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Energy Economic Potential of Utility-Scale Photovoltaics in the United Arab Emirates

Hosni Ghedira

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Key skills:

- Satellite data management and processing
- Solar radiation modelling
- Ground data analysis, data mining and quality control
- High performance computing
- Machine learning and statistical modelling
- Solar irradiance measurements
- Real-time remote sensing
- Software development and programming
- Solar technology assessment
- GIS and Map-server development
- Artificial intelligence
- Climatology and Atmospheric Science

3x Faculty Members
8x Postdoctoral Researchers
5x Research Engineers
8x Research Assistants
2x Visiting Scientists

Publications (2012-2017):
32 Journal papers
56 Proceeding papers
5 Technical reports

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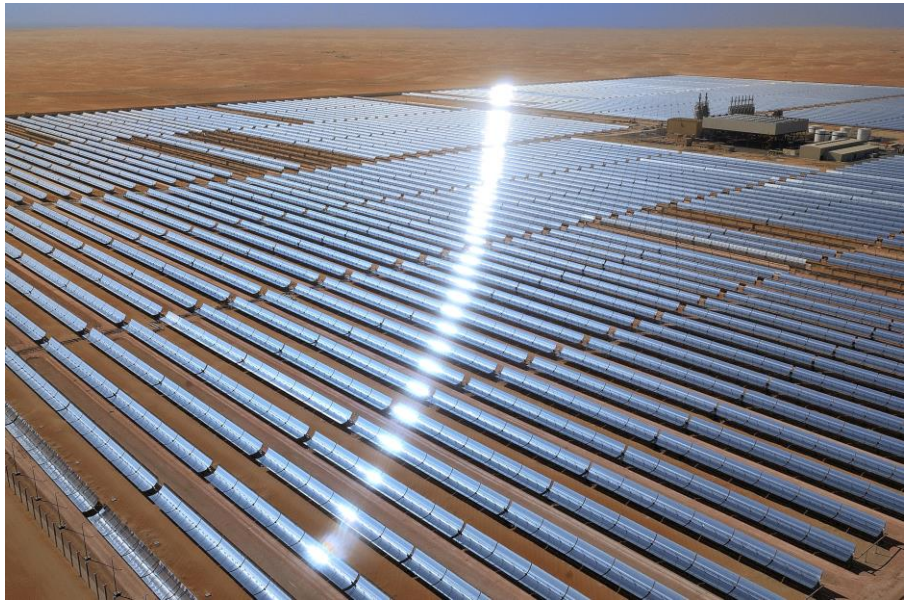
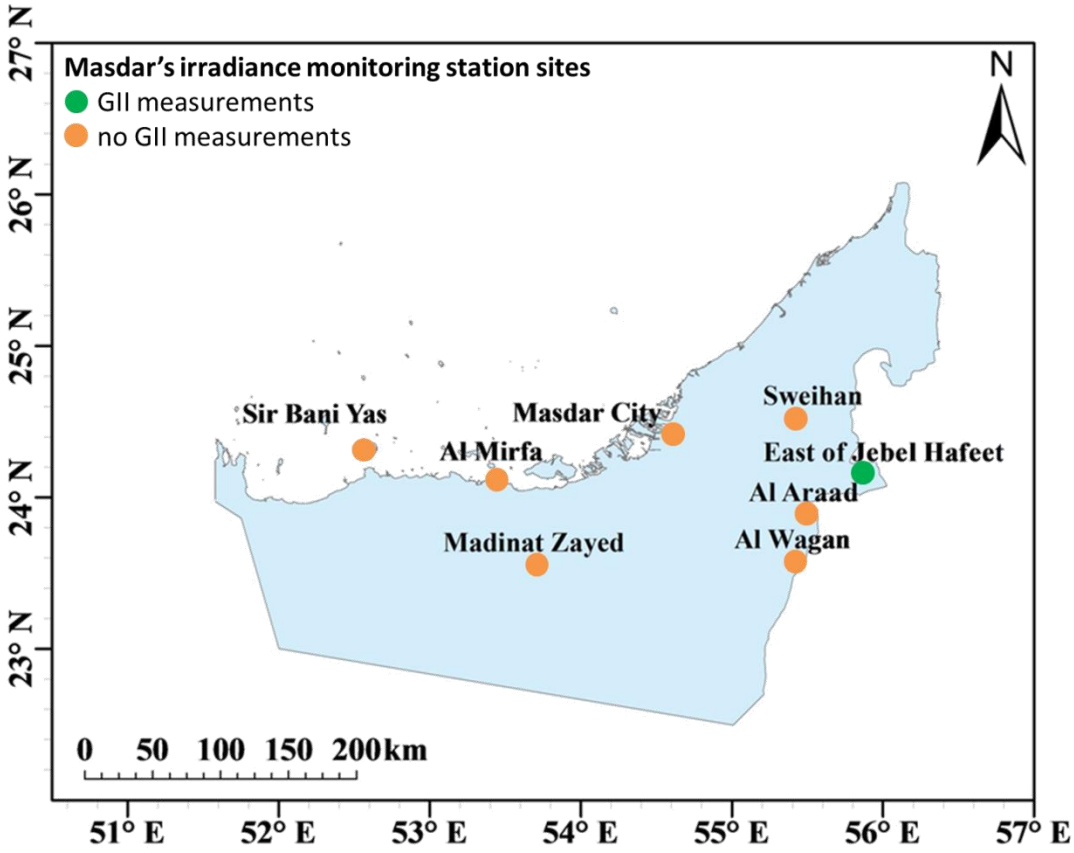
Utility-Scale Solar Plants (UAE)

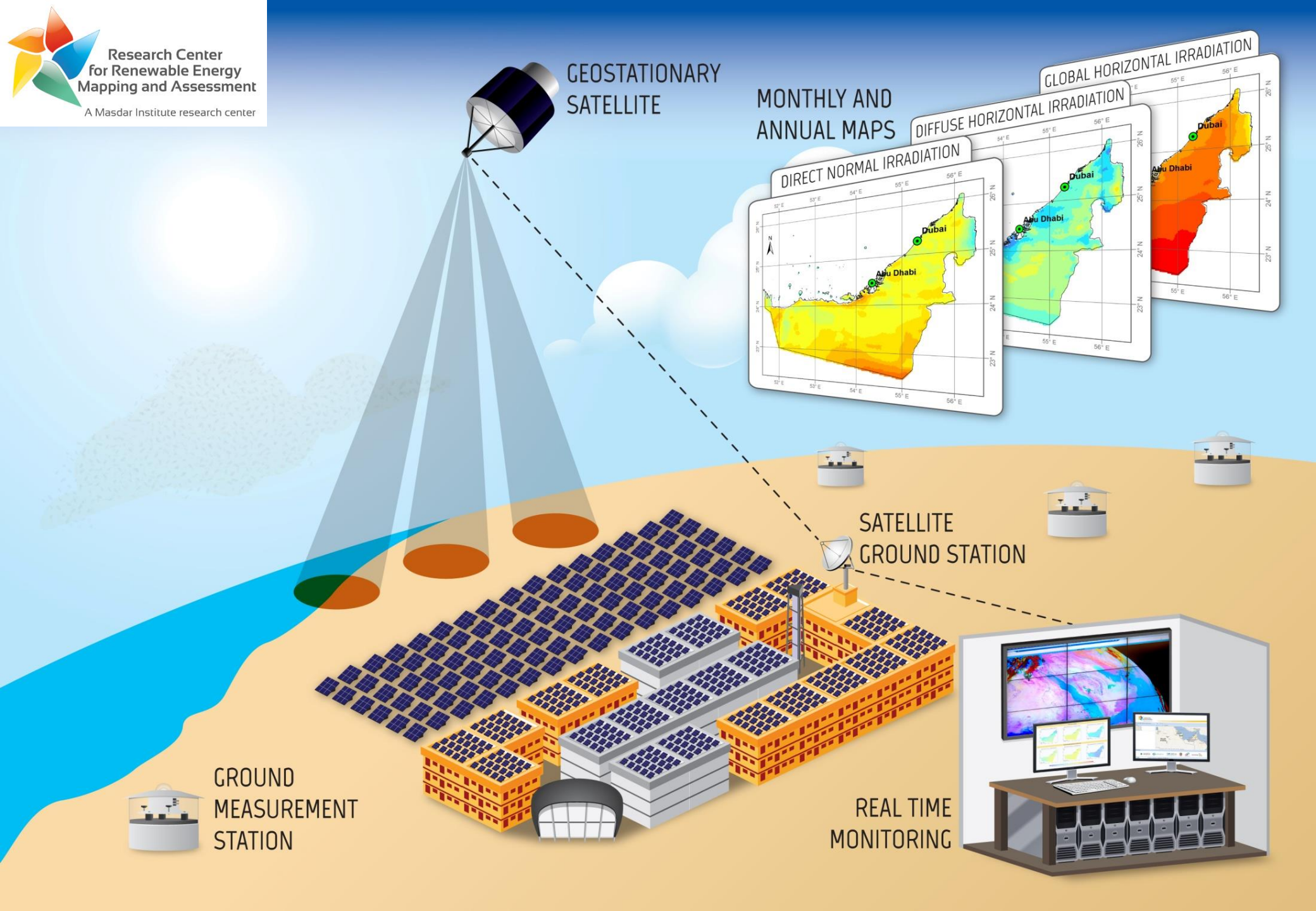
Masdar City: 10 MW PV
Operational since April 2009



100 MW Shams-1: The World's largest CSP plant
Operational since March 2013

Long History of Solar Radiation Measurements

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for Renewable Energy
Mapping and Assessment
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GEOSTATIONARY
SATELLITE
MONTHLY AND
ANNUAL MAPS
DIRECT NORMAL IRRADIATION
DIFFUSE HORIZONTAL IRRADIATION
GLOBAL HORIZONTAL IRRADIATION
Dubai
Abu Dhabi
SATELLITE
GROUND STATION
GROUND
MEASUREMENT
STATION
REAL TIME
MONITORING

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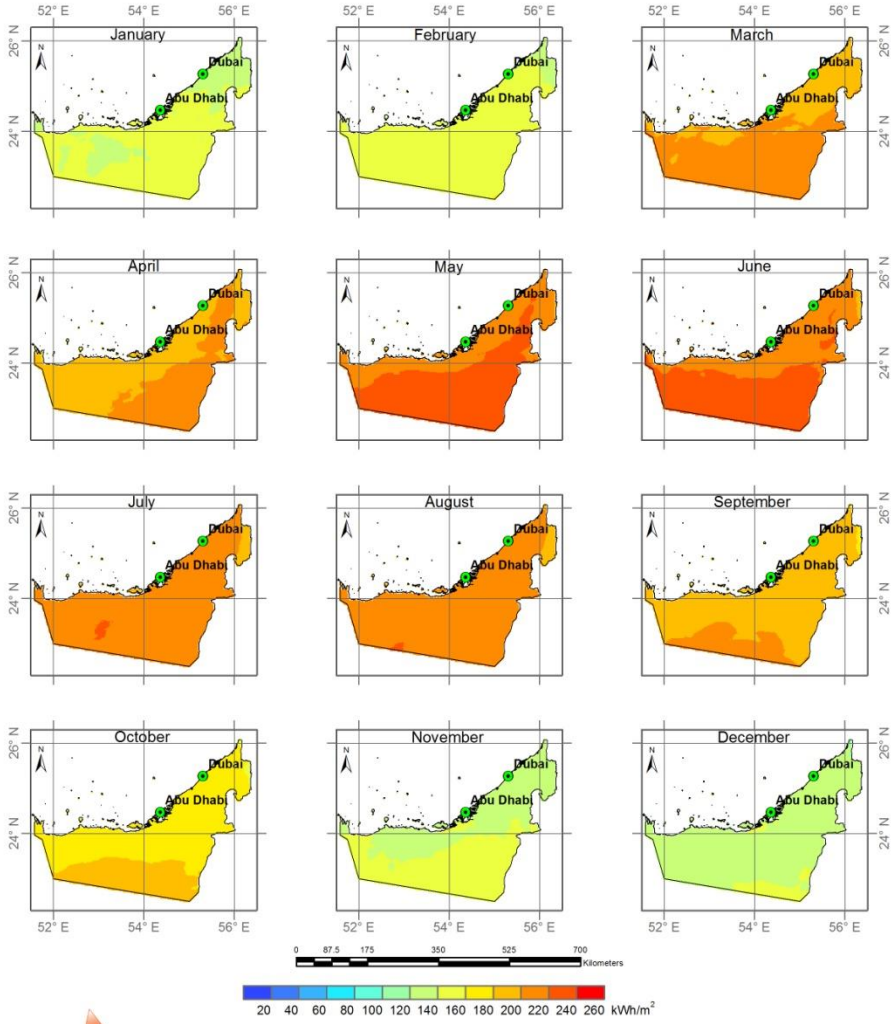
Global Horizontal Irradiation 2010



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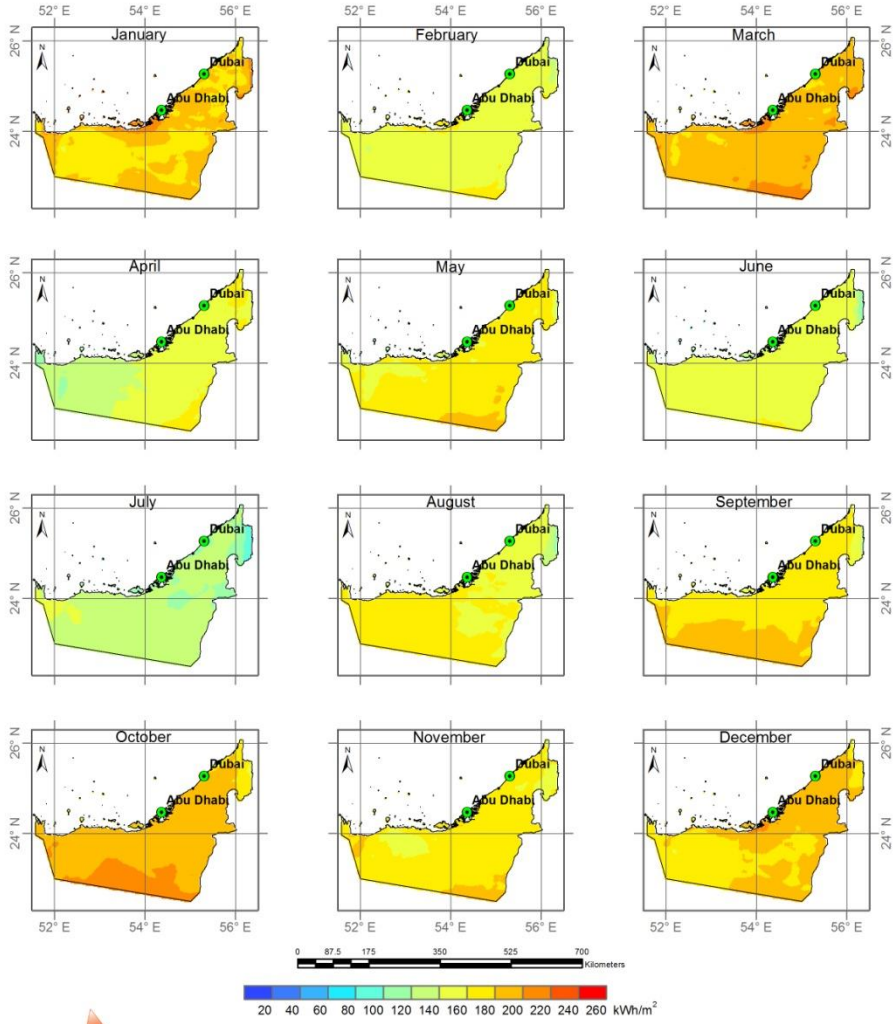
Direct Normal Irradiation 2010



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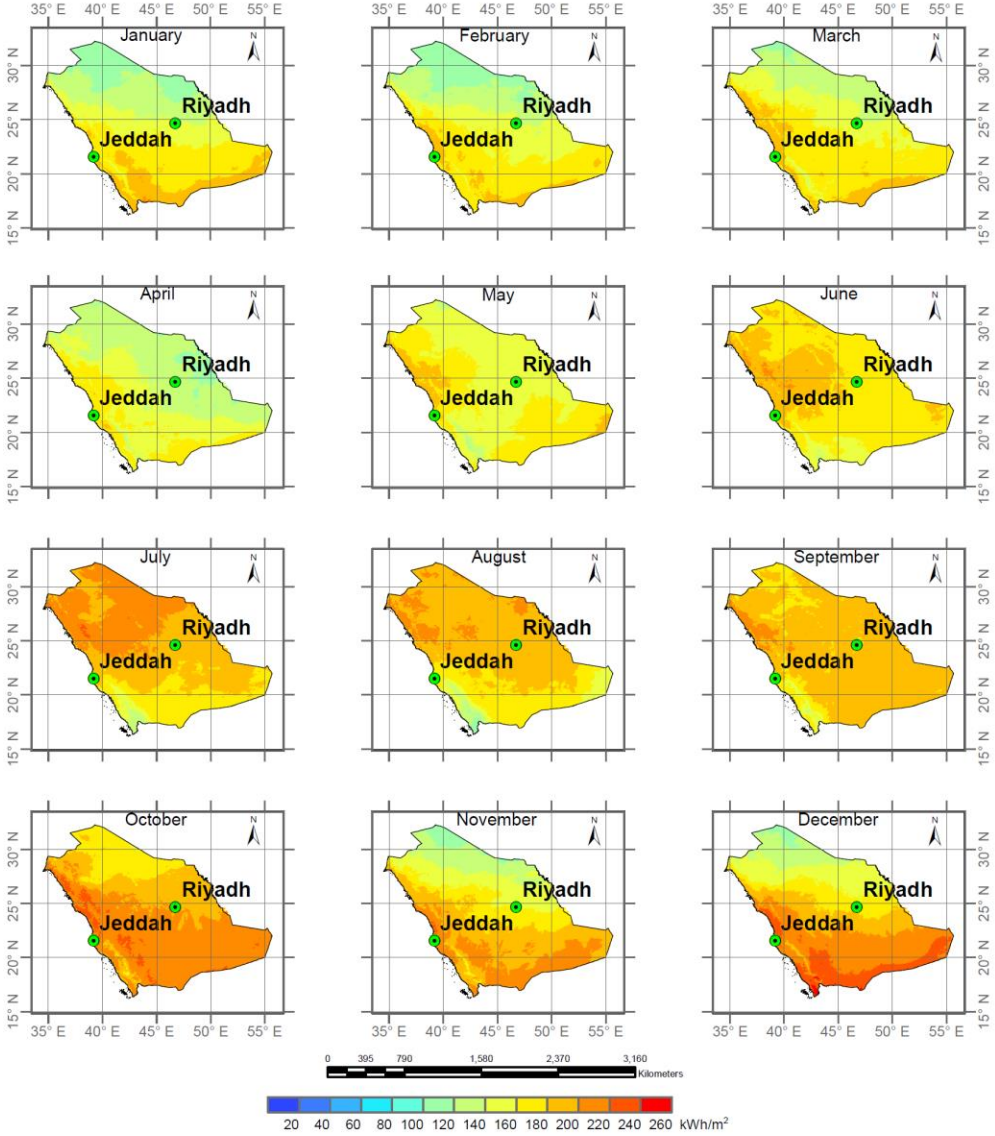
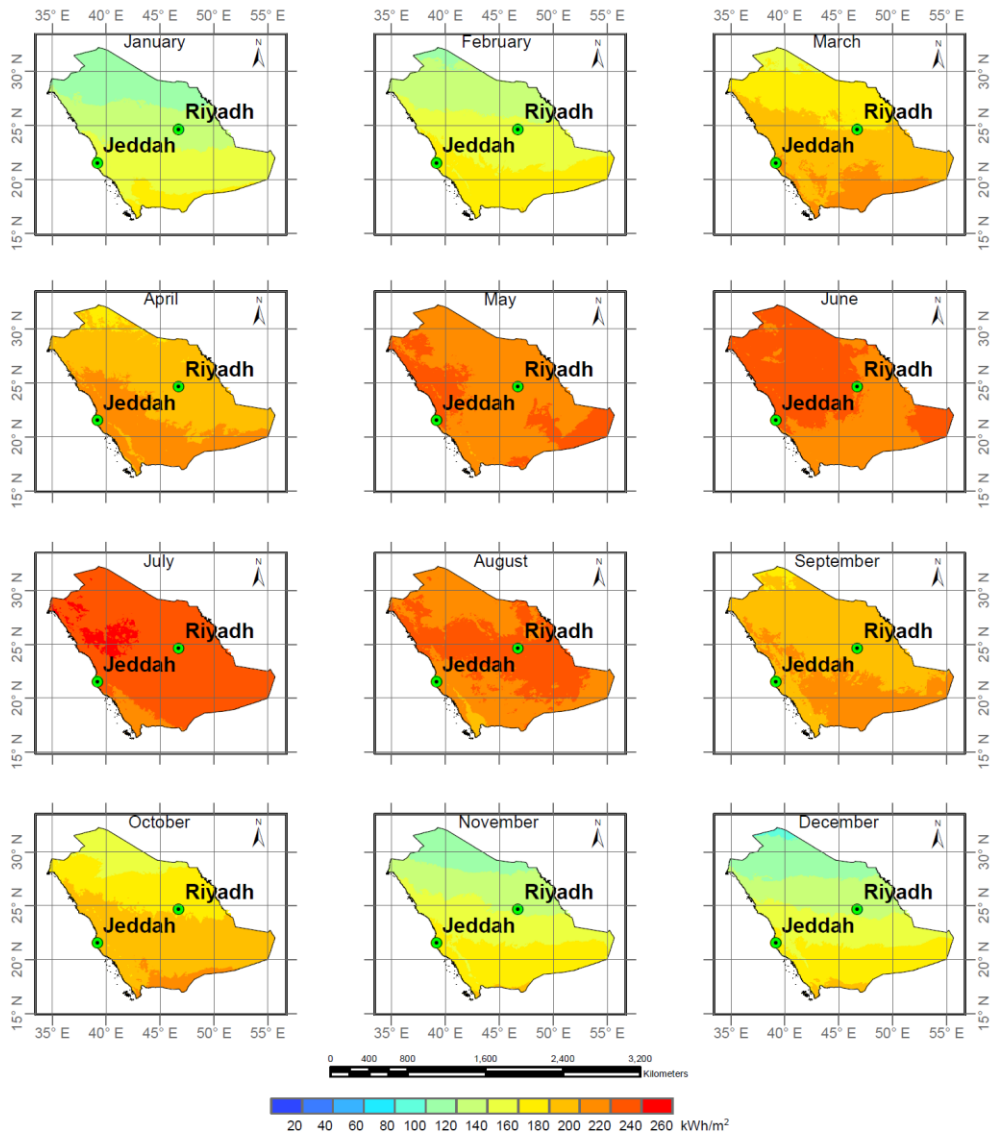
Direct Normal Irradiation 2013



Global Horizontal Irradiation 2013



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مدينة الملك عبد الله للطاقة الذرية والمتجددة
K•A•CARE

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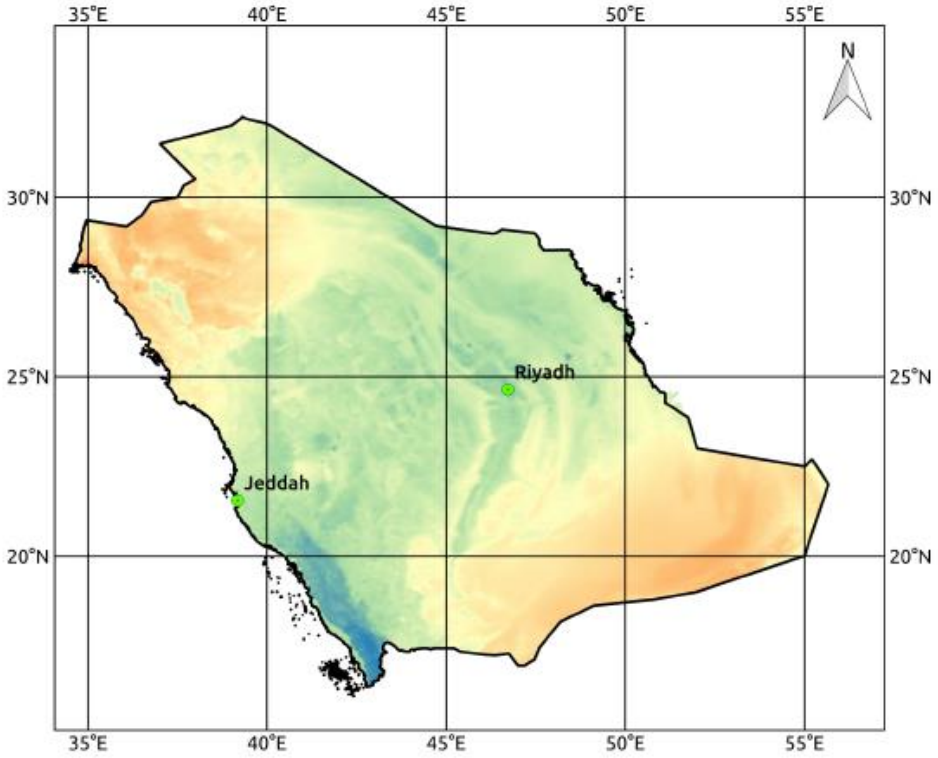
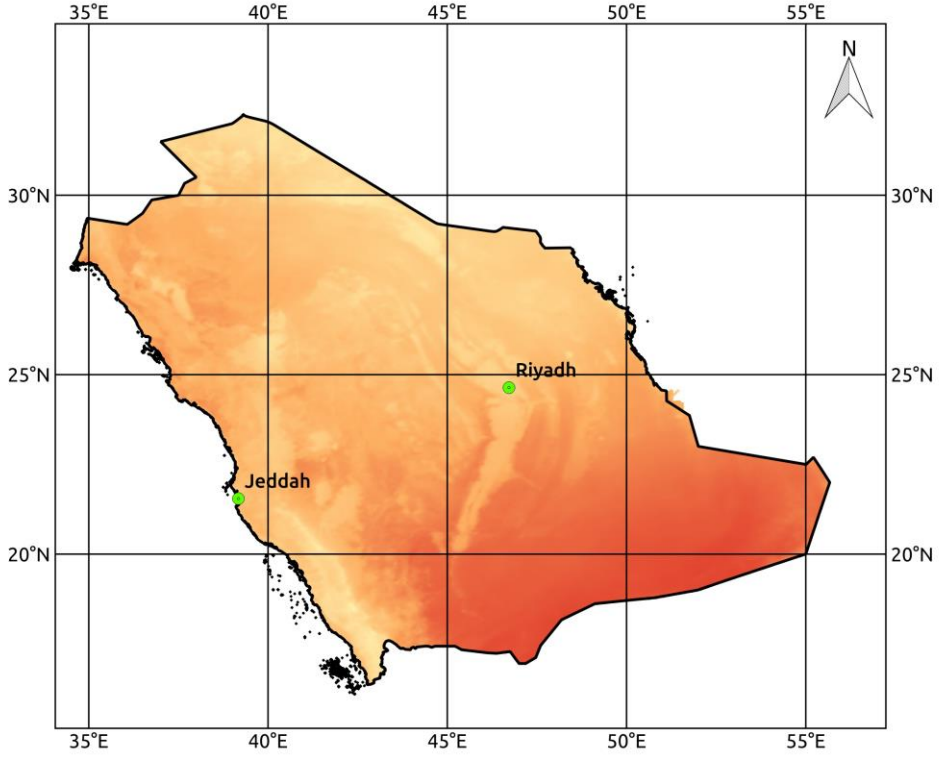
Direct Normal Irradiation 2015



0 250 500 750 km

1400 1700 2000 2300 2600 2900 3200 kWh m $^{-2}$

Global Horizontal Irradiation 2015



250 0 250 500 750 km

1400 1600 1800 2000 2200 2400 2600 kWh m $^{-2}$

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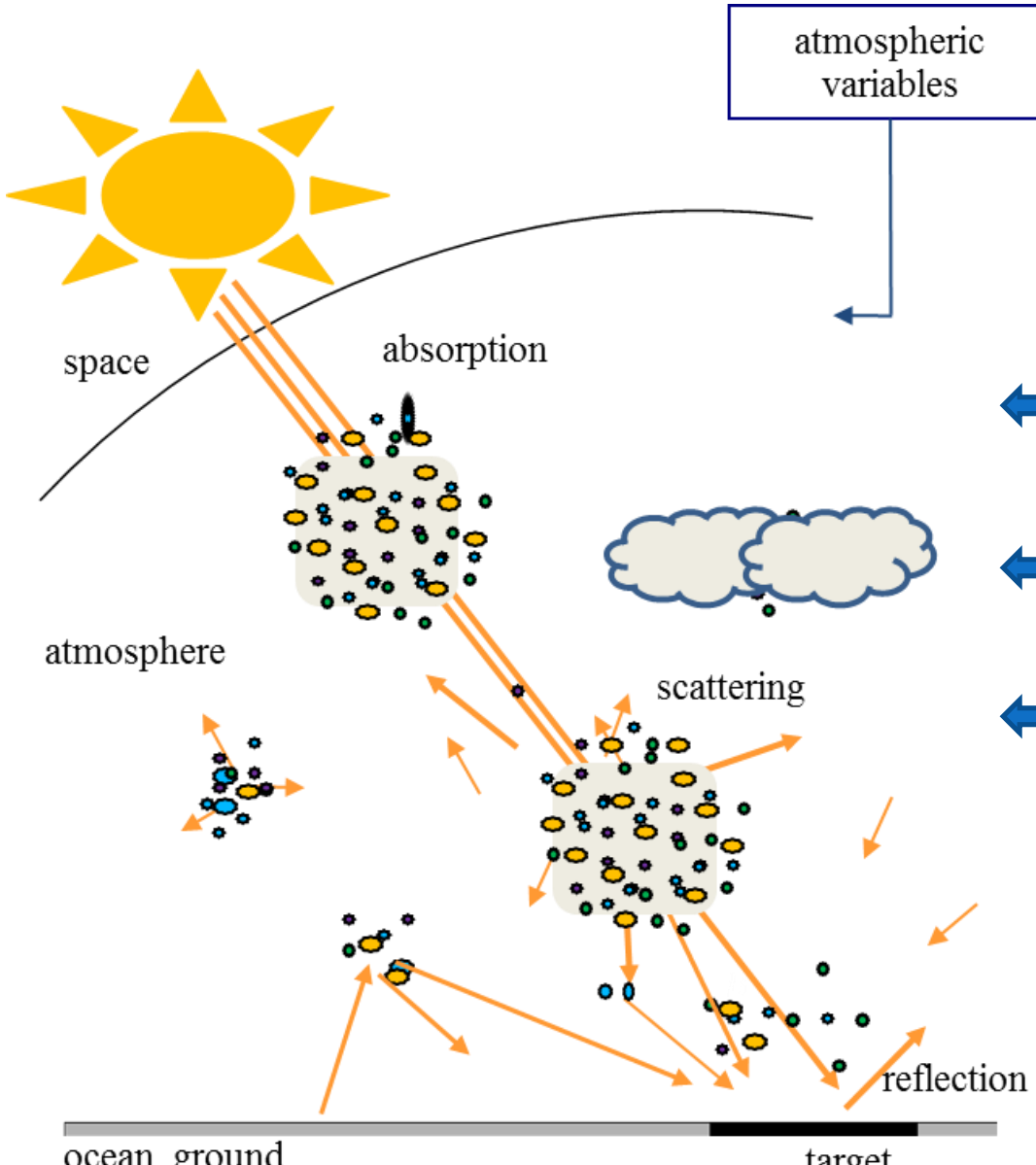

Total column content in water vapor

Cloud optical depth

Aerosol optical depth at 600 nm

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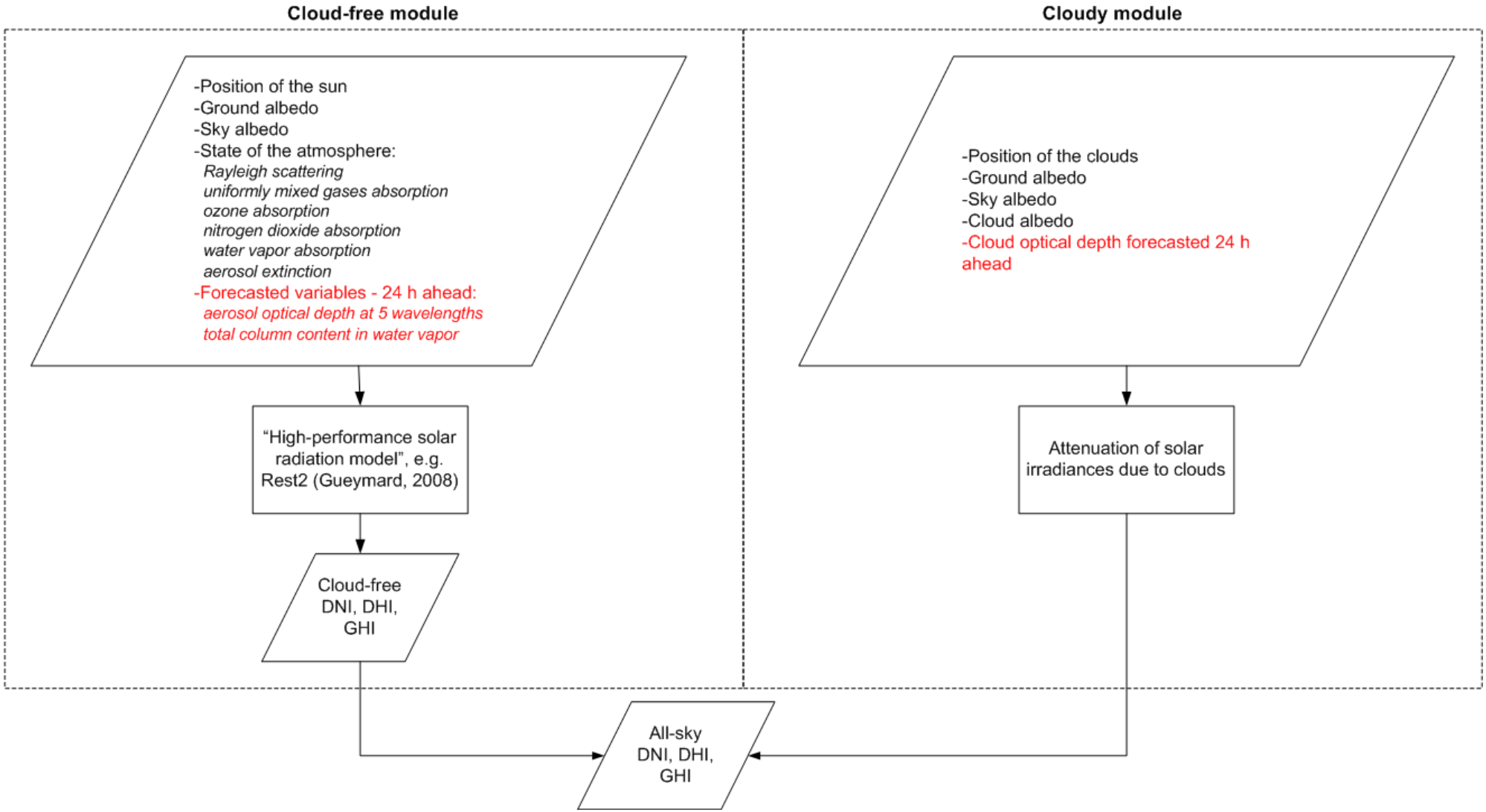

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Examples of forecasted inputs
19 Feb., 2017 at 0900 UTC

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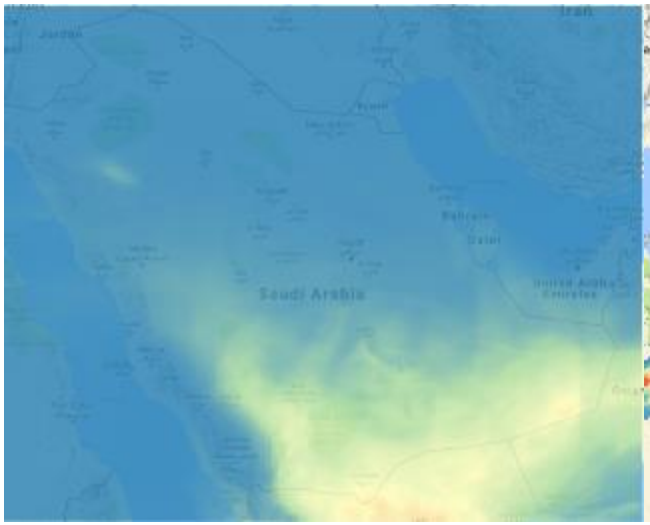
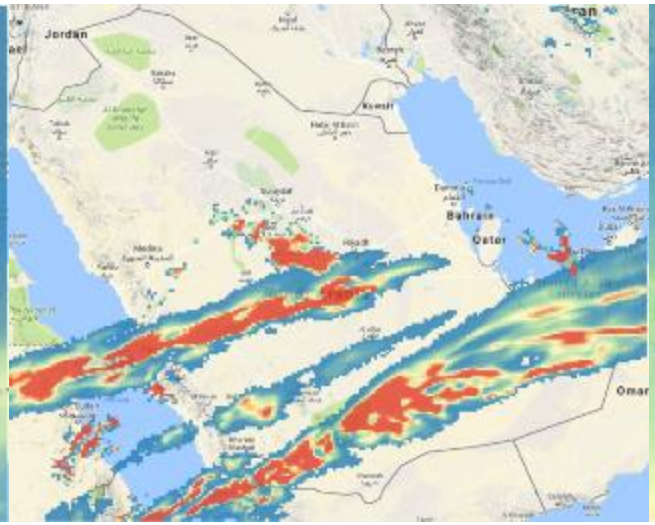
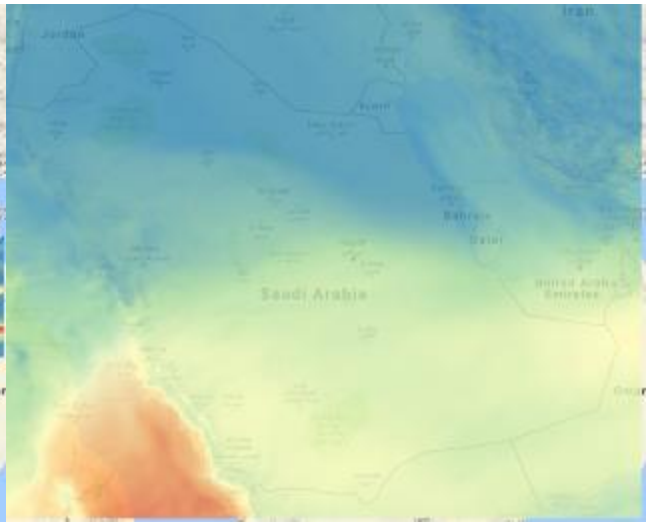
Aerosol optical depth at 600 nm



Cloud optical depth



Total column content in water vapor



units: cm

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Preliminary results: cloud-free DNI, DHI, GHI
19 Feb., 2017 at 0900 UTC

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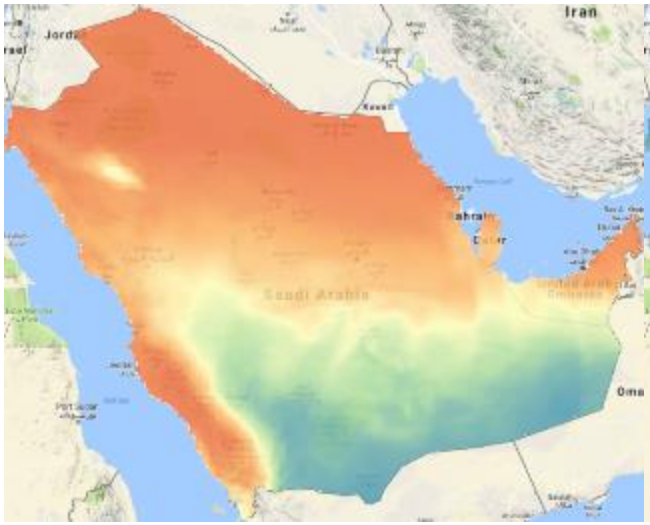
DNI



units: W m^{-2}

DHI

units: W m^{-2}

GHI

units: W m^{-2}

200 400 600 800 1000 1200

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Dust Deposition & PV Performance

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- Arid and semi-arid regions are particularly vulnerable to the accumulation of dust on PV panels.
- Higher degradation in PV performance due to soiling in tropical regions with lower tilt angles.

It is important to investigate the influence of soling on PV system performance to comprehend the losses in performance.

Such an investigation would also facilitate feasibility studies of cleaning mechanisms and development of appropriate **cleaning frequency schedule**.

- CHIMRE simulates realistic values of the 12-hour and 24-hour accumulated dry and wet deposition fluxes (in μg cm^{-2}) of aerosols over the horizontal surfaces along with the ambient dust concentrations and Aerosol Optical Depths.
- Daily accumulated dust deposition fluxes show large variability and the values are in between in 0.1 and 100 μg cm^{-2} and values may exceed 100 μg cm^{-2} on stormy days.
- Lower soiling rates during calm period (winter/autumn) and higher during dusty months (spring/summer).

Density (mg/cm^2)	a-Si (%)	CIGS (%)	CdTe (%)	c-Si (%)
1.2	−10.8	−9.1	−9.7	−9.1
4.25	−33.0	−28.5	−30.1	−28.6
14	−66.0	−59.6	−61.9	−59.6
19	−77.4	−70.6	−73.1	−70.6
30	−98.4	−97.8	−98.1	−97.8

H. Qasem et al. Progress in Photovoltaics: Research and Applications (2014)

AGEDI · Environment Agency - Abu Dhabi · IRENA International Renewable Energy Agency · Supreme Council of Energy المجلس الأعلى للطاقة

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Dust Deposition – CHIMERE

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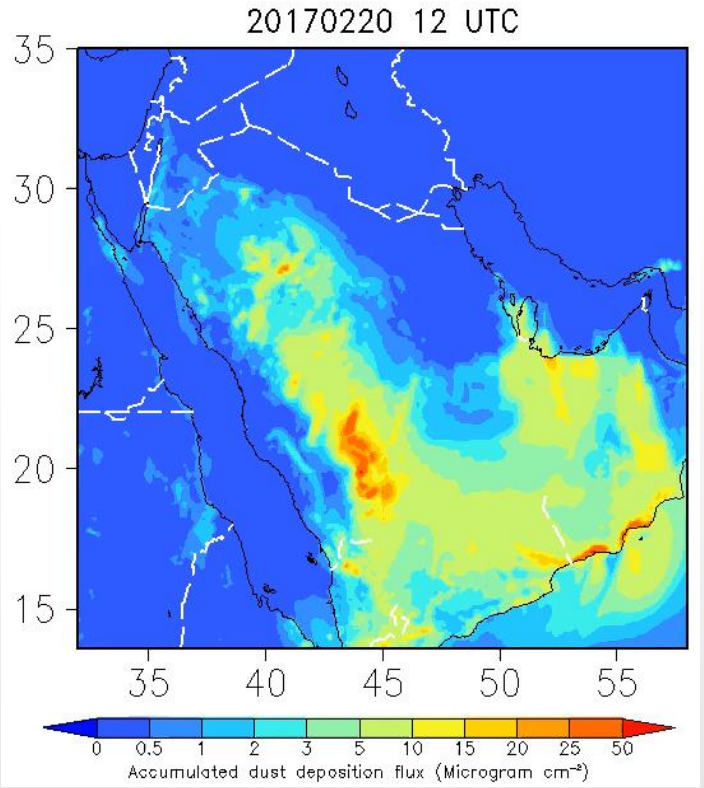
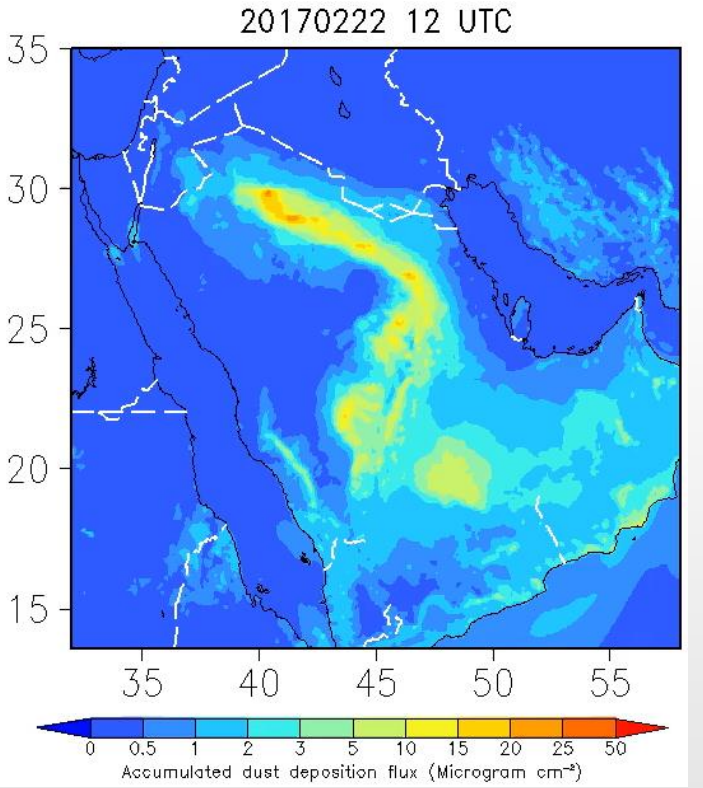


Forecasted 12-hour accumulated dust deposition

- High spatial variability in the deposited flux
- Significant change in the accumulated dust within a day



AGEDI
هيئة البيئة - أبوظبي Environment Agency - ABU DHABI
IRENA International Renewable Energy Agency
المجلس الأعلى للطاقة Supreme Council of Energy

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Dust Deposition – CHIMERE

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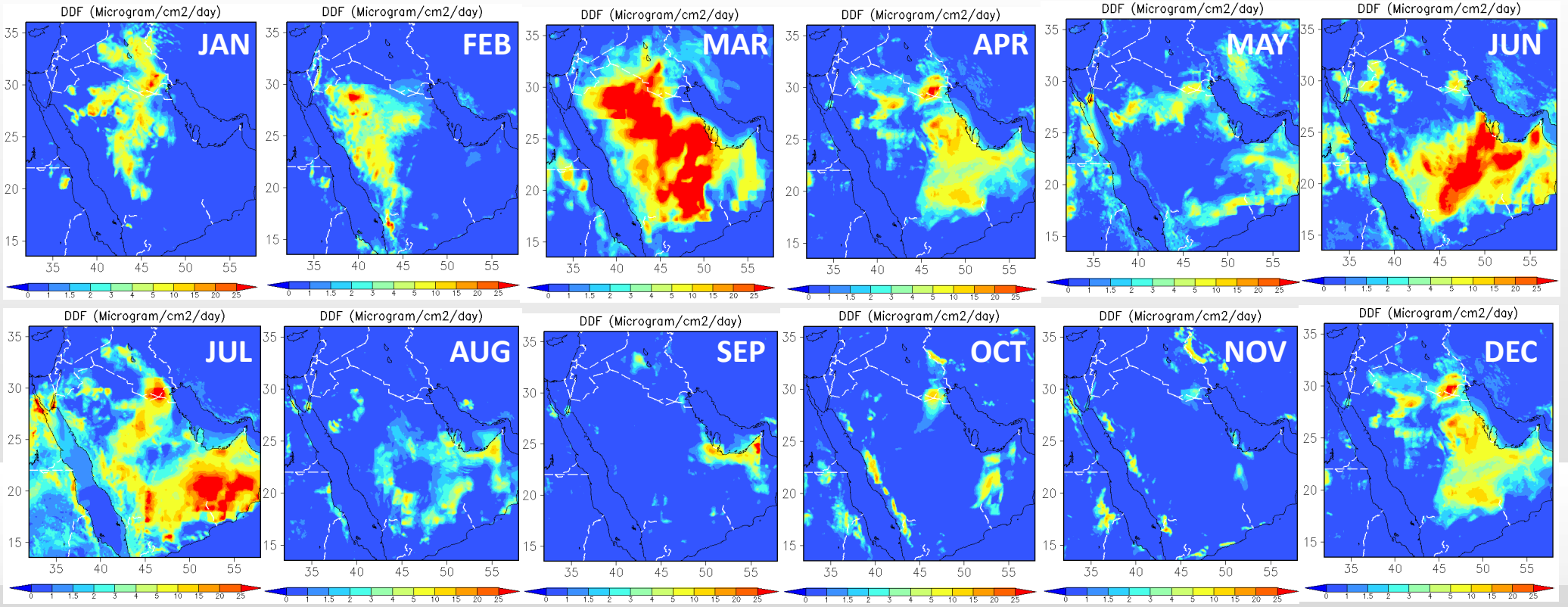
Simulation of Dust Deposition Flux – Monthly means (2010)



Overview

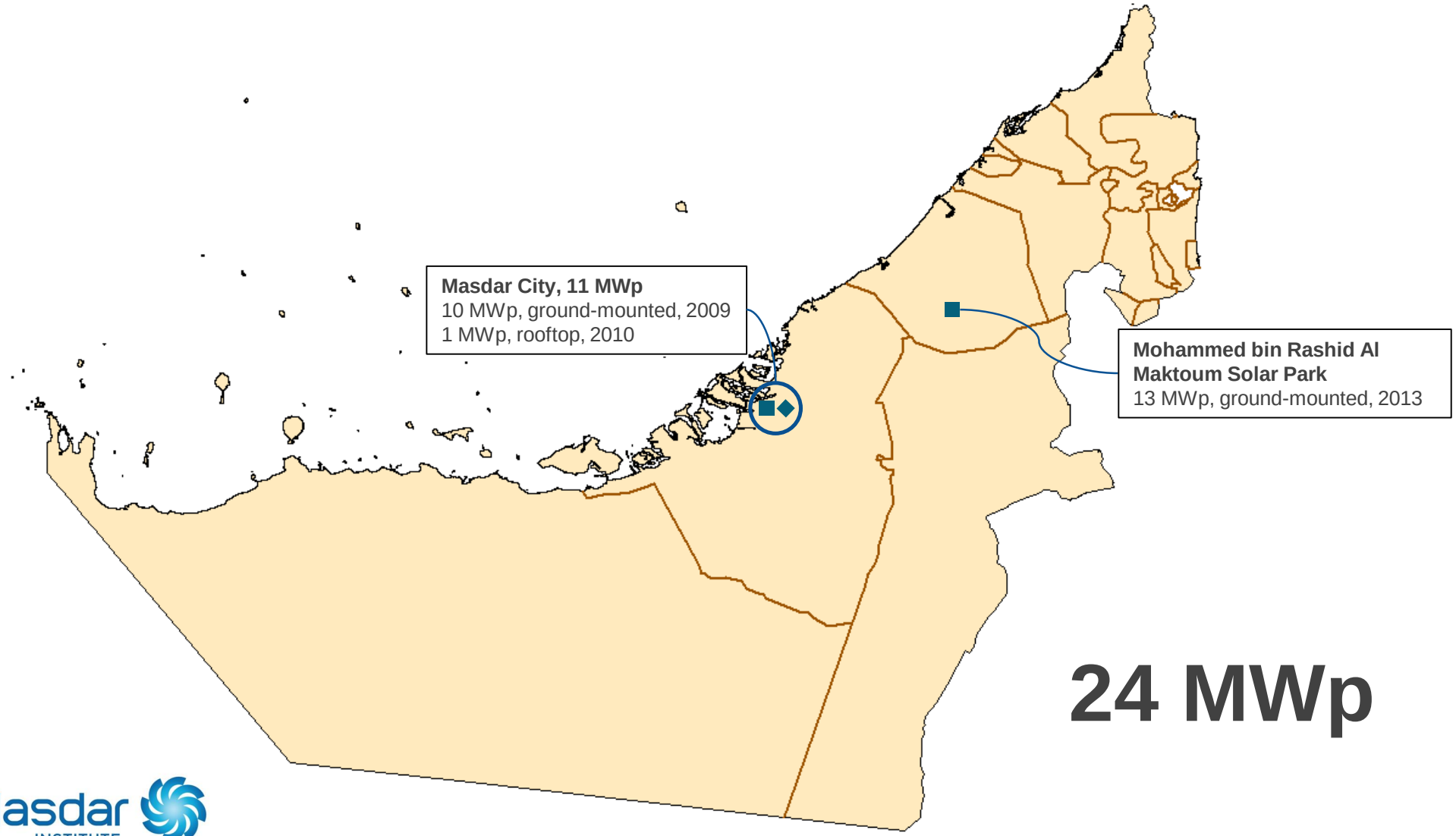
- The results of many previous studies indicate that the potential of utility-scale solar photovoltaic (PV) power generation is exceptionally large on the Arabian Peninsula.
- The recent record-low solar power bids given in Dubai and Abu Dhabi support these findings implying that an electricity generation cost well below 2.5 USD per kWh is possible for PV power stations to be installed in the region by the end of the 2010s.
- Based on the announced capacity additions, the installed PV capacity is expected to experience tremendous growth by the end of the decade.
- PV power generation represents a lucrative mean to diversify energy mix in the MENA Region.

Overview (Cont.)

- Careful site selection is imperative to minimize the cost of PV electricity generation.
- As opposed to natural gas-fired combined cycle power plants, the cost of PV power generation is mainly determined by the capital expenses involved in power station construction.
- Capital expenses include many components that show a high spatial variability.
- The potential for electricity generation itself varies in space – primarily following the geographical pattern of solar resource.
- It is also in the government's interest to form a profound understanding of PV plant site suitability and accordingly optimize the future site zoning decisions to minimize the cost of PV electricity generation and create attractive investment ecosystem.

1. Photovoltaics in the UAE: Current Status and Future Prospects

Operational Utility-Scale Capacity in 2016



24 MWp

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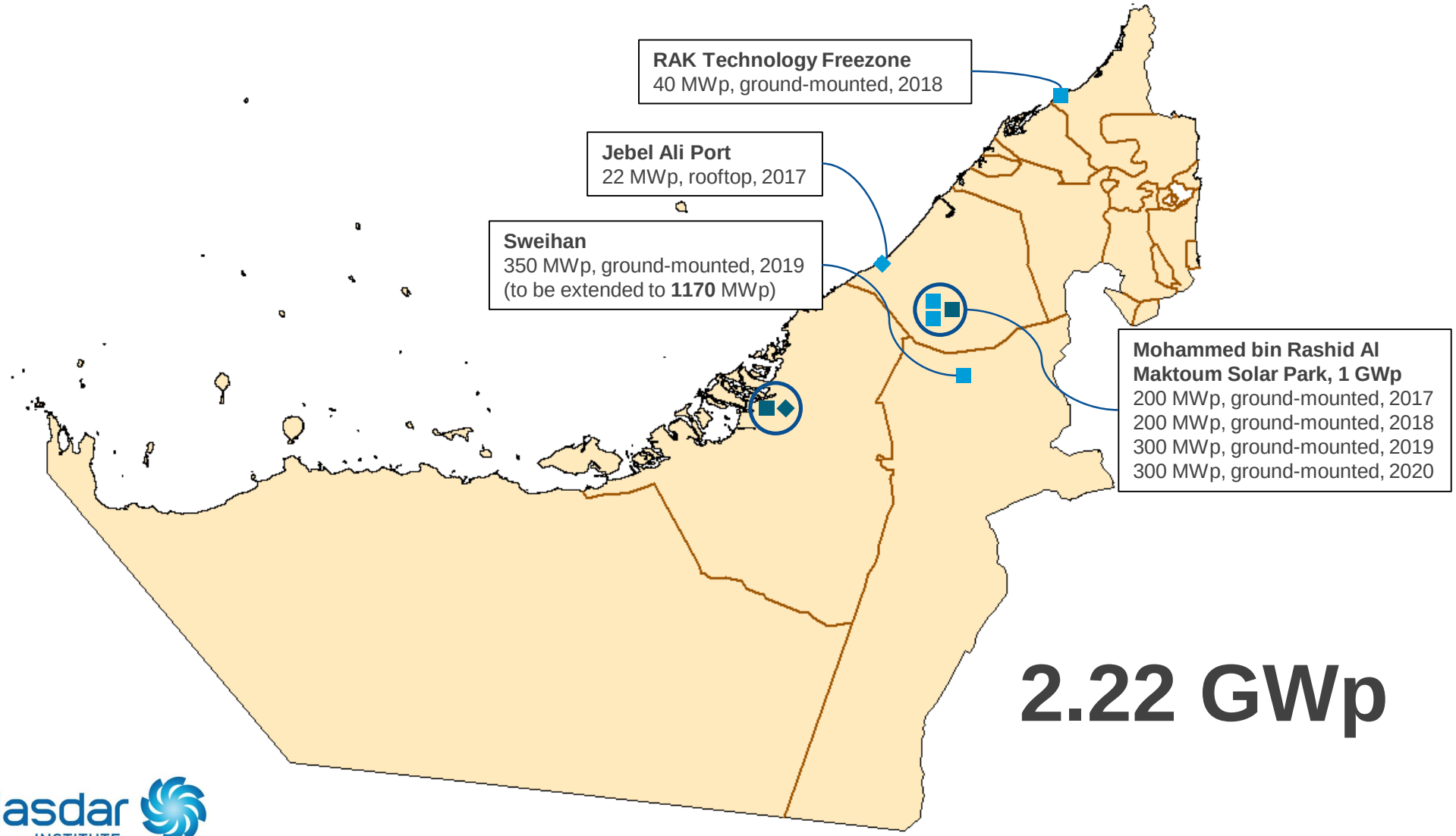
1. Photovoltaics in the UAE: Current Status and Future Prospects

Announced Utility-Scale Capacity by 2021



2.22 GWp

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Assessment of energy economic PV potential

- The assessment of energy economic PV potential is done by modelling the levelized cost of the electricity (LCOE) generated by a potential PV power station at each site.
- A particular attention is paid to the spatial variability of different cost components. Instead of commonly used capacity-specific cost estimates, the assessment is based on decomposed cost components specific to site and plant configuration parameters.
- The capacity-specific cost data are converted into more appropriate cost component-tailored indicators, which enable the allocation of spatial cost factors more accurately to the components actually affected.

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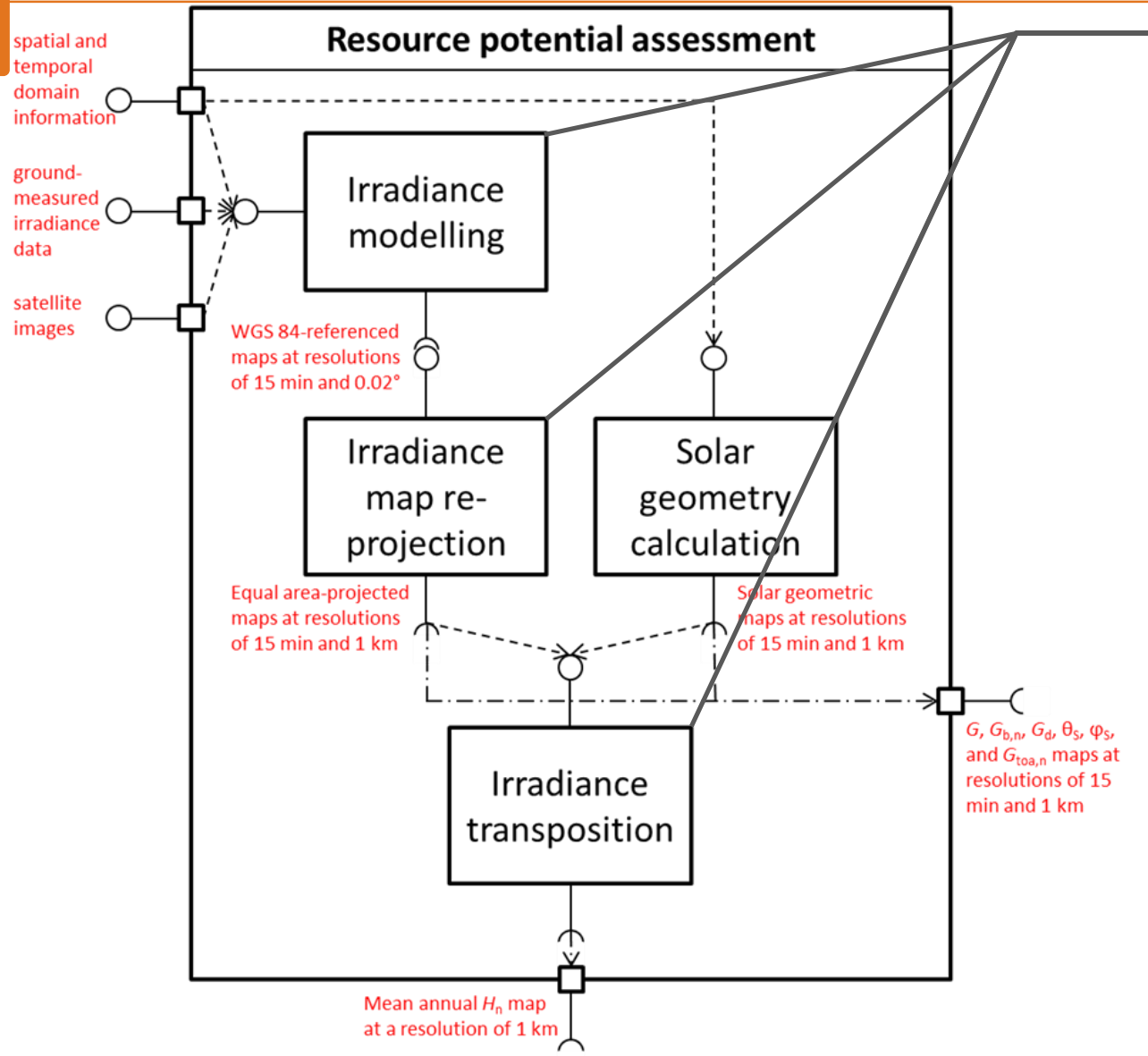
Cost categorization and spatial factors used in the economic analysis

Cost category	Cost component	Specific cost unit	Spatial cost factors
Land	Land acquisition	USD/ha (plant area)	land value
	Earthworks	USD/m^3	cut and fill volume
EPC	Foundation	USD/m^2 (array area with FM and 1AT) /USD/tracker (2AT)	land cover road distance to a cement factory/industrial area slope
	Mounting structures	USD/m^2 (array area) / USD/tracker	wind load slope
	Solar modules	USD/Wp	
	Module cables	USD/module	slope
	Solar cables / DC main cables	USD/m^3 (cable volume)	slope
	Junction boxes	USD/junction box	slope
	AC BOS	USD/MVA	slope
	Civil works	USD/ha (plant area)	slope
	Auxiliary systems	USD/Wp	slope
Connecting infrastructure	Road connection	USD/km	Euclidean distance to a road slope
	Grid connection	USD/km	Euclidean distance to grid land/marine connection slope
	Substation	USD/substation	slope
Intra-country transportation		USD/m^3/km	road/Euclidean marine distance to a primary port
Project development		USD (% of total EPC)	
O&M	Arrays	USD/m^2/year (array area)	dust deposition slope
	Civil works	USD/ha/year (plant area)	slope
	Power block	USD/power block/year	
	Plant management	USD/MWp/year	
	Utilities	USD/MWp/year	
	Road connection	USD/km/year	Euclidean distance to a road slope
	Grid connection	% of transmission line cost	

3. PV Resource Potential in the UAE

3. PV Resource Potential in the UAE – *Methodology*



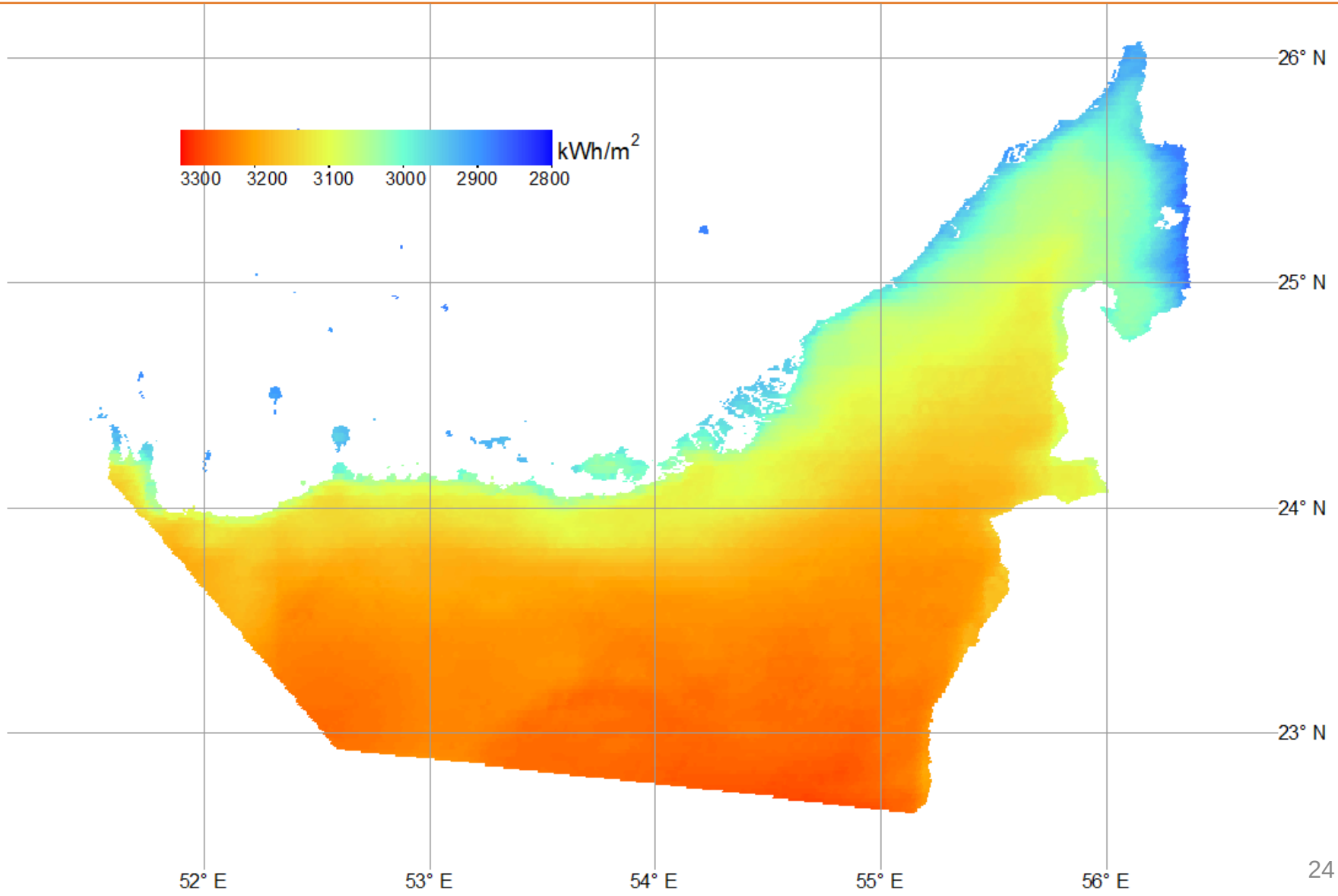
Irradiance modelling

1. Ground measurements at eight monitoring stations over 2007-2013

2. Thermal channel images taken by Meteosat satellites converted into brightness temperature maps

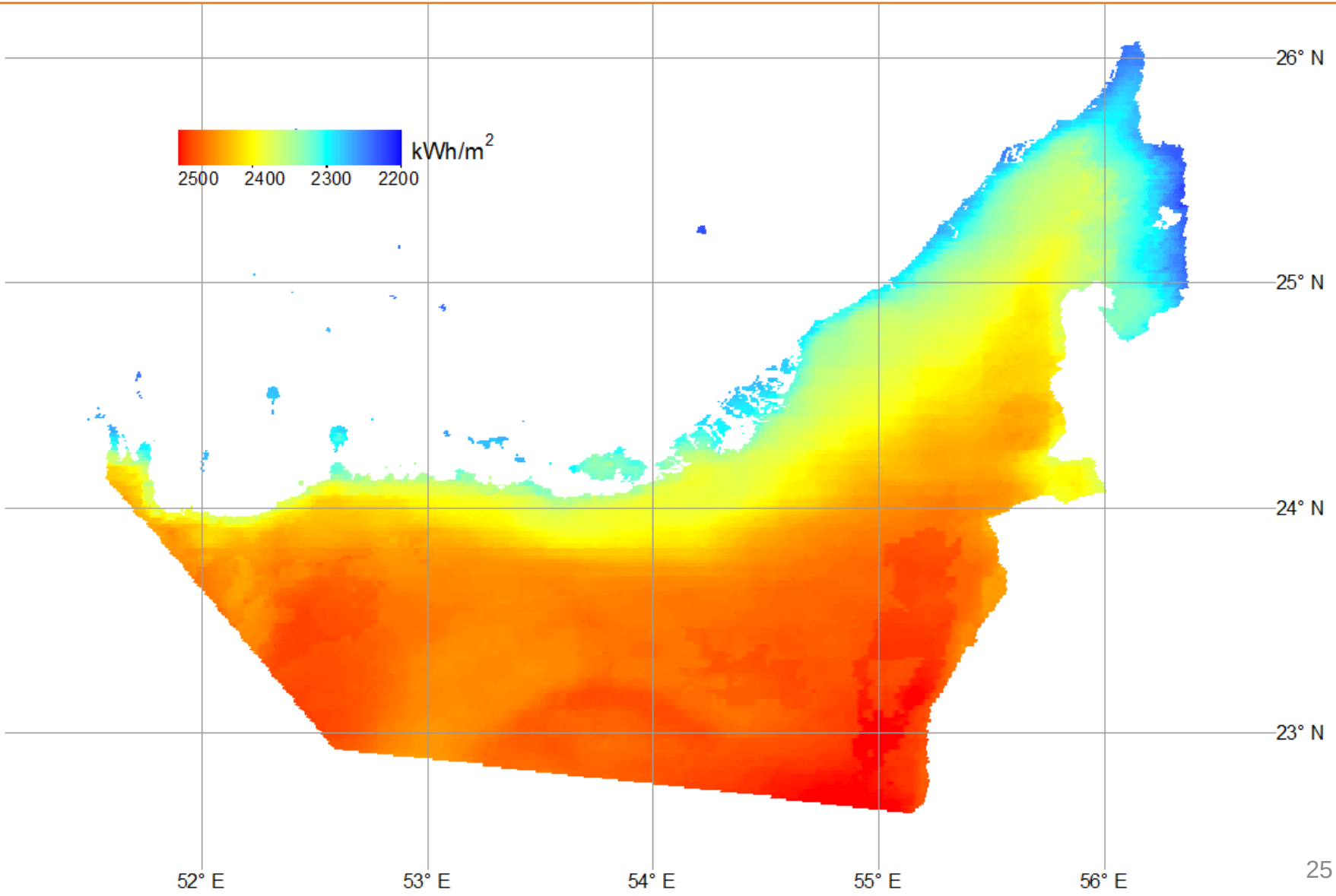
➔ Artificial neural network model relating the ground measurements to the satellite images

3. PV Resource Potential in the UAE – *Global Normal Irradiation*



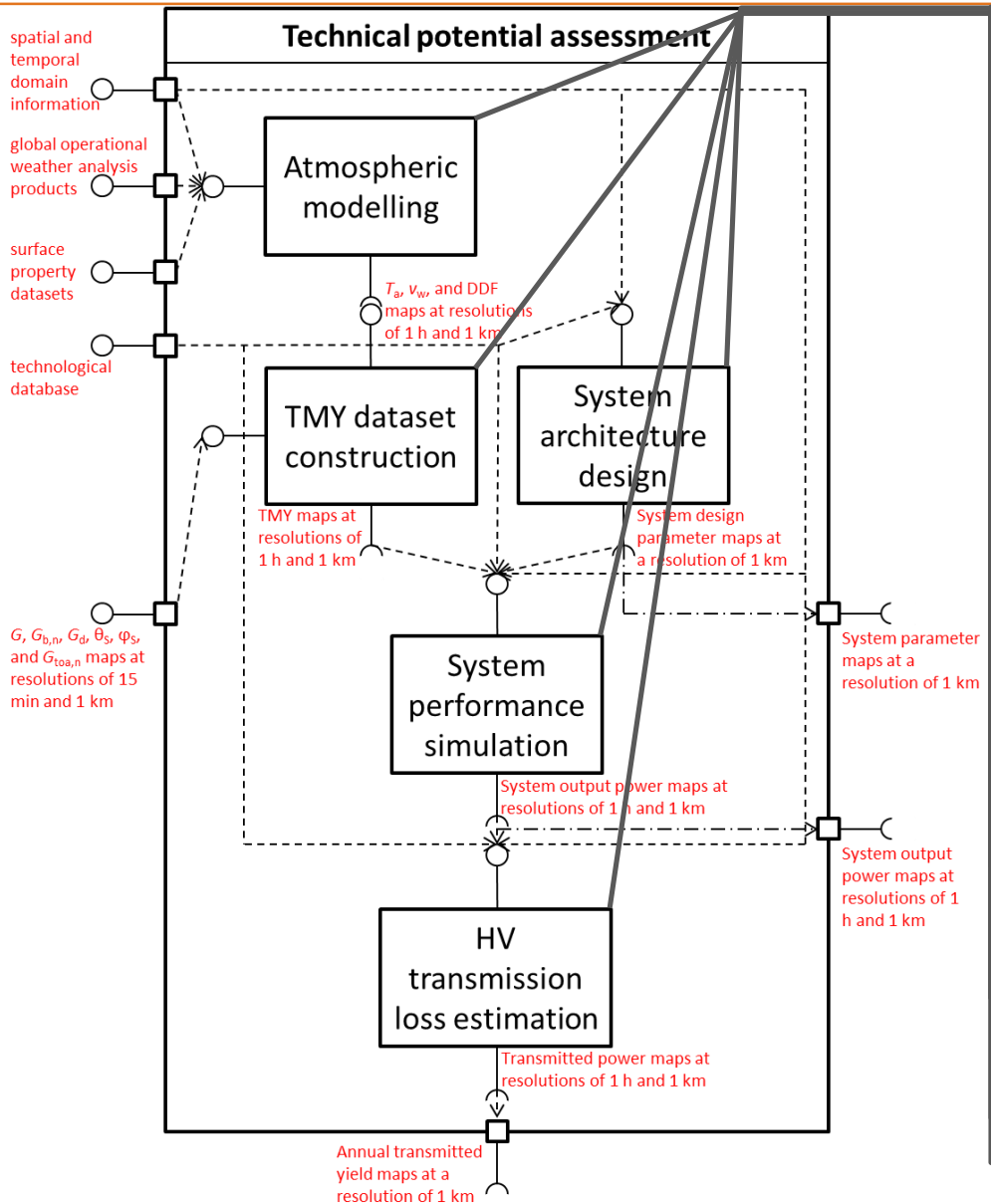
3. PV Resource Potential in the UAE

Global Polar-Aligned Irradiation



4. PV Technical Potential in the UAE

4. PV Technical Potential in the UAE – *Methodology*

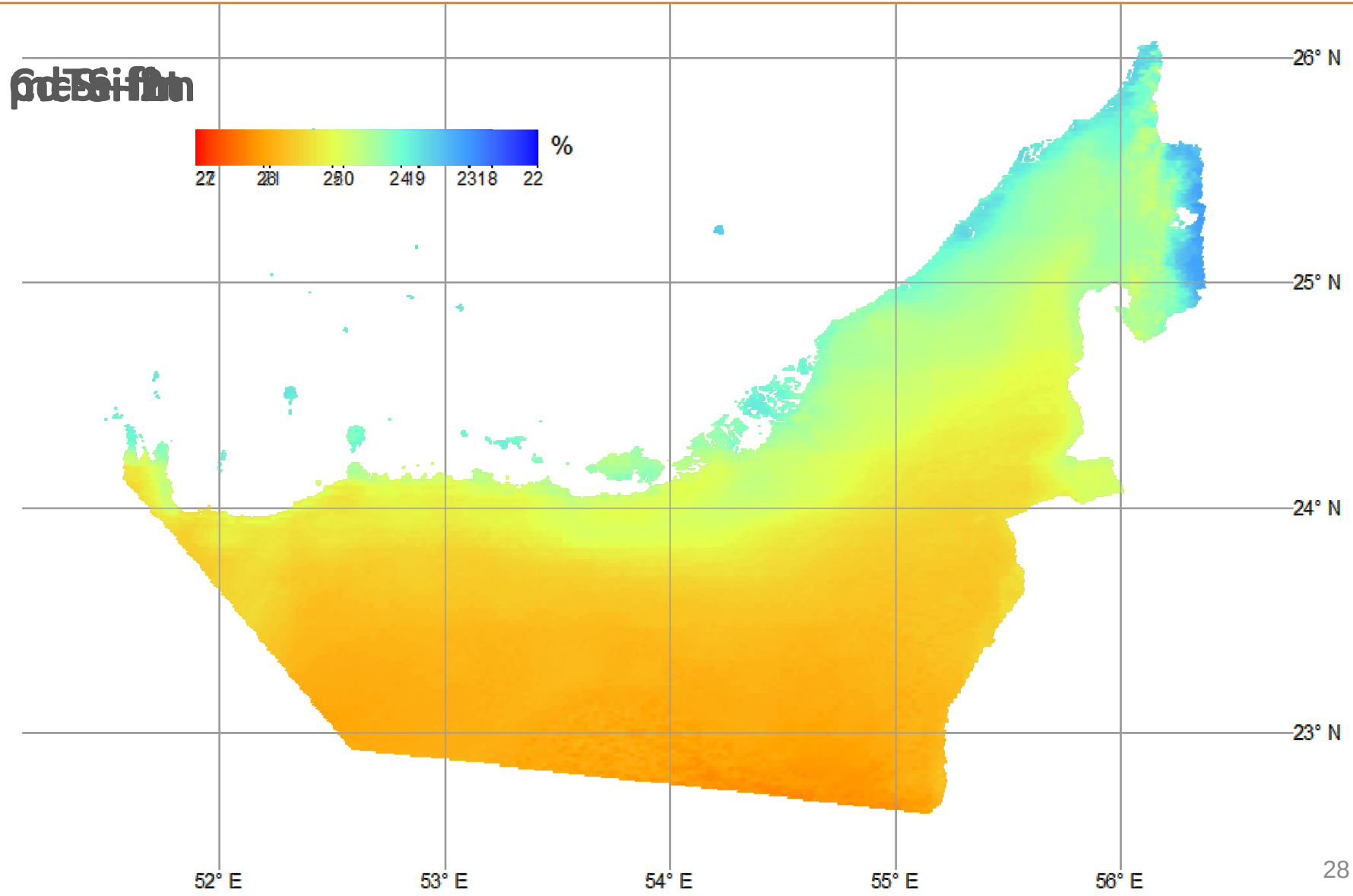


HV* transmission loss estimation

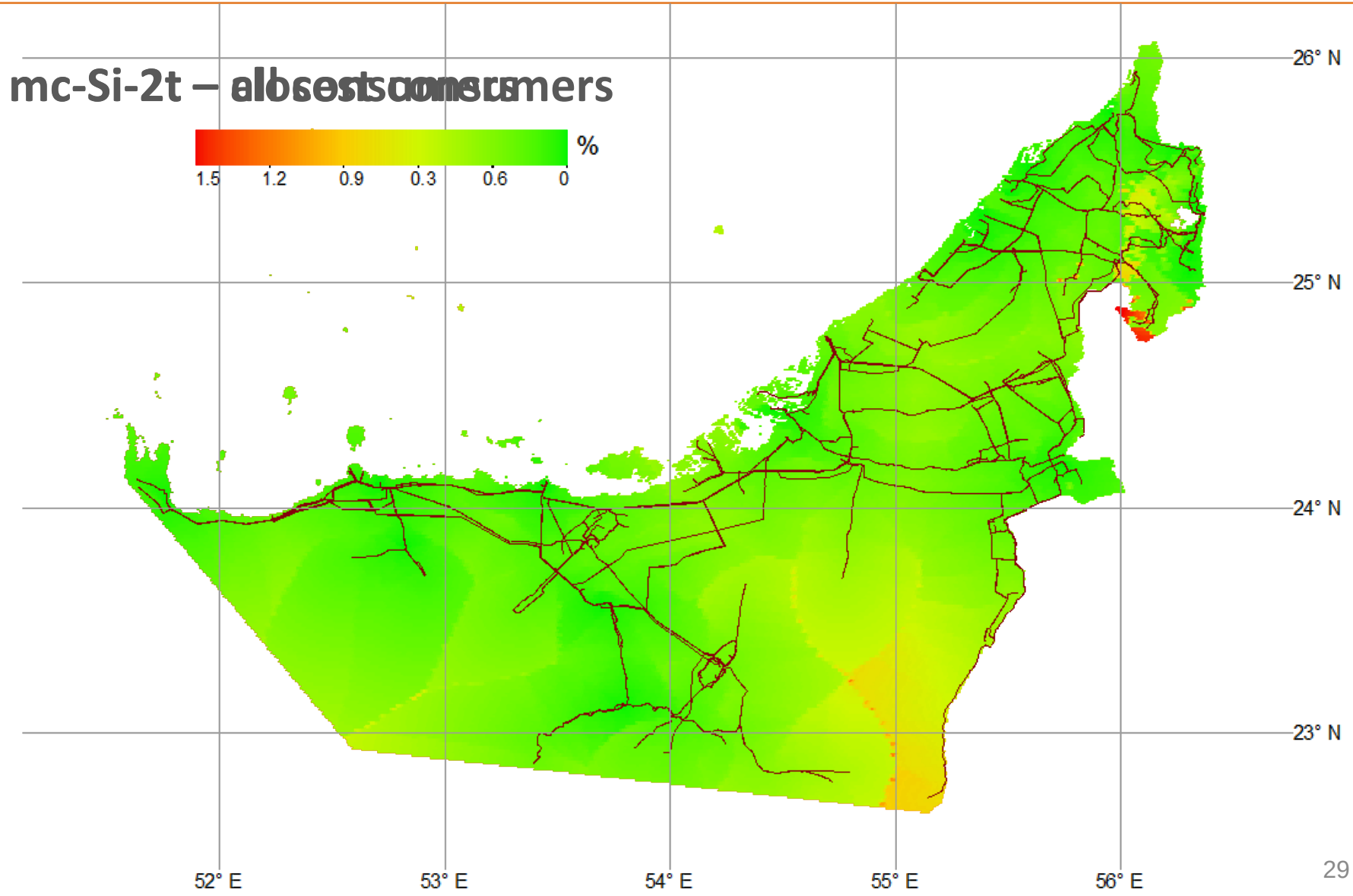
- Estimation of the losses due to the transmission of electricity from the grid connection point to all or the closest consumers
  - All consumers – computation based on the estimated emirate-specific electricity consumptions in 2014 distributed to 17 urban areas ➔
  - Closest consumers – the closest urban area assumed to consume the entire generation
- Technical assumptions:
  - Overhead (rocky terrains): 400kV, 1.15 kA (rating), 24 mΩ/km
  - Underground (other terrains): 400kV, 2 kA (rating), 9.4 mΩ/km
  - Transmission capacity utilization: 75 % consumption (incl. air conditioning)

* TMY: Typical Meteorological Year, PV: Photovoltaic, UAE: United Arab Emirates, USA: United States of America
* AC: alternating current, DC: direct current

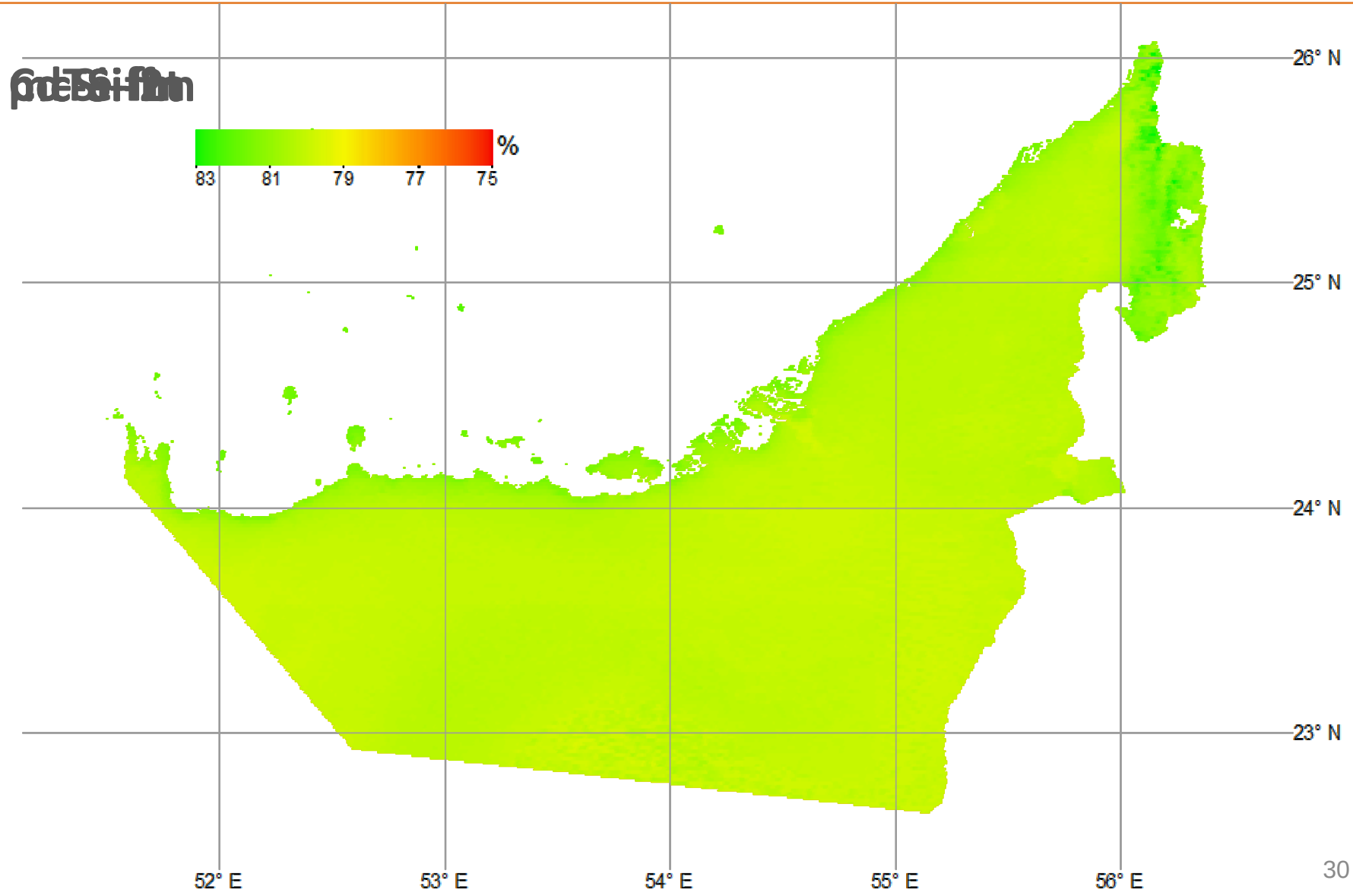
4. PV Technical Potential in the UAE – *Plant Capacity Factor*



4. PV Technical Potential in the UAE – *Transmission Loss*

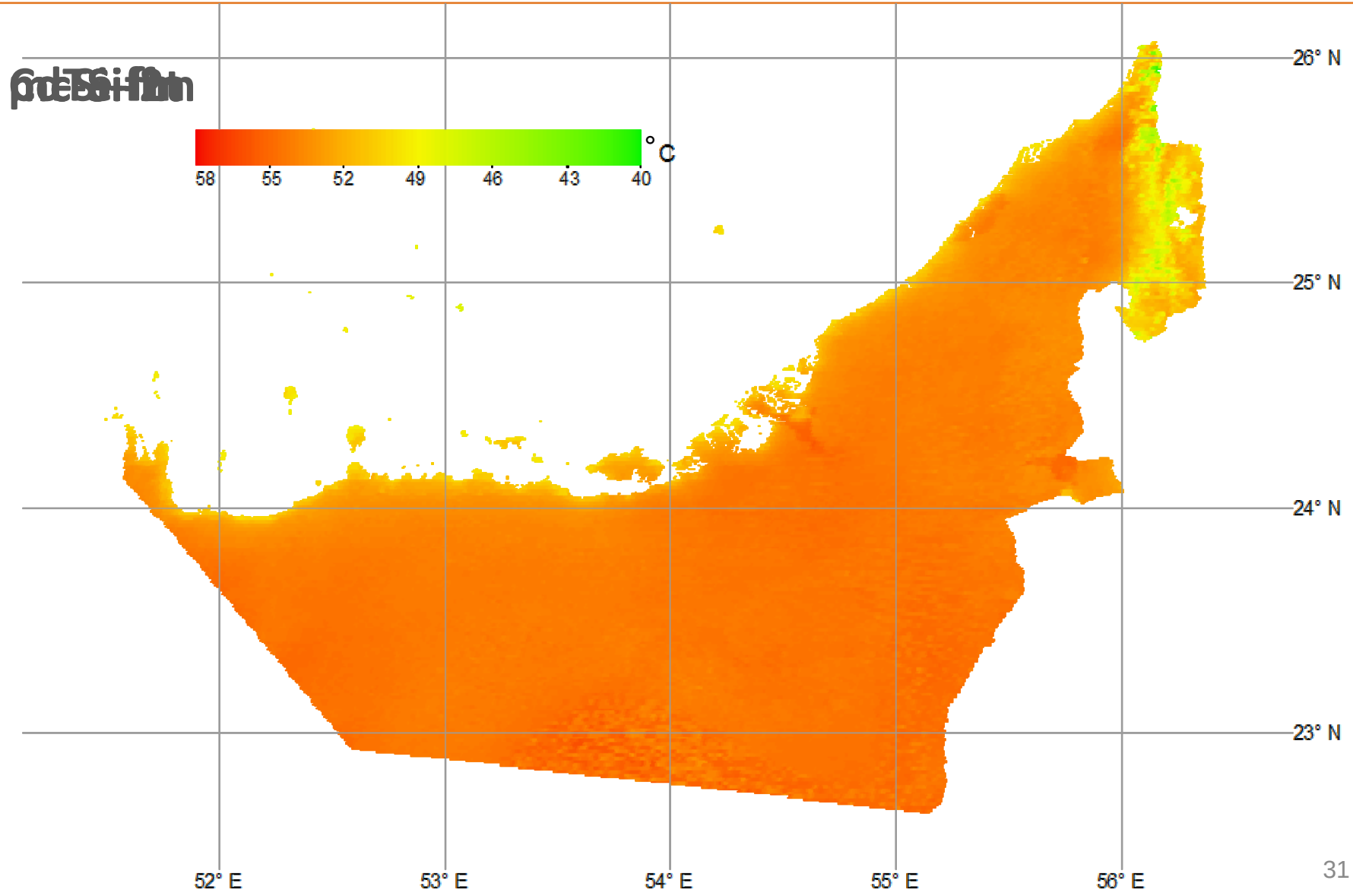


4. PV Technical Potential in the UAE – *Plant Performance Ratio*



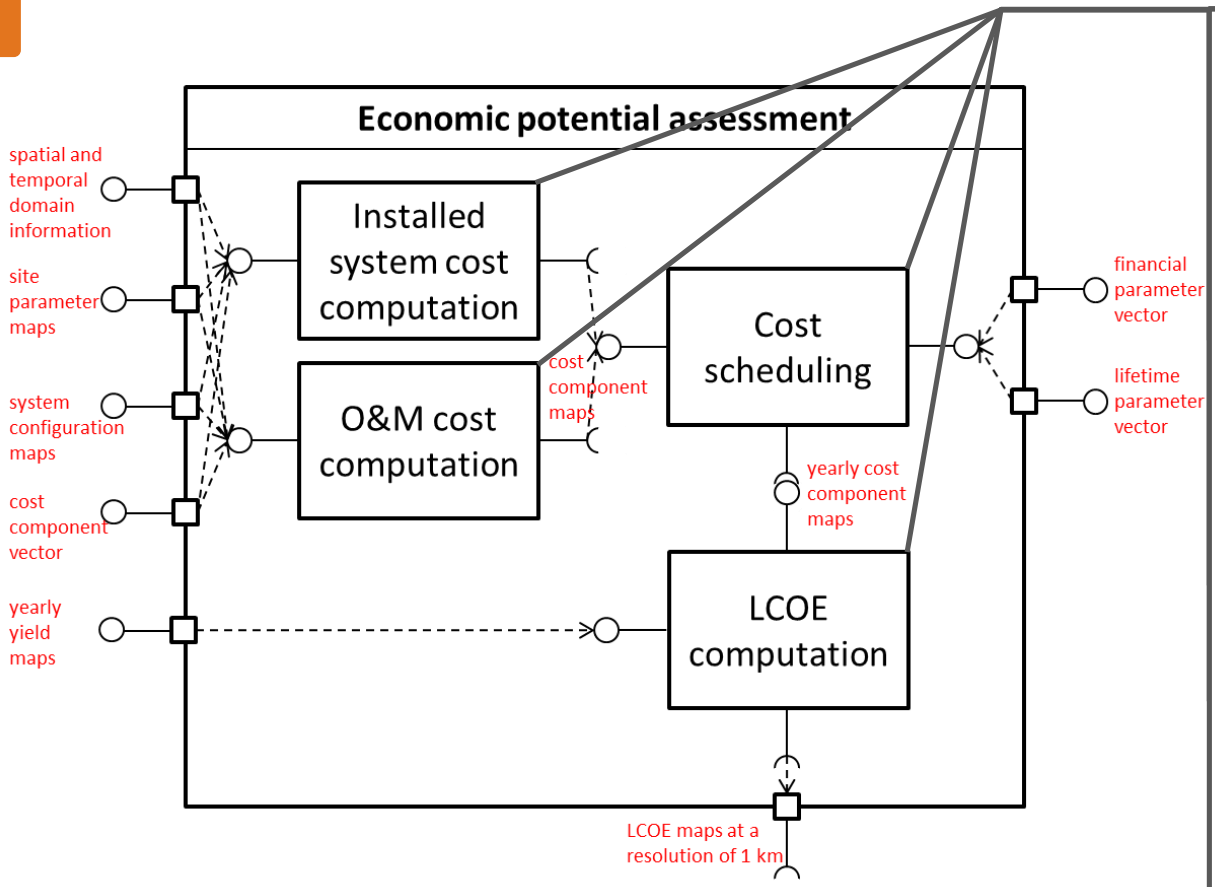
4. PV Technical Potential in the UAE

Plant Output-Weighted Average Solar Cell Temperature



5. PV Economic Potential in the UAE

5. PV Economic Potential in the UAE – *Methodology*



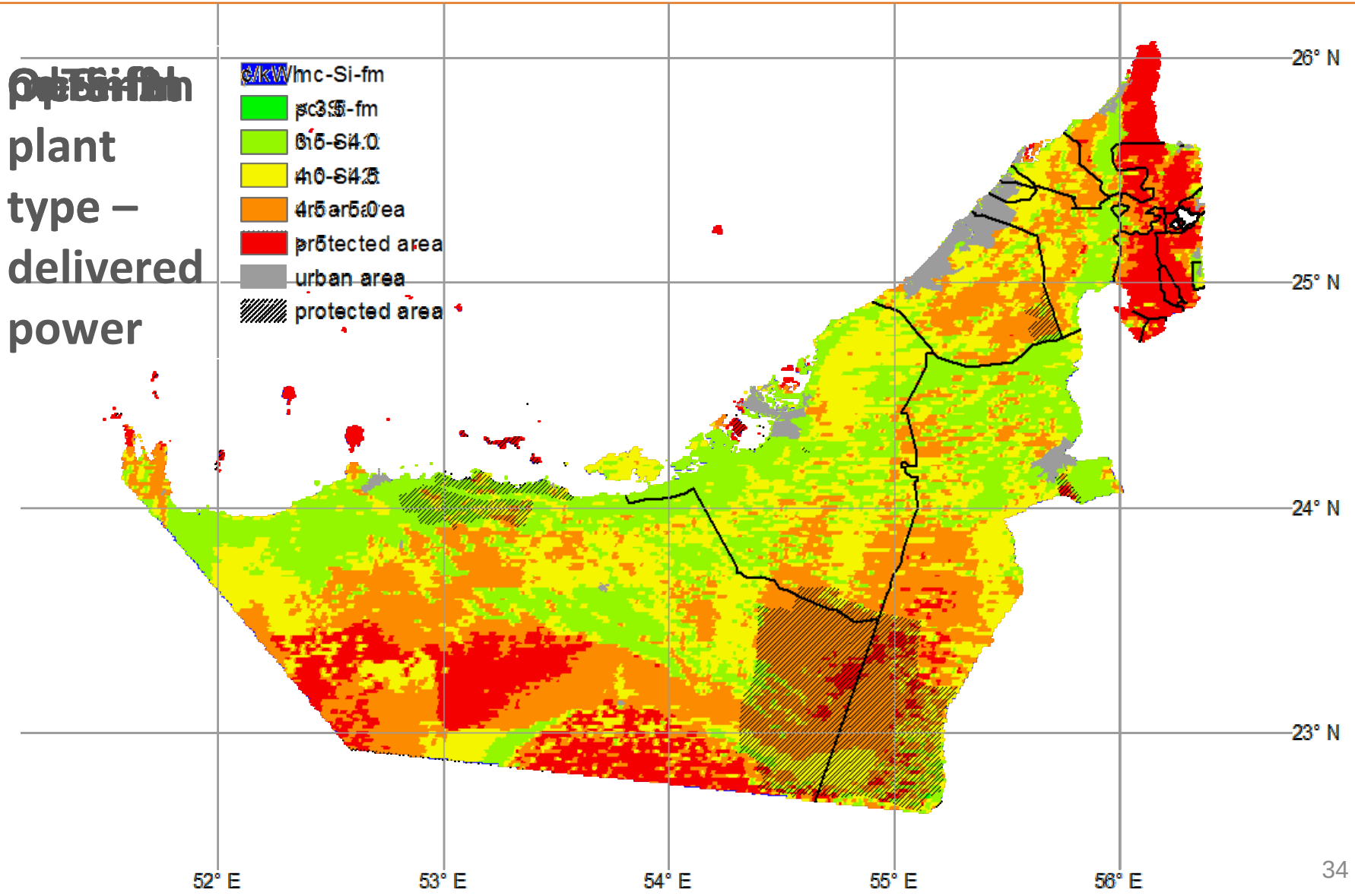
Installed system cost computation [USD/Wp]

Generation of maps for each component of the installed system cost

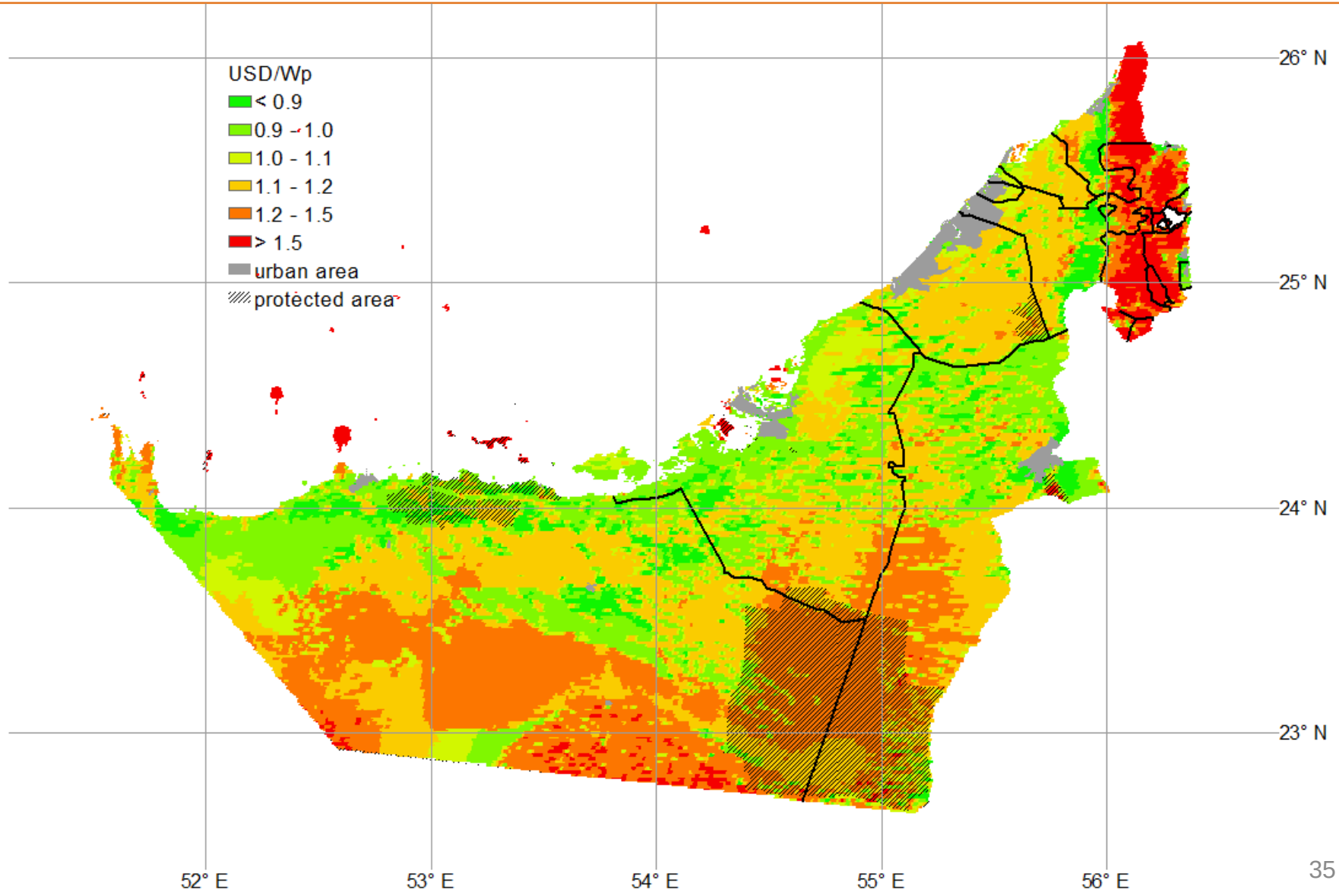
- earthworks
- EPC* (array foundations, mounting structures, solar modules, DC cabling, junction boxes, AC balance of system, civil works, auxiliary systems)
- road construction
- high-voltage transmission line construction
- substation
- intra-country transportation
- project development

* EPC: engineering, procurement and construction

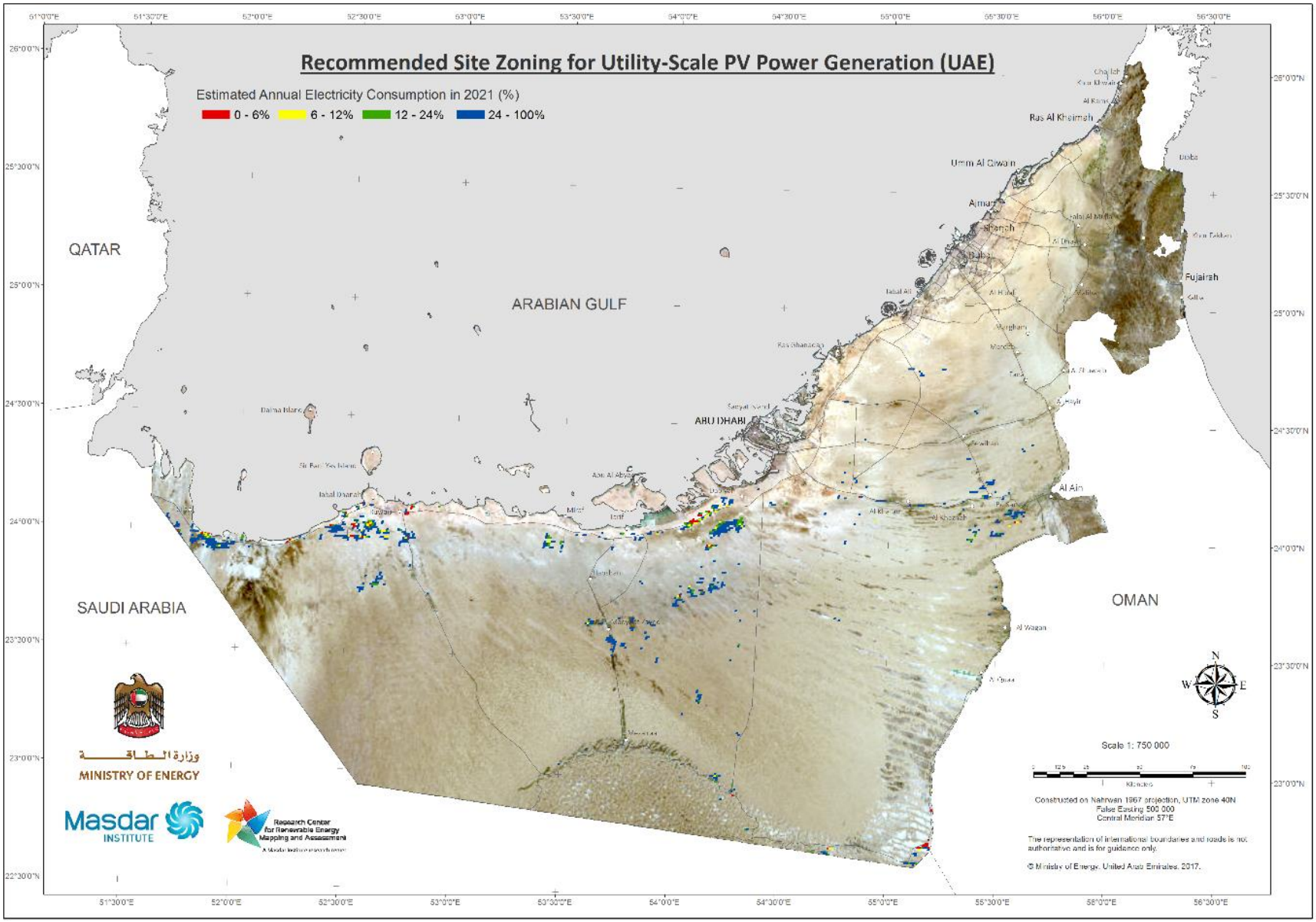
5. PV Economic Potential in the UAE – *Levelized Cost of Electricity*



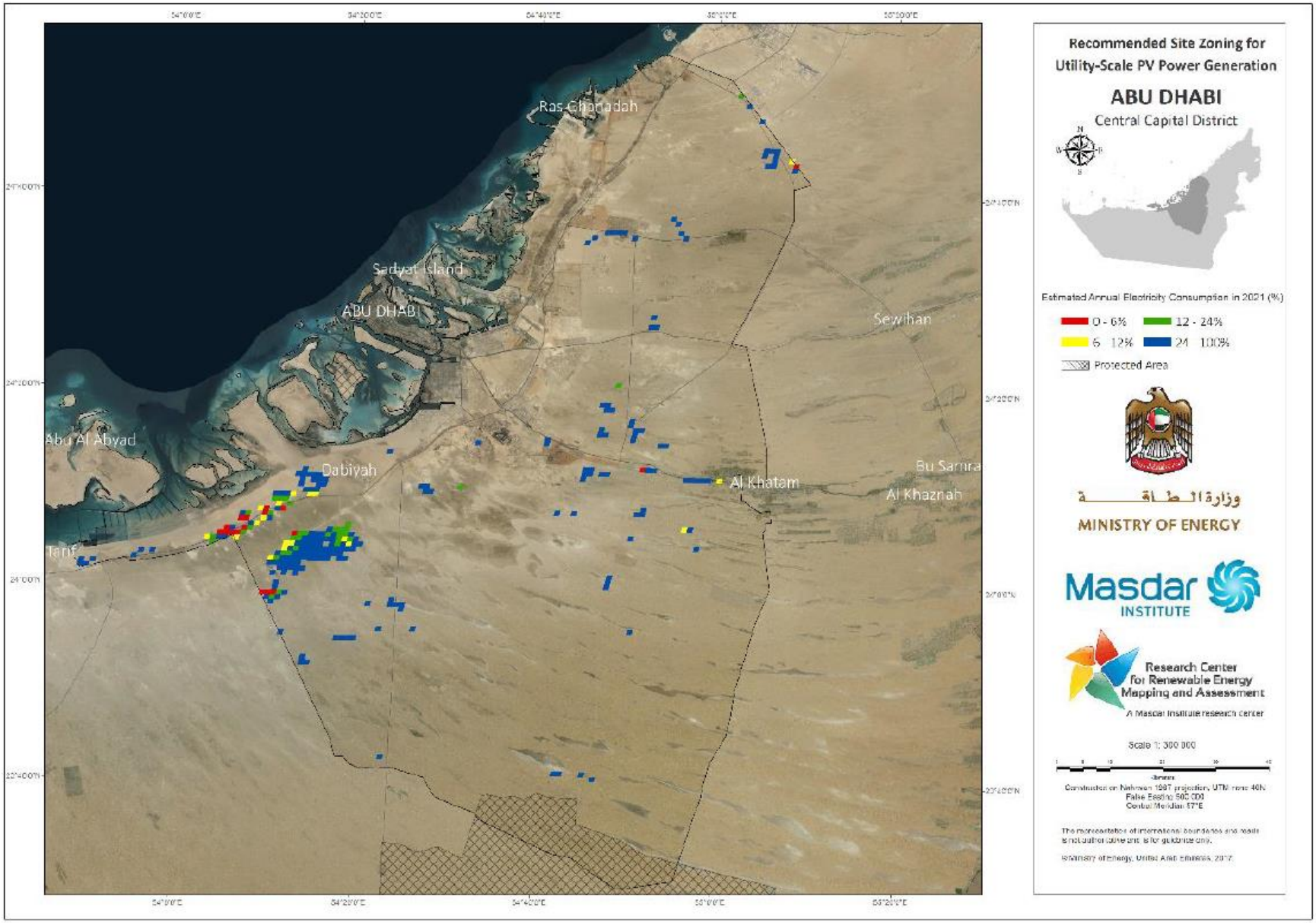
5. PV Economic Potential in the UAE – *Installed System Cost*



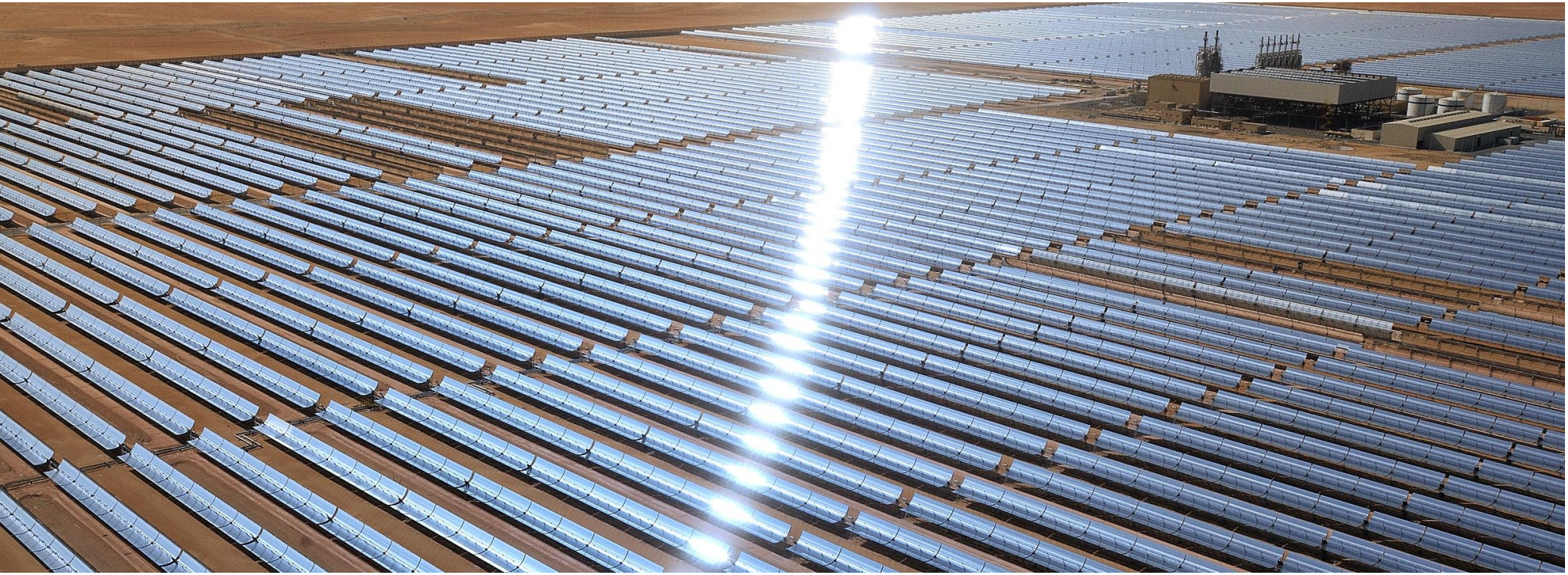
Recommended site zoning for utility-scale PV power generation in the United Arab Emirates.



Recommended site zoning for utility-scale PV power generation in Abu Dhabi Central Capital District.

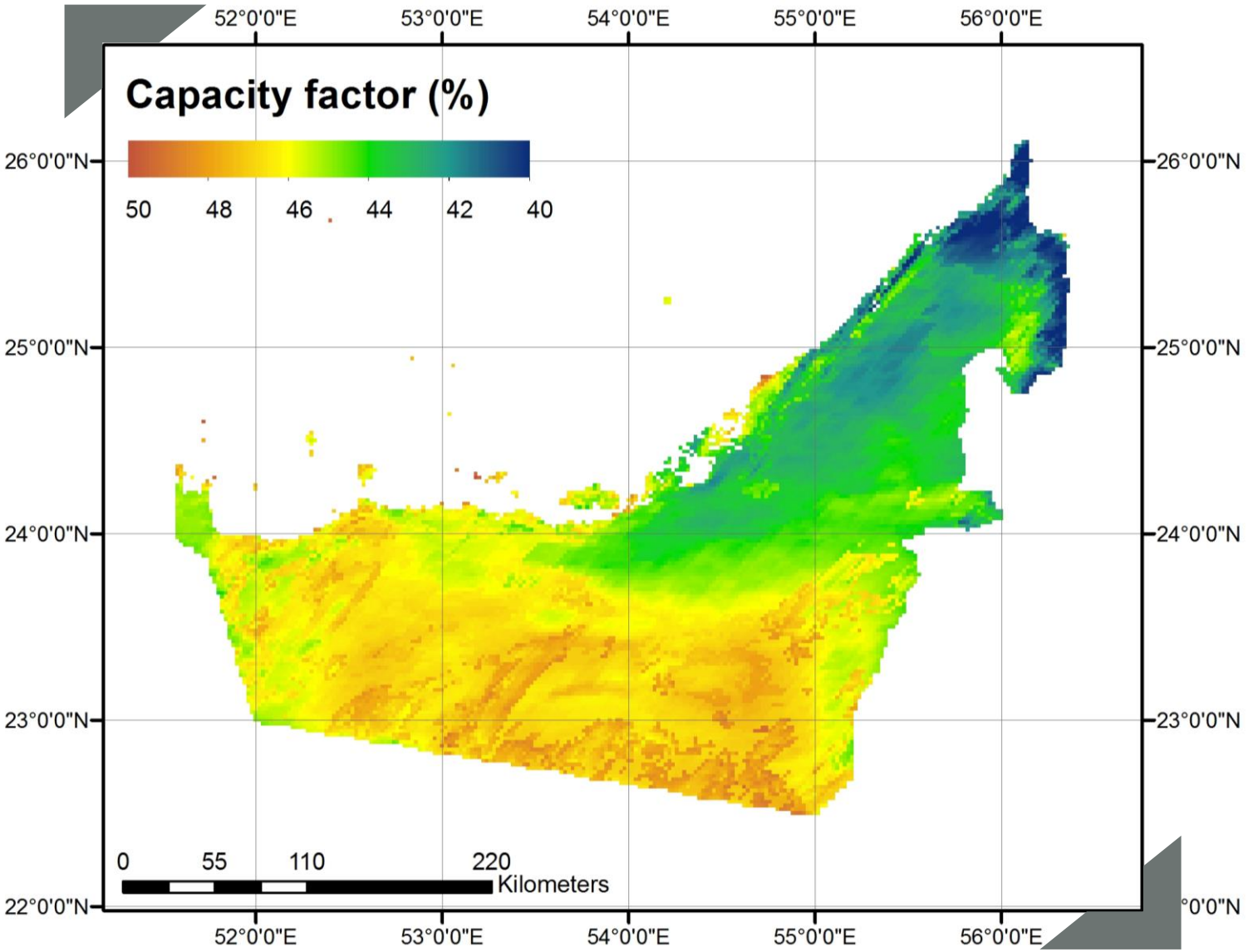


6. CSP Site Zoning Proposal



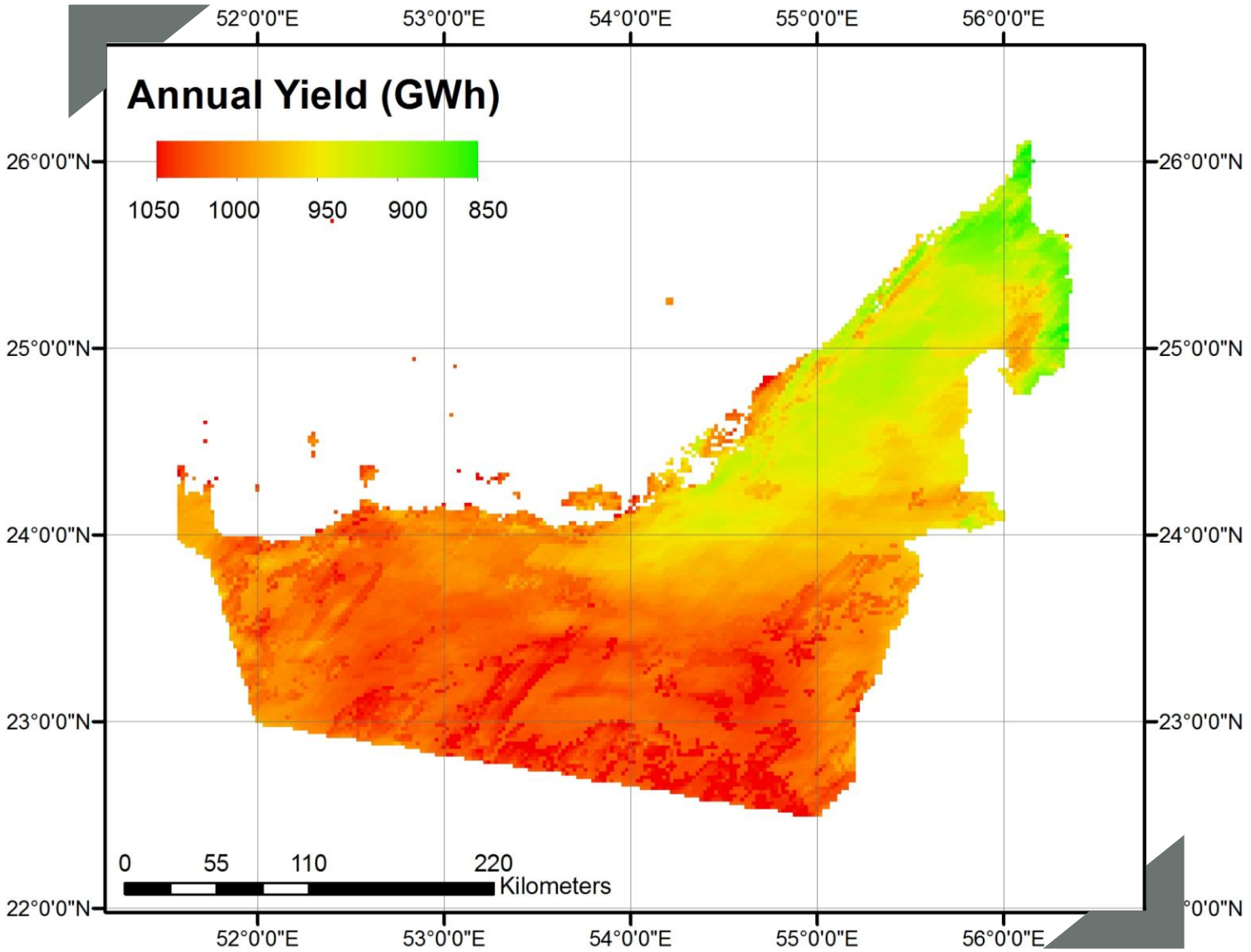
Capacity Factor

- Capacity: 250 MW
- Solar Field:
  - Luz LS-2
  - 2008 Schott PTR70
  - Therminol VP-1
  - NS
- Dry Cooled SEGS 80 MWe Turbine
- TES: 8h, 5299.4 MWth
- SM: 2.5



Annual Yield

- Capacity: 250 MW
- Solar Field:
  - Luz LS-2
  - 2008 Schott PTR70
  - Therminol VP-1
  - NS
- Dry Cooled SEGS 80 MWe Turbine
- TES: 8h, 5299.4 MWth
- SM: 2.5



Thank You

For more information: hghedira@masdar.ac.ae