Solar PV and Grid Integration

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May 24, 2017

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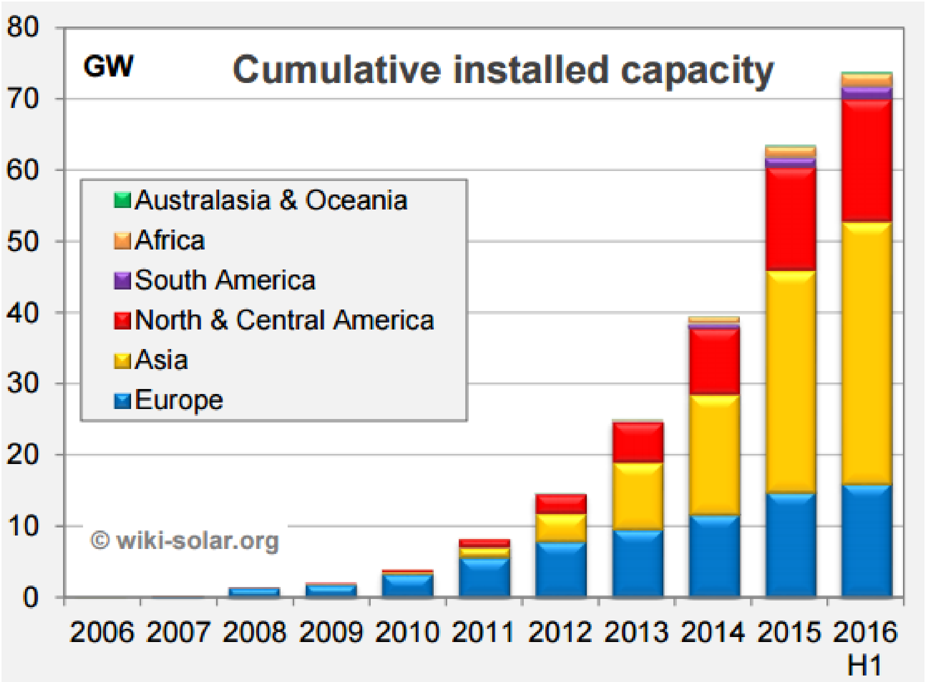
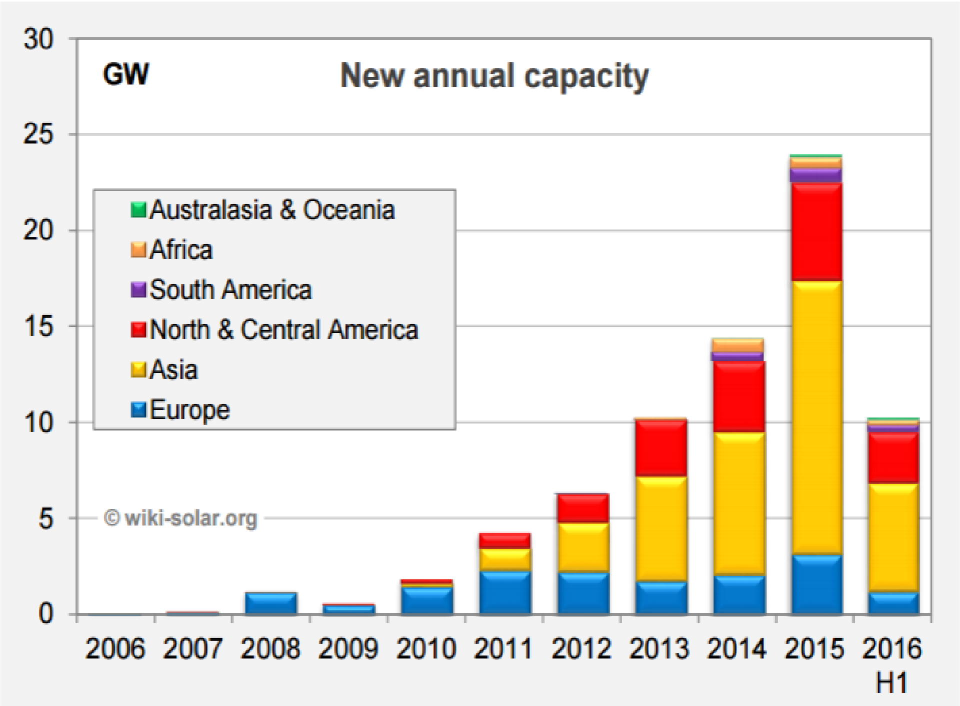
Session 2:
Markets, pricing and policies

Utility Scale Capacity installed

Cumulative Utility-Scale Solar Installations by continent at mid-2016



New capacity of utility-scale solar projects by continent and year



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Reference: www.wiki-solar.org

Renewable Energy incentive mechanisms

Renewable energy targets	REGULATORY POLICIES							FISCAL INCENTIVES AND PUBLIC FINANCING				
	Feed-in tariff / premium payment	Electric utility quota obligation / RPS	Net metering / net billing	Transport obligation / mandate	Heat obligation/ mandate	Tradable REC	Tendering[i]	Capital subsidy, grant, or rebate	Investment or production tax credits	Reductions in sales, energy, VAT or other taxes	Energy production payment	Public investment, loans, or grants

POLICIES		2014	2015
Countries with policy targets	#	164	**173**
States/provinces/countries with feed-in policies	#	110	**110**
States/provinces/countries with RPS/quota policies	#	98	**100**
Countries with tendering / public competitive bidding [5]	#	60	**64**

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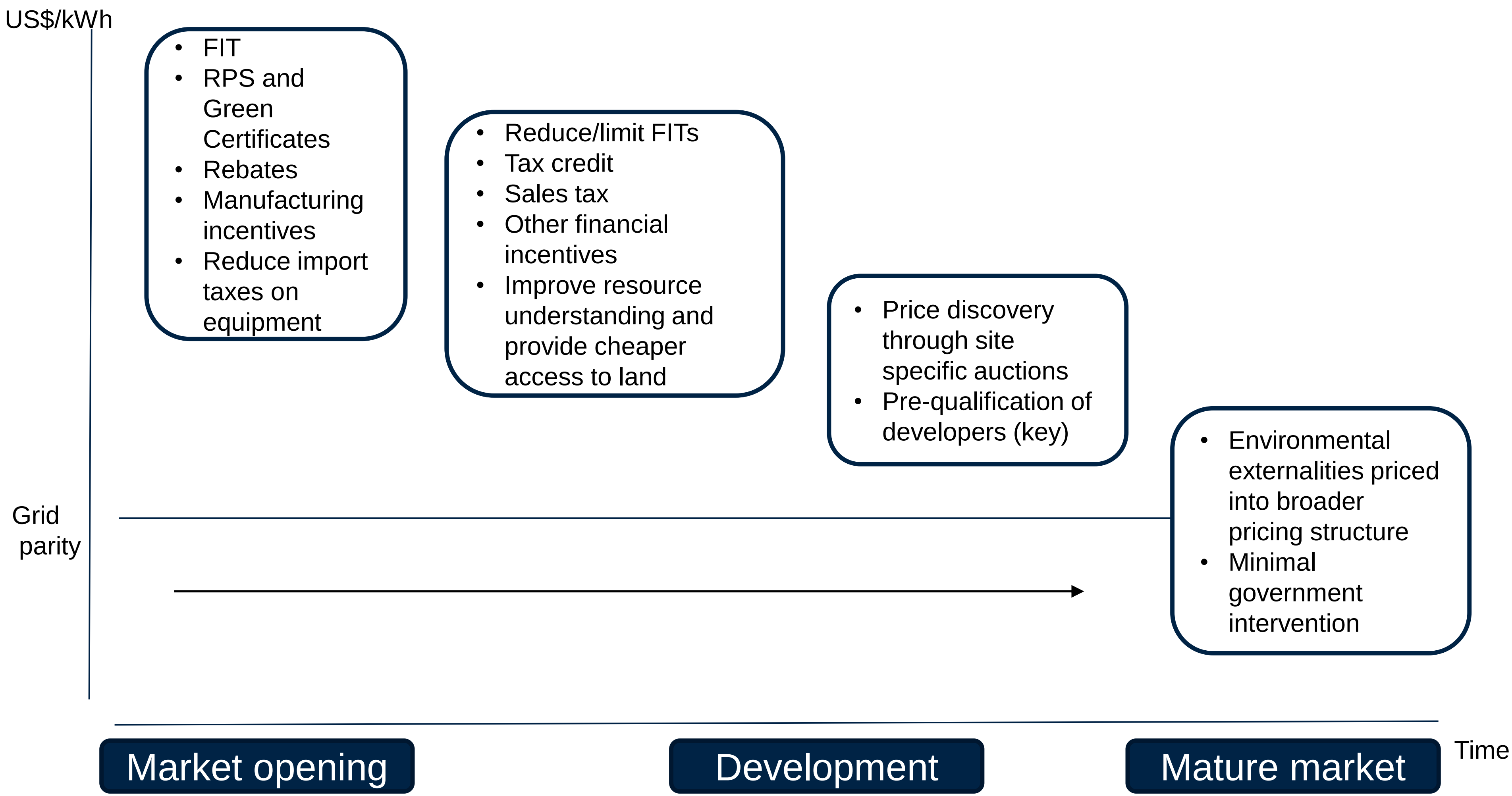
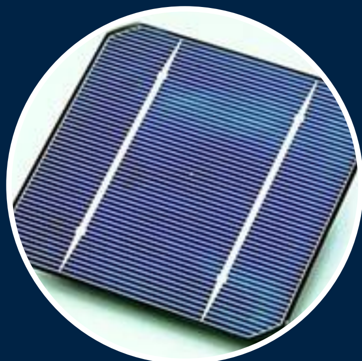
Reference: REN21, Renewables 2016 Global Status Report, http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf

Government role varies with the maturity of the market and the policy lessons learned

Lessons from Spain, Germany, China, US and Brazil, 2003-2015

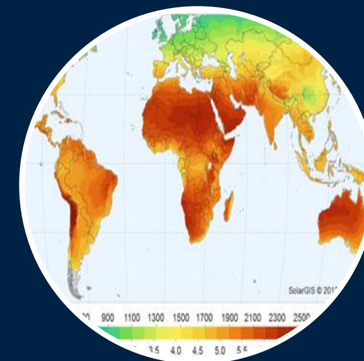


Nature of PV technology enables fast costs decrease



PV technology is highly modular, allowing wide range of applications

PV panels are similar to high-tech, not to steel-based technologies

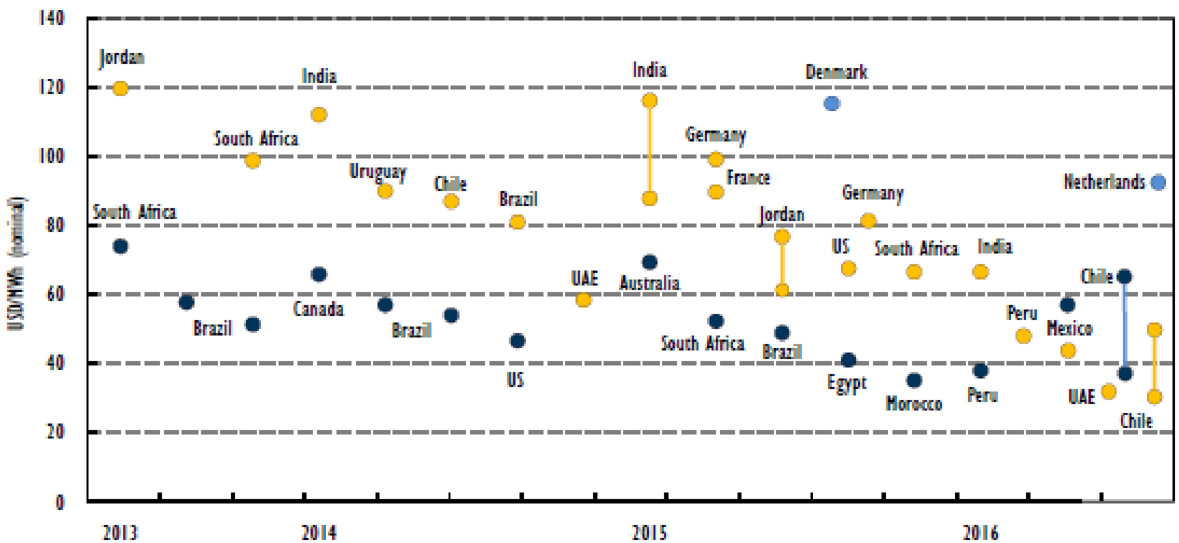


PV resource is available anywhere in the world, allowing global spread

PV is unlike any other power-generation technology

Current PV prices

- Over the last few years market-based prices of solar PV electricity in developing countries are showing a clear rapidly decreasing trend
- Single-digit PV electricity prices (per kWh) can now be achieved in most developing countries
- Typical prices today are in the range USc 6-8/kWh, have been reached in countries with policies conducive to PV deployment
- Prices significantly below USc 6/kWh announced in some markets are exceptional and require not only excellent solar resources but also outstanding financing conditions and are likely to include forward pricing of generation equipment



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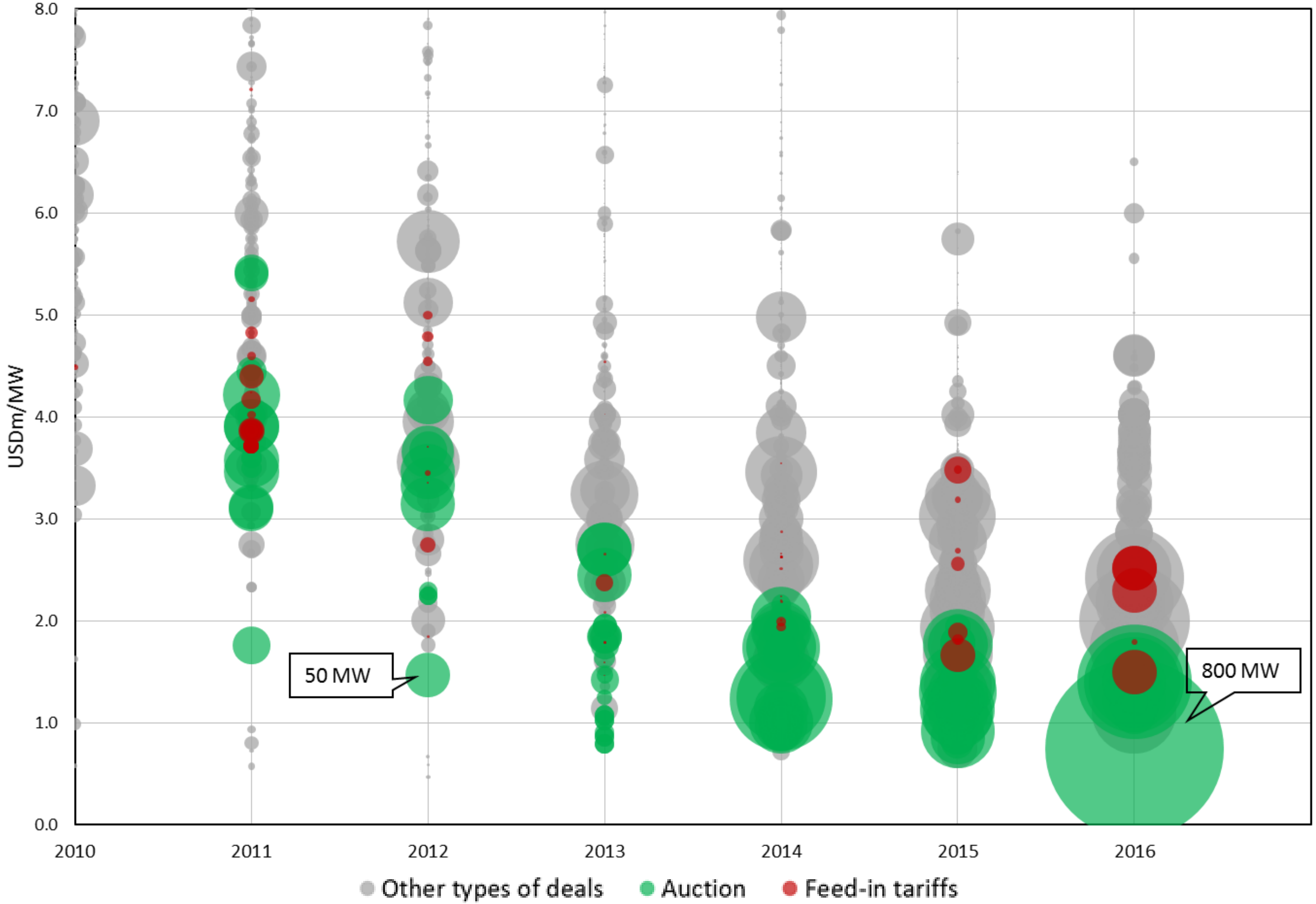
Installed costs of solar PV are decreasing



Note: Size of every bubble corresponds to the size of the respective PV plant

Source: World Bank based on BNEF and IHS data

- Installed costs of PV are as low as $1 million/MW, especially when procured through auctions but also for some bilateral deals

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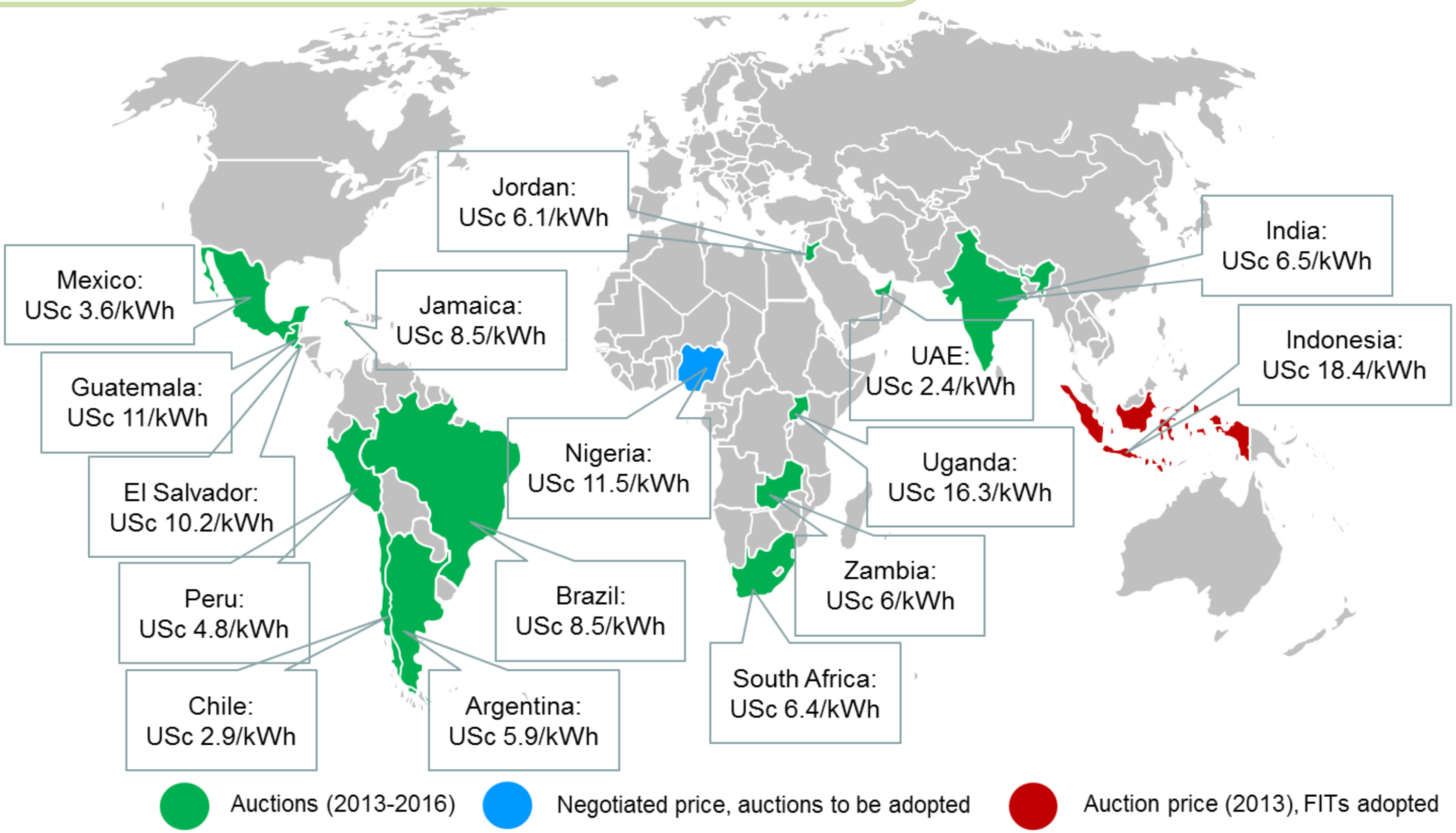
Solar power have become cost-competitive in several markets, even without subsidies, not only because of good resources

Rooftop solar cheaper than electricity retail rates in
at least 11 countries



Source: World Bank

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Price Drivers

- **The low PV electricity prices have been achieved through competitive procurement processes (auctions)** governed by clear, concise rules and selection criteria, with realistic timelines and workable local content requirements that have become popular in numerous countries and helped to drive down prices
- **Additionally to the increased use of auctions, low-cost financing, decreases in equipment prices**, improvements in capacity factors of plants due to technological progress and market expansion to places with excellent solar resources are the main drivers for decreases in prices
- Large international companies that currently dominate auctions are using several price-reduction strategies including use of forward pricing of equipment, balance sheet financing, integration of their value chain
- Risk perception of large players differs compared to their smaller competitors, as they can have extremely good knowledge of certain markets (e.g. markets where they already operate other technologies)

Future prices

- Price reductions are expected to continue in the years to come, module costs are expected to reach level downward of USD 0.3/W within the next 2 years, representing just about USc 1/kWh in levelized costs of electricity and there is still significant potential in cost reductions of balance of system, installation and financing costs
- Moving out of situation of equipment oversupply and low interest rates, moving towards commercial debt conditions for more plants and expansion to countries with less abundant solar resources could impact the rate of price decreases
- Generalizing auction results even for countries with similar insolation remains challenging as underlying policy and economic conditions as well as design of auctions across countries differ
- MDBs can play an important role in reducing financing costs by de-risking projects and providing, where appropriate, access to low cost capital along with policy advice and assistance in structuring of solar PV capacity procurement

Session 3: Solar Technology Overview

- Introduction
- Solar PV technologies
