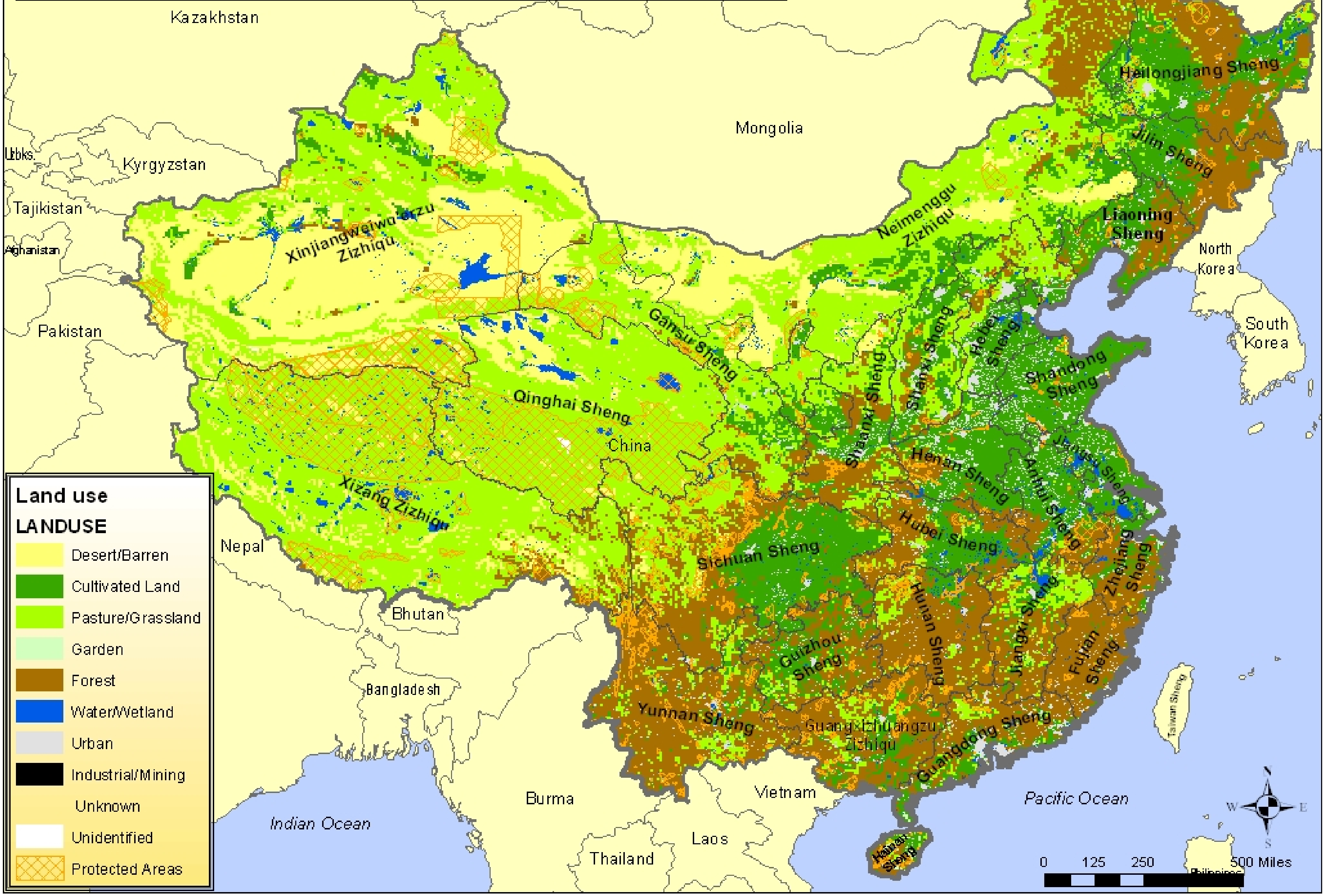


Assumptions: Land Use & Protected Areas

- Bodies of water → Excluded
- Urban areas → Excluded
- Protected areas → Excluded
- Mining areas → Excluded

- Desert/barren land→ 100% available
- Pasture/grassland, cultivated land, gardens → 50% available
- Forest/shrub land → 10% available

Land Use & Protected Areas



Analysis Steps to Determine Resource Potential

1. Define necessary information
2. Procure relevant GIS data
3. Identify and define assumptions
4. **Determine the area available for potential development in each province, by resource class**
5. Perform calculations based on assumptions

Example Calculation for Xizang Zizhiqu

- 38,260 km^2 of 7-8 kWh/m^2-day solar DNI
  - 22,726 km^2 on ≤ 3% slope (100% available)
    - 20,736 km^2 in grassland
      - Grassland is 50% available: 20,736 km^2 * 50% = **10,368** ***discounted*** **km^2** on 7-8 kWh/m2 DNI land with ≤ 3% slope in grassland

Analysis Steps to Determine Resource Potential

1. Define necessary information
2. Procure relevant GIS data
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4. Determine the area available for potential development in each province, by resource class
5. **Perform calculations based on assumptions**

Calculations

- **GWh** = Zone area x DNI x Efficiency x Collector area to land area Ratio
- **MW** = Zone area x 30 MW per km^2

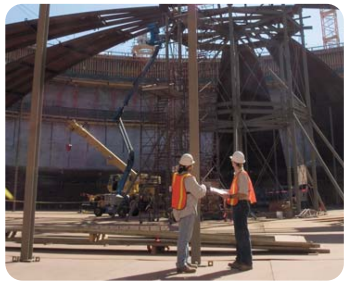
<u>From our previous example (Xizang Zizhiqu)</u>

- 10,368 km^2 * 7.5 kWh/m^2-day * 15% * 25% (w/ conversions)= **1,100 GWh/yr**

Efficiency (15%)

Collector area to land area Ratio (25%)

- 10,368 km^2 * 30 MW/km^2 (w/ conversions)= **320 GW**



Analysis Results

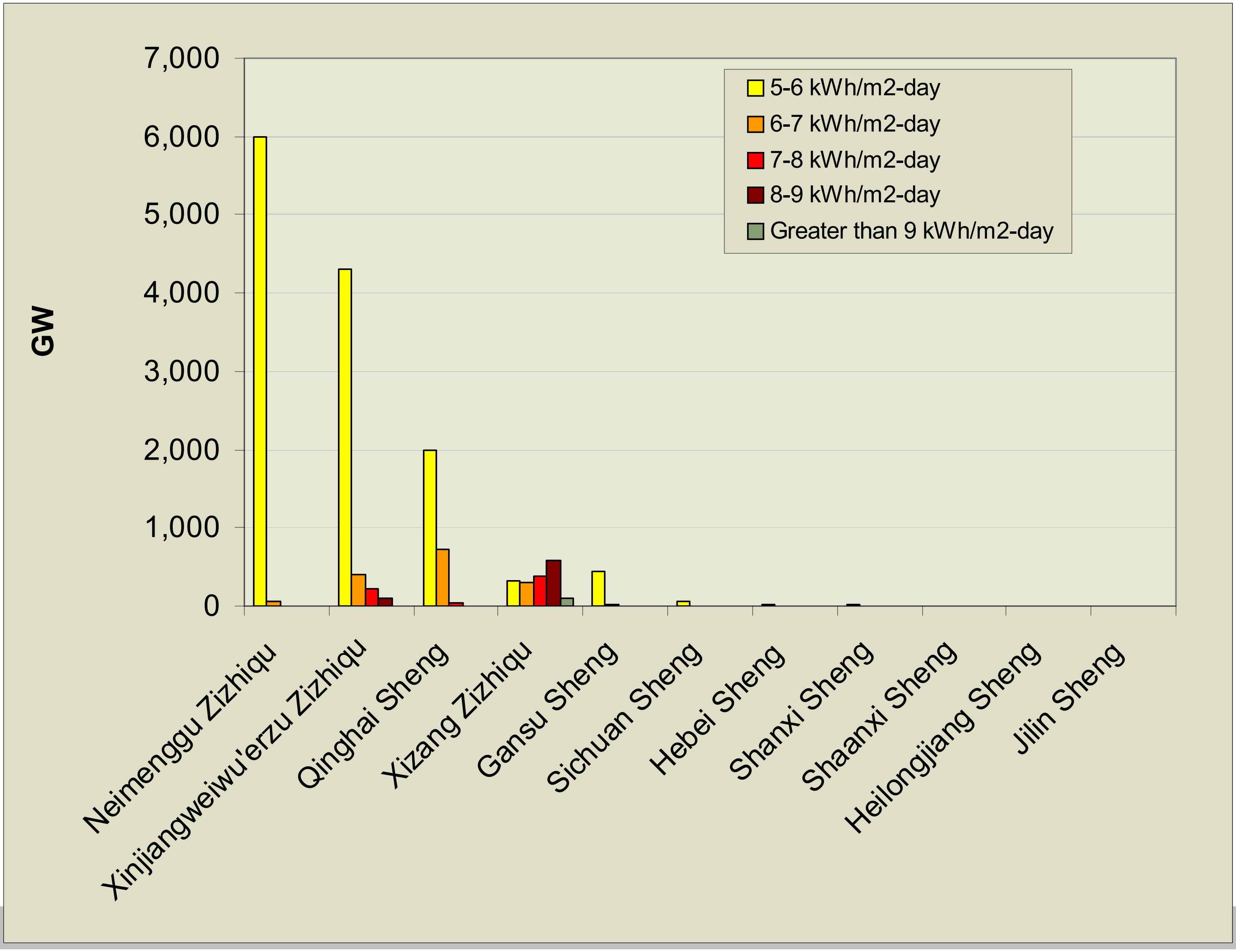
Overall Results

- **16,000 GW** of potential at < 3% slope, and DNI above 5 kWh/m^2-day
  - 42,000 TWh/year
- This compares to China's current electricity use of 3,000+ TWh/year
- China has roughly similar CSP resources to the United States, though those resources are generally located farther from load centers

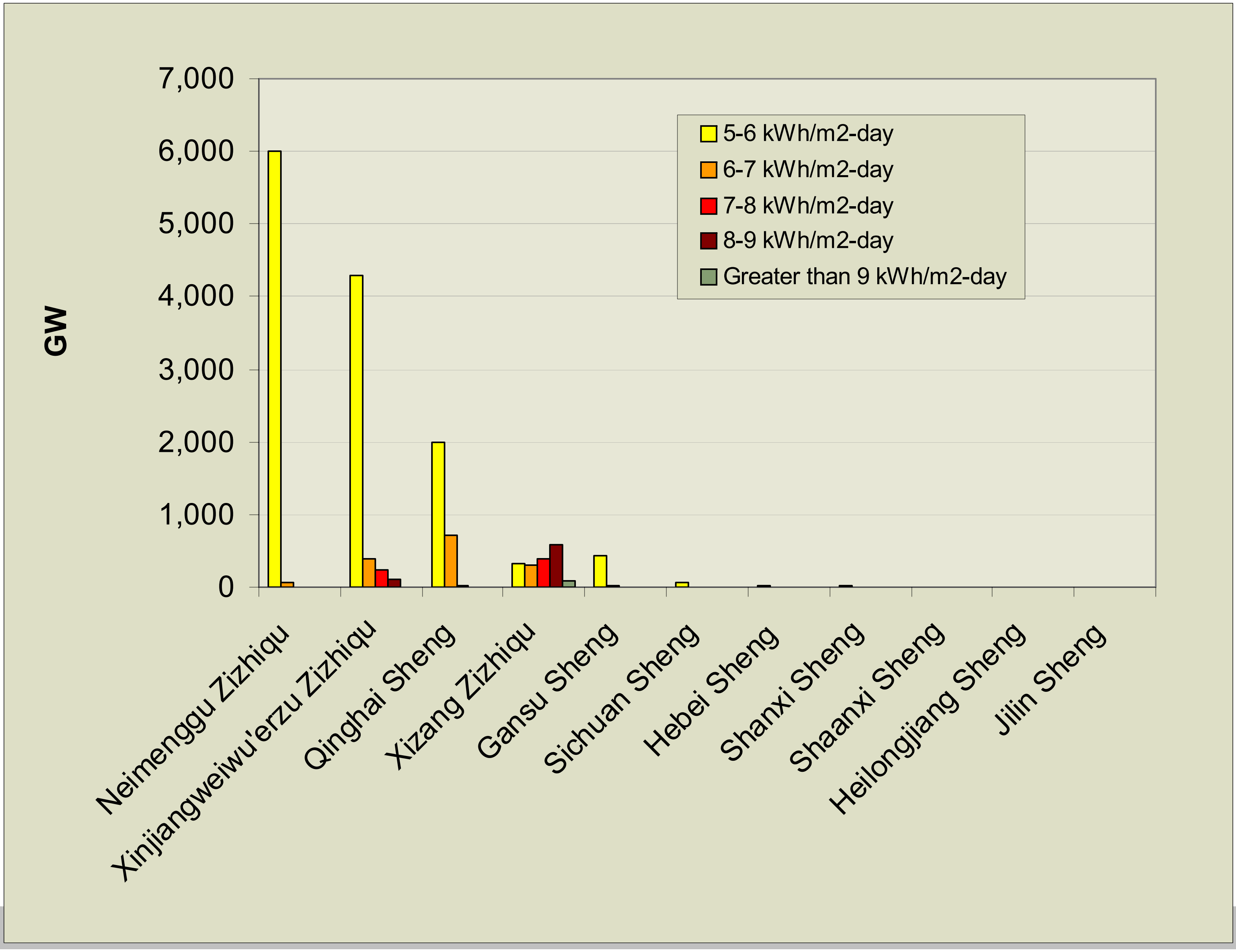
Results – Solar Resource by Province by Class

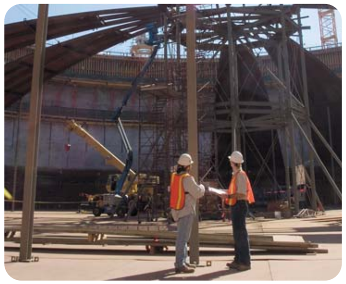
Province	5 to 6 kWh/m^2-day GW	5 to 6 kWh/m^2-day TWh/yr	6 to 7 kWh/m^2-day GW	6 to 7 kWh/m^2-day TWh/yr	7 to 8 kWh/m^2-day GW	7 to 8 kWh/m^2-day TWh/yr	8-9 kWh/m^2-day GW	8-9 kWh/m^2-day TWh/yr	9 and up kWh/m^2-day GW	9 and up kWh/m^2-day TWh/yr
Neimenggu Zizhiqu	6,000	15,000	59	170	0	0	0	0	0	0
Xinjiangweiwu'erzu Zizhiqu	4,300	11,000	400	1,100	230	780	110	420	0	0
Qinghai Sheng	2,000	4,900	720	2,100	31	100	0	0	0	0
Xizang Zizhiqu	320	770	300	860	380	1,300	580	2,200	93	370
Gansu Sheng	440	1,100	15	42	0	0	0	0	0	0
Sichuan Sheng	56	140	0	0	0	0	0	0	0	0
Hebei Sheng	26	64	0	0	0	0	0	0	0	0
Shanxi Sheng	18	44	0	0	0	0	0	0	0	0
Shaanxi Sheng	9	21	0	0	0	0	0	0	0	0
Heilongjiang Sheng	7	17	0	0	0	0	0	0	0	0
Jilin Sheng	4	10	0	0	0	0	0	0	0	0
Total	**13,000**	**32,000**	**1,500**	**4,300**	**650**	**2,100**	**690**	**2,600**	**93**	**370**

Results – GW by Province by DNI Class



Results – TWh/yr by Province by Class





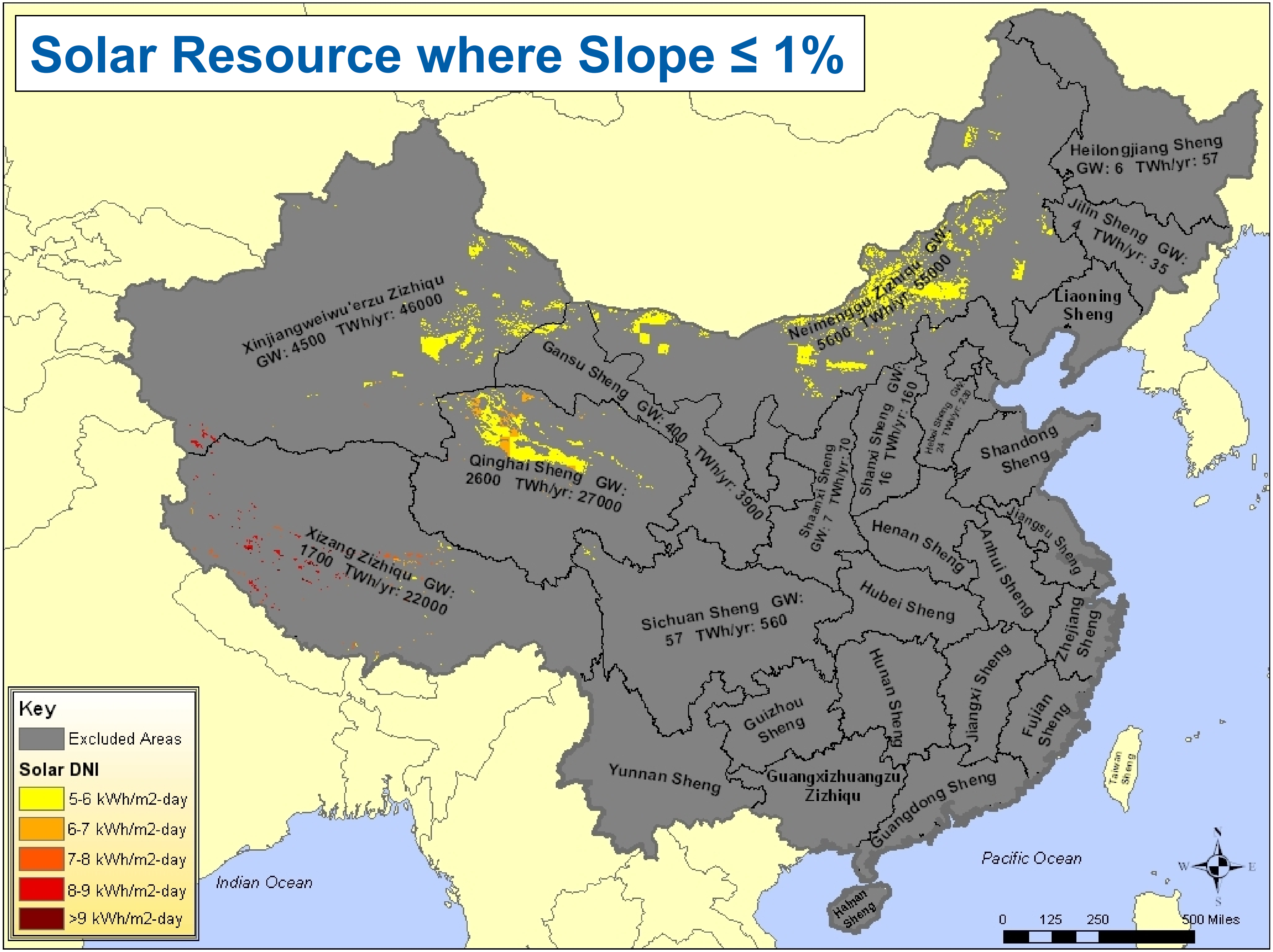
Comparison with the US and Spain

Comparison with the US and Spain

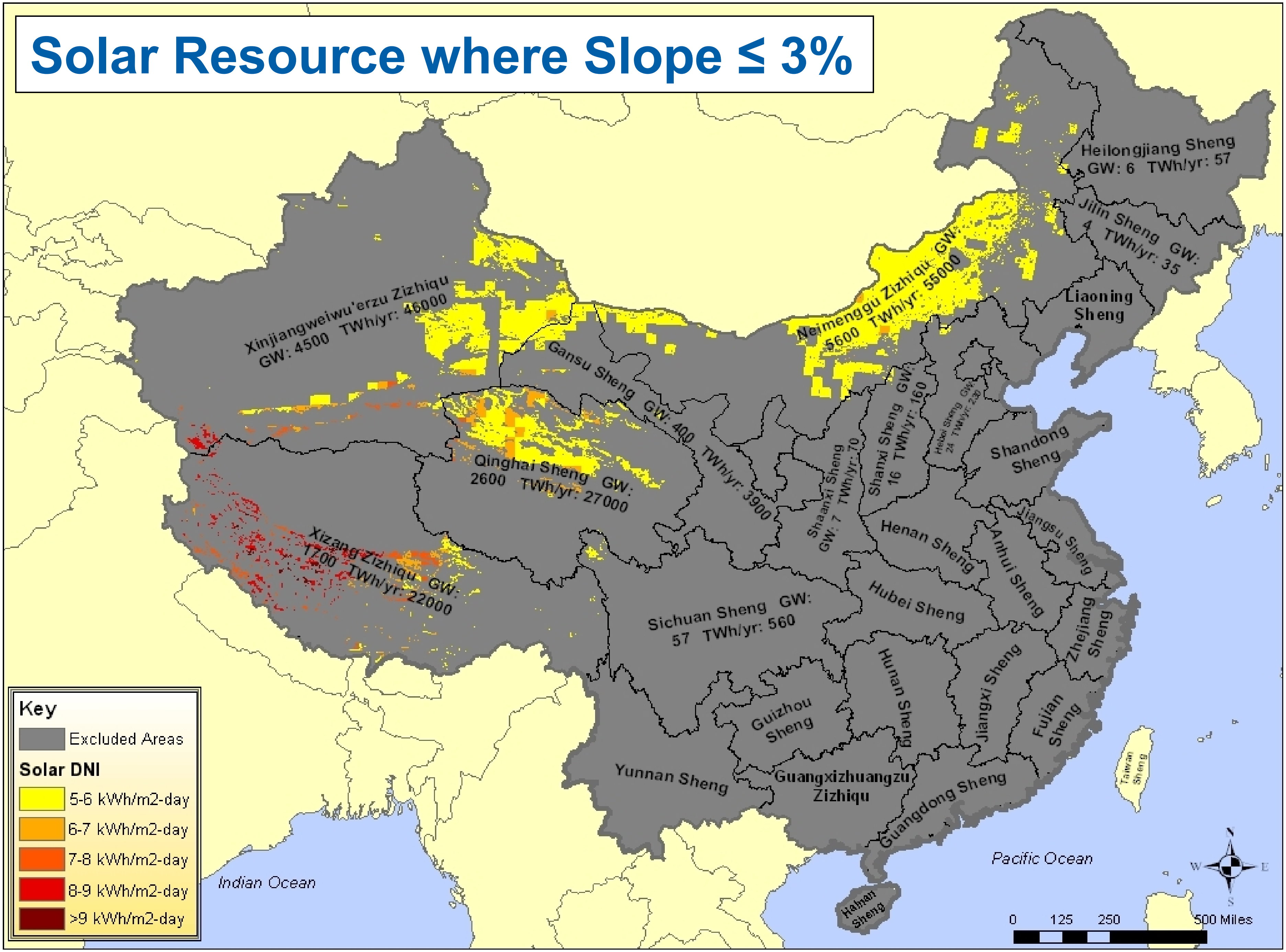
- Comparable analysis performed for the US and Spain
  - Slope $\leq$ 3%, DNI $\leq$ 5 kWh/m^2
- China and US resources are comparable in size
- Spanish resource is much lower

	GW	TWh/yr	GW DNI ≥ 7 kWh/m^2
China	16,000	42,000	1,400
US	15,000	40,000	1,300
Spain	720	1,900	0.67

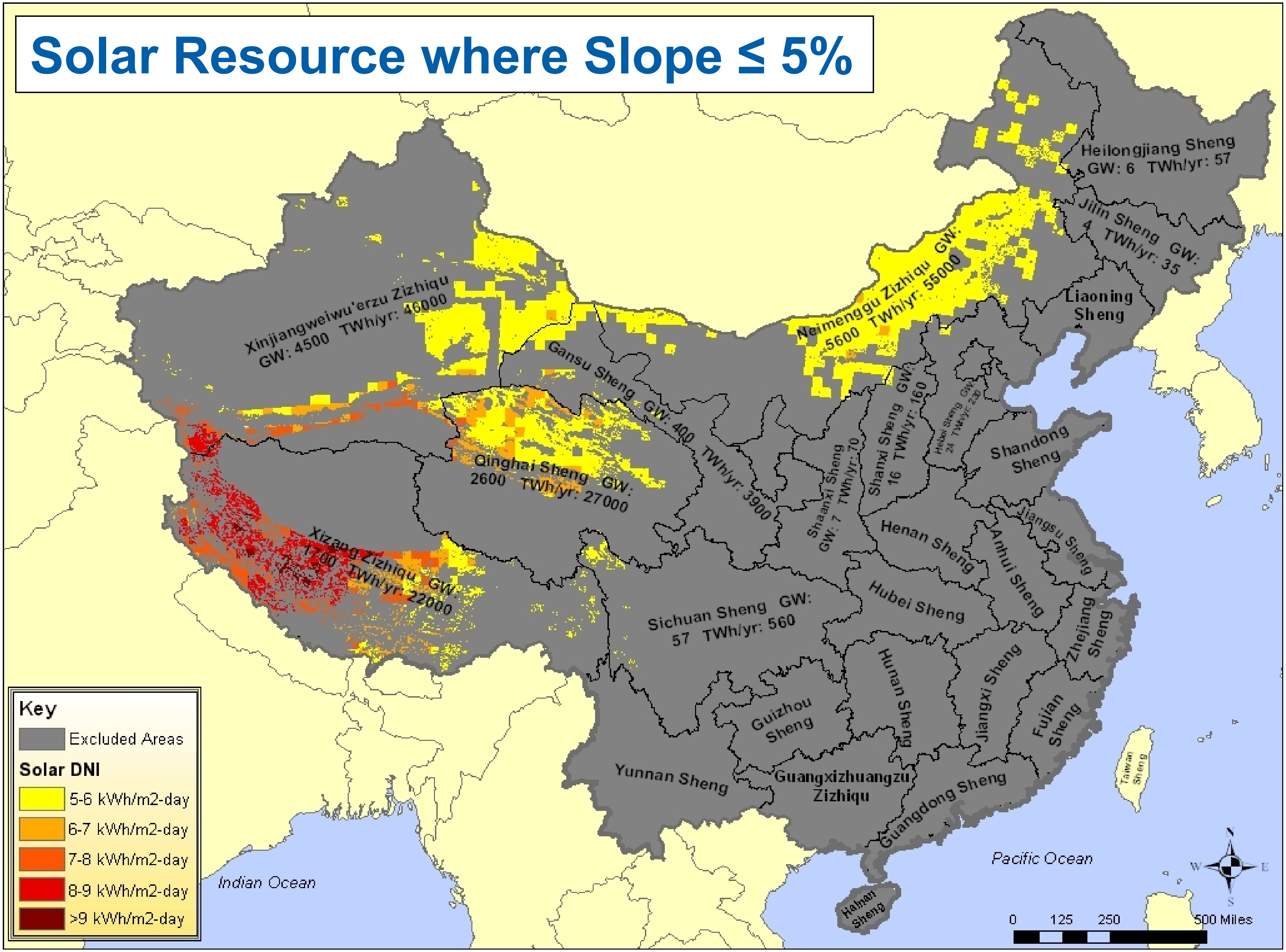
Solar Resource where Slope ≤ 1%

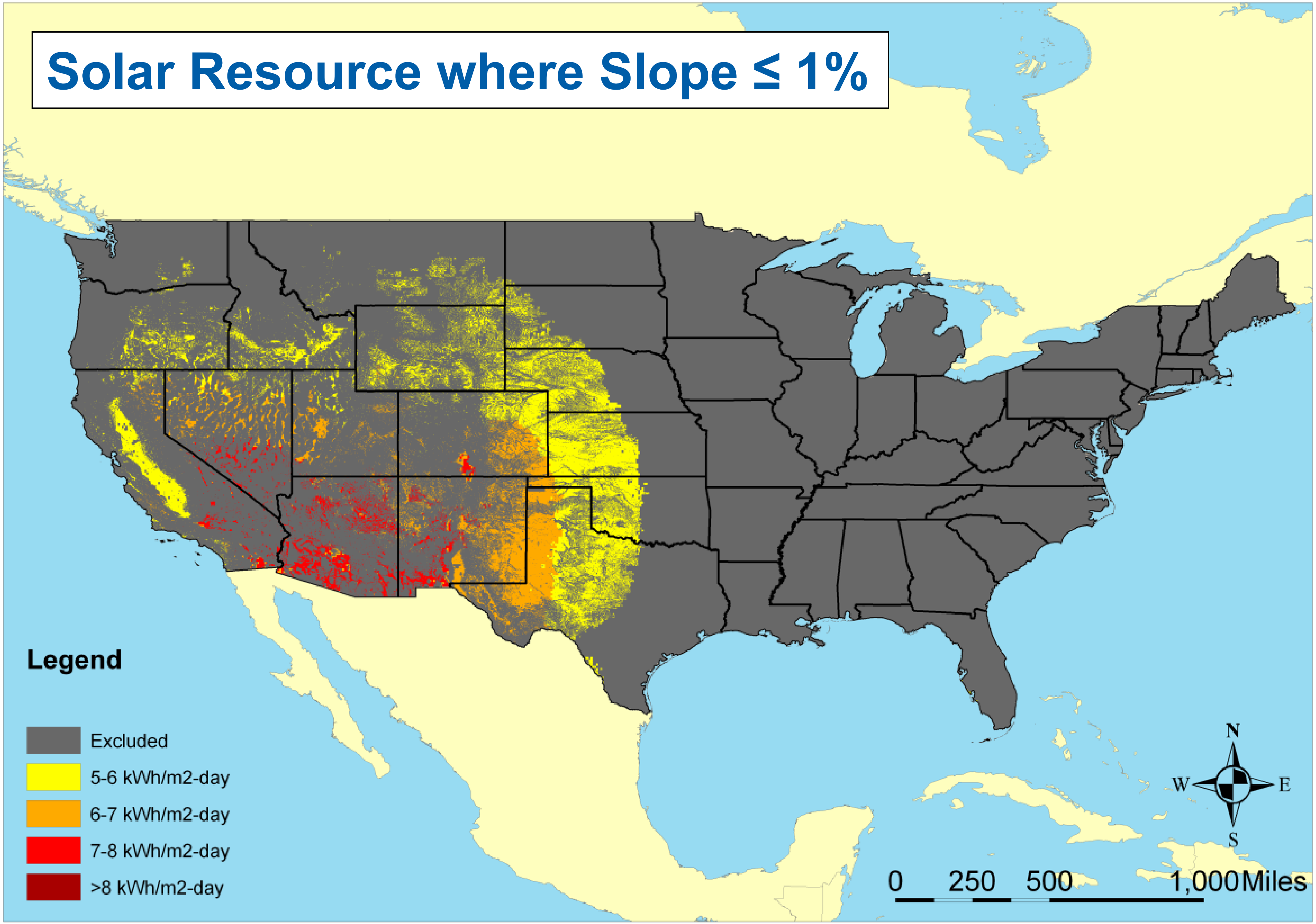


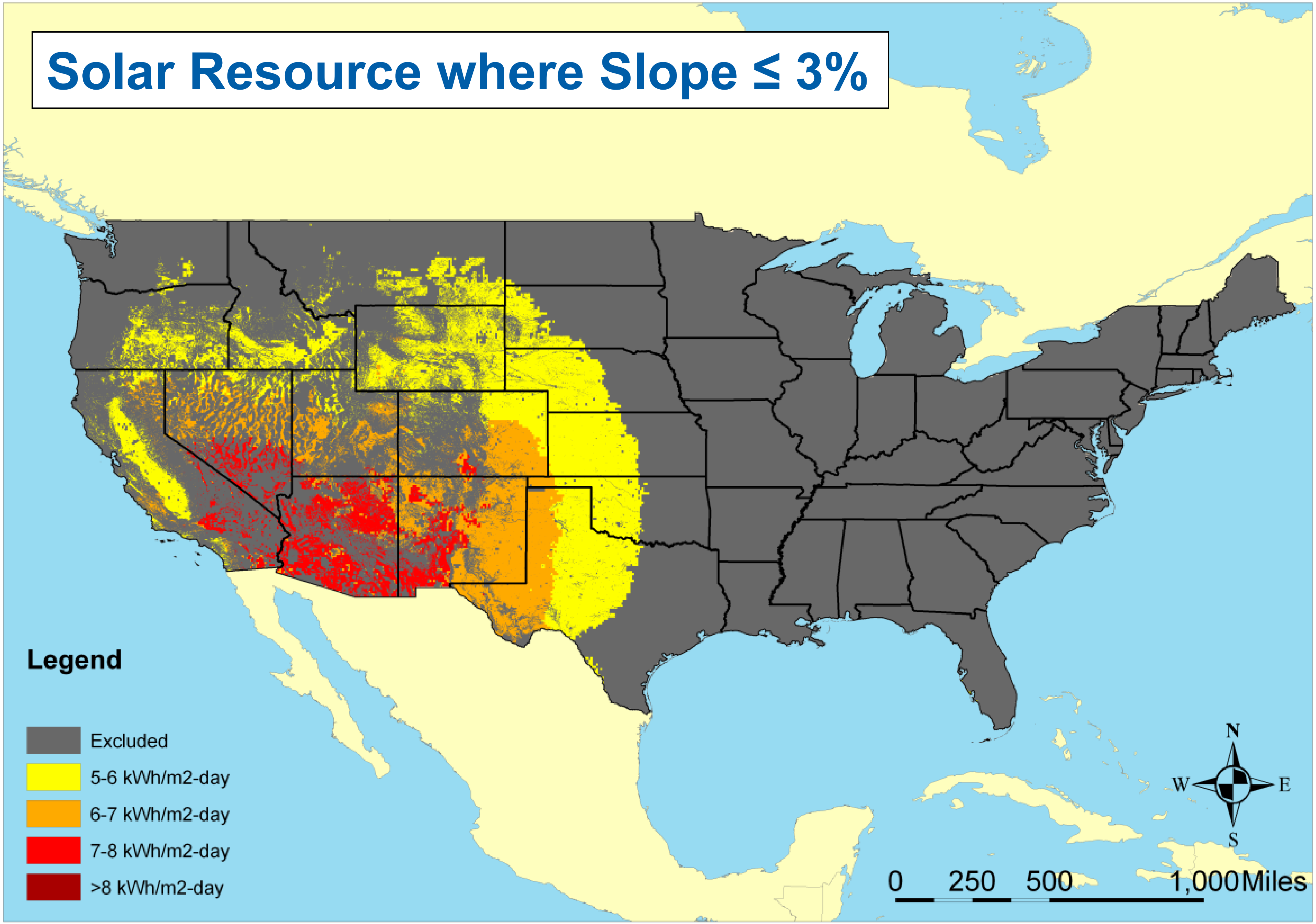
Solar Resource where Slope ≤ 3%



Solar Resource where Slope ≤ 5%

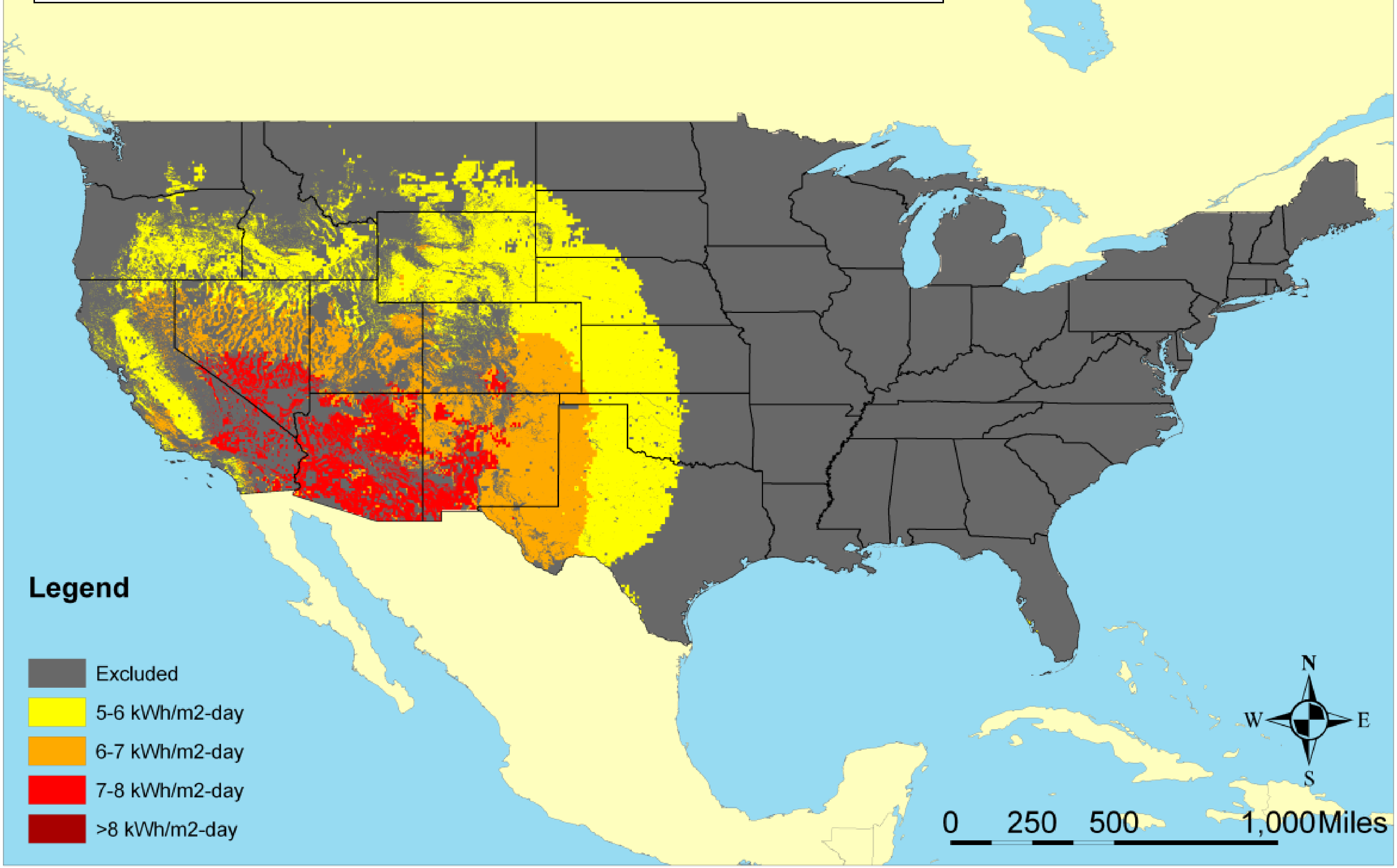



Solar Resource where Slope ≤ 1%
Legend
Excluded
5-6 kWh/m2-day
6-7 kWh/m2-day
7-8 kWh/m2-day
>8 kWh/m2-day
N
W
E
S
0
250
500
1,000Miles

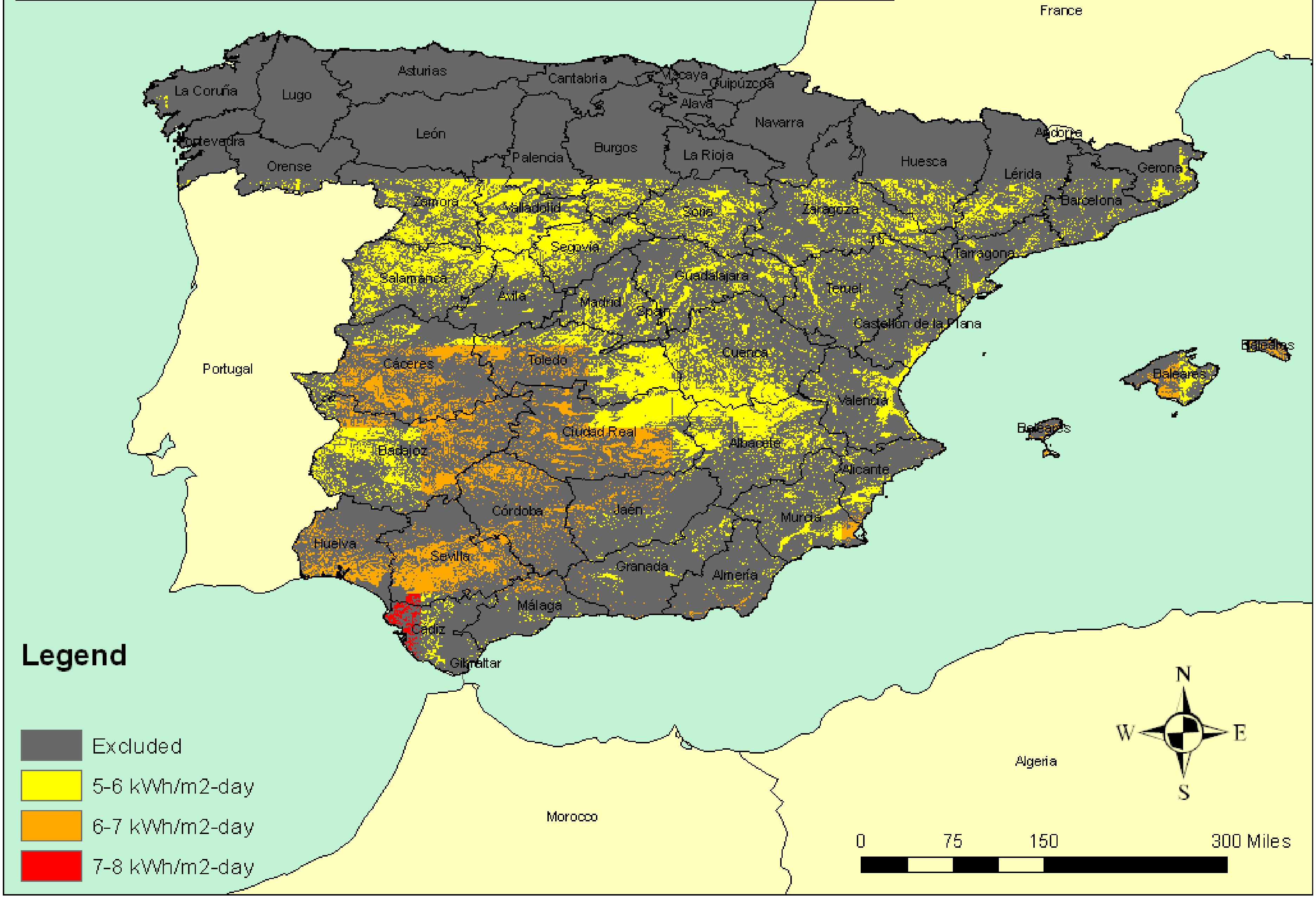


Solar Resource where Slope ≤ 3%
Legend
Excluded
5-6 kWh/m2-day
6-7 kWh/m2-day
7-8 kWh/m2-day
>8 kWh/m2-day
N
W
E
S
0
250
500
1,000Miles

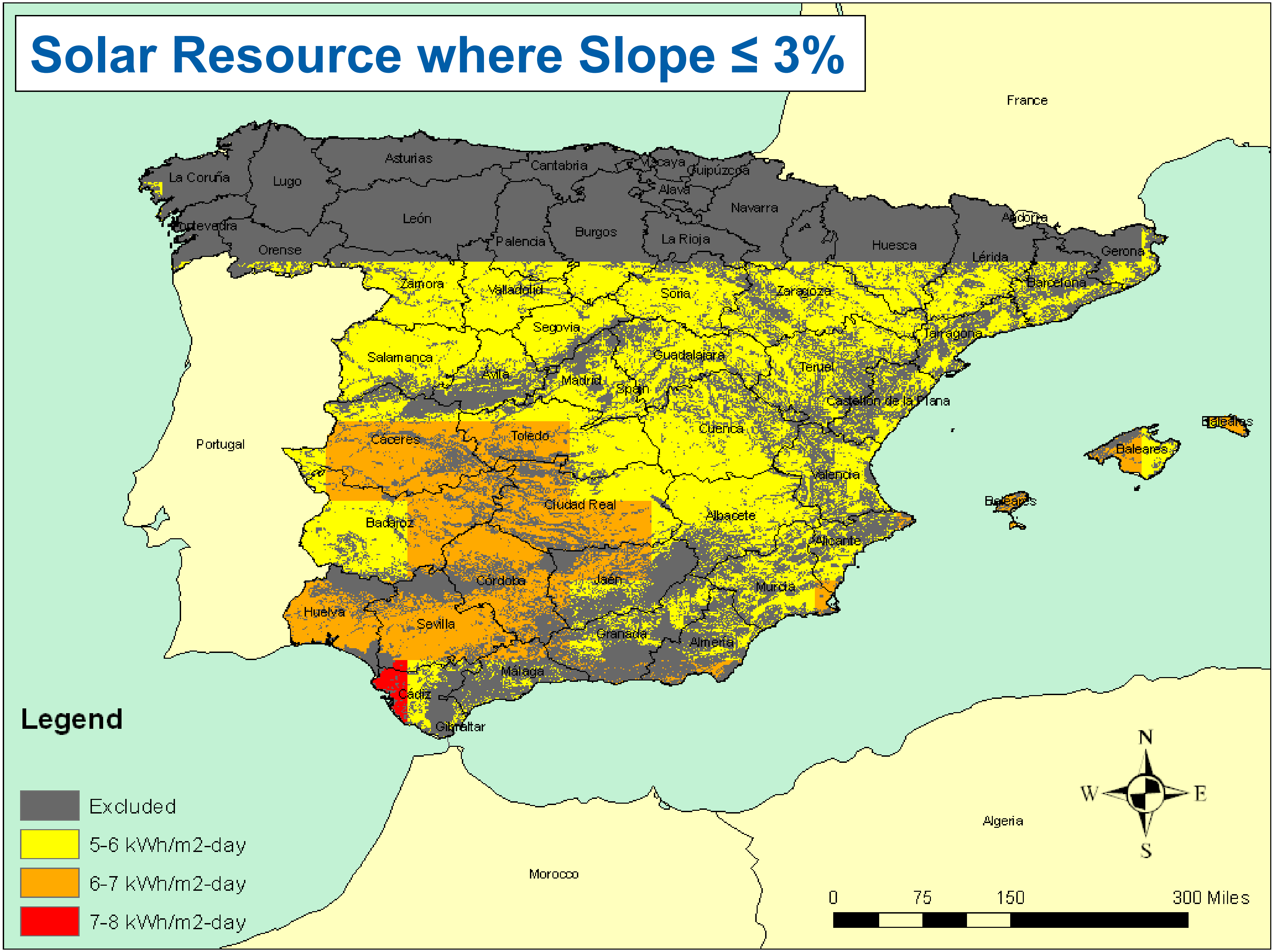
Solar Resource where Slope ≤ 5%

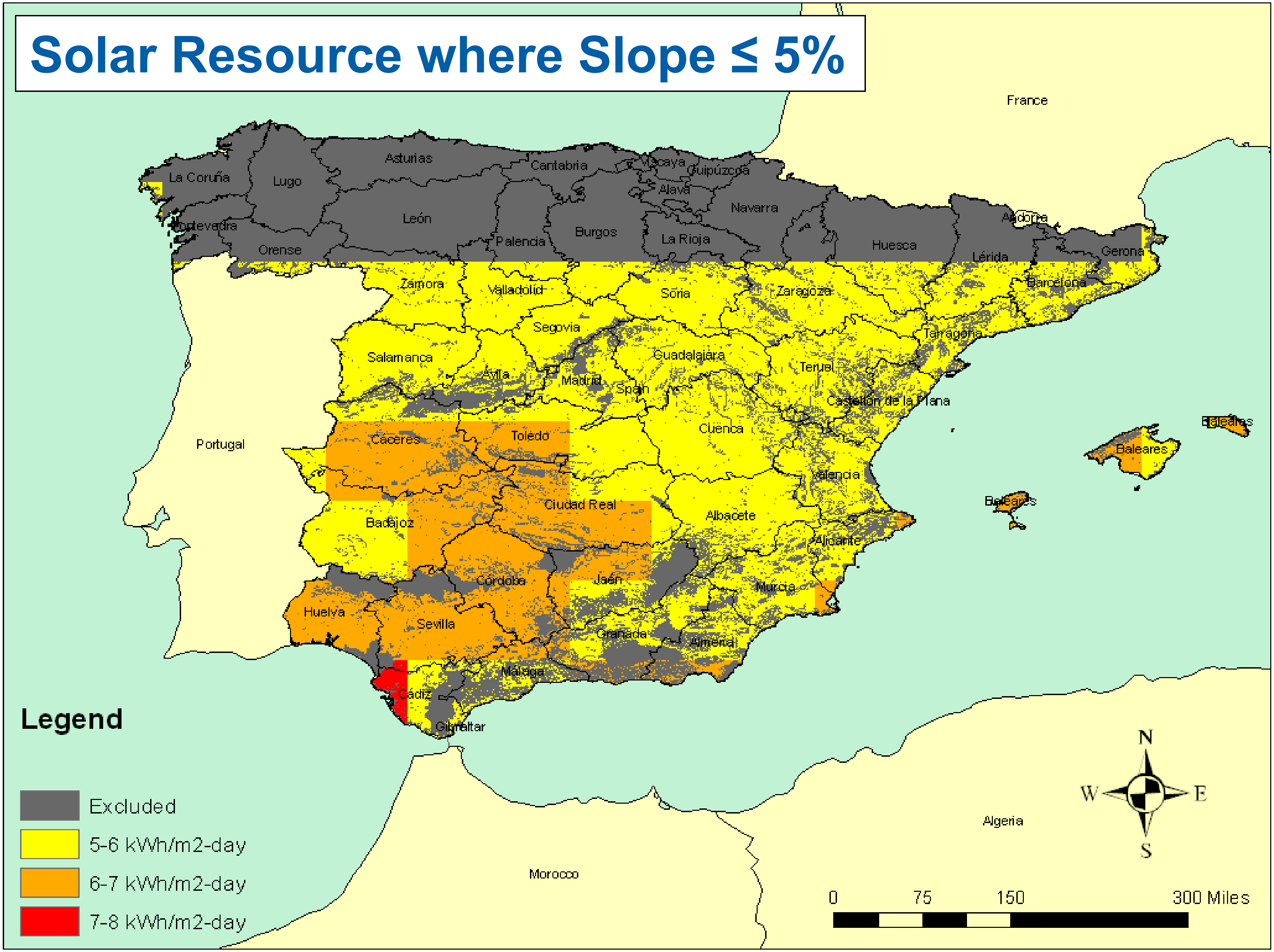


Solar Resource where Slope ≤ 1%

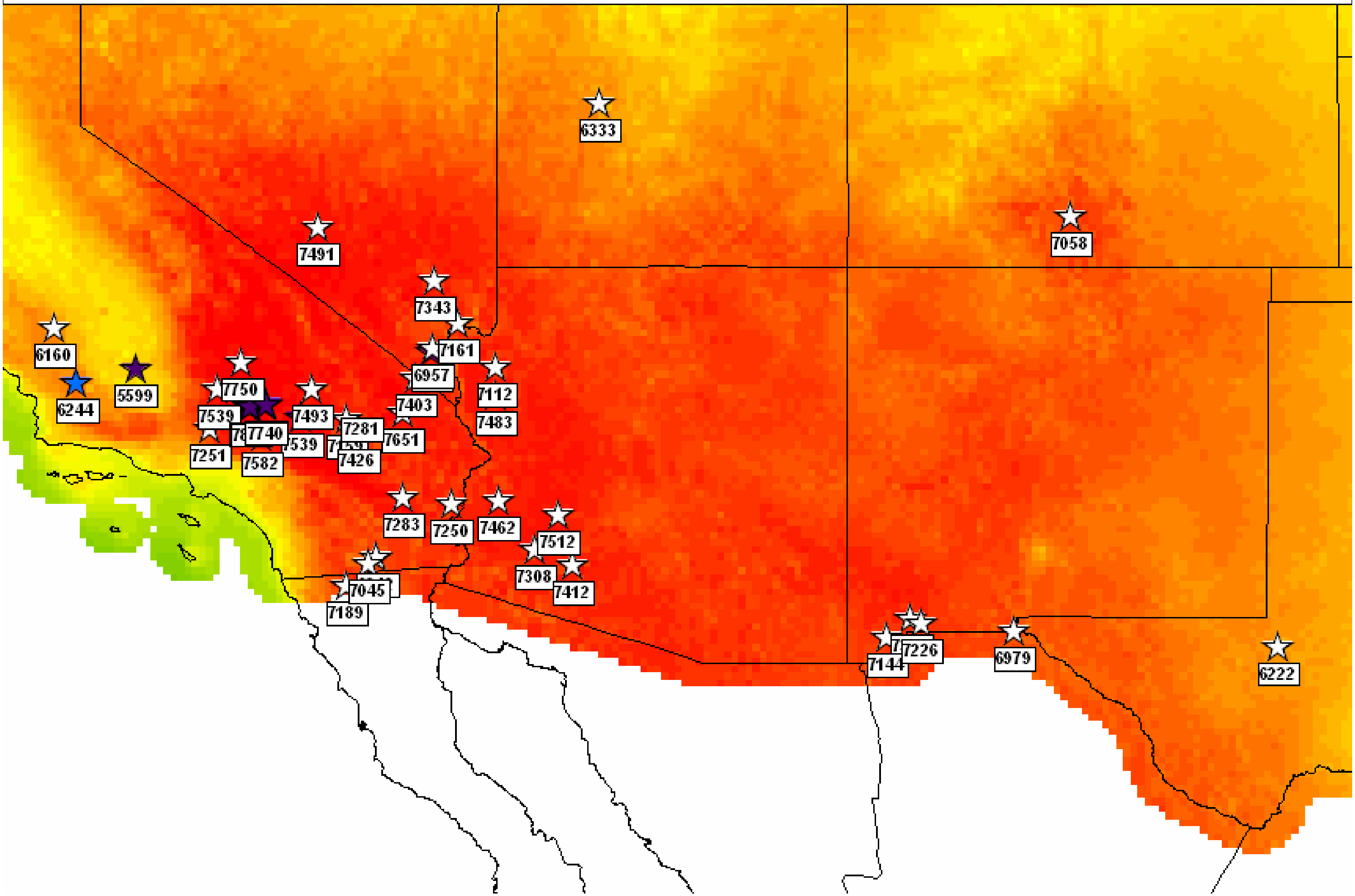


Solar Resource where Slope ≤ 3%




Solar Resource where Slope ≤ 5%
France
Asturias
Cantabria
Vizcaya
Guipúzcoa
La Coruña
Lugo
Alava
Navarra
León
Pontevedra
Andorra
Orense
Palencia
Burgos
La Rioja
Huesca
Lérida
Gerona
Zamora
Valladolid
Soria
Zaragoza
Barcelona
Segovia
Tarragona
Salamanca
Guadalajara
Teruel
Avila
Madrid
Spain
Castellón de la Plana
Portugal
Cuenca
Baleares
Caceres
Toledo
Baleares
Valencia
Baleares
Ciudad Real
Albacete
Badajoz
Alicante
Córdoba
Jaén
Murcia
Huelva
Sevilla
Granada
Almería
Málaga
Cádiz
Gibraltar
Legend
Excluded
5-6 kWh/m2-day
6-7 kWh/m2-day
7-8 kWh/m2-day
N
W
E
S
Algeria
Morocco
0
75
150
300 Miles

DNI for Operating, Under Construction, and Planned US Solar Thermal Plants Typically Over 7,000 Wh/m^2-day



Conclusions

- The CSP resource in China is sizable, and is comparable to that in the US
- The CSP resource is much larger than current total electricity demand in China
- The location of the best CSP resources in China are not located near large load centers, necessitating transmission expansion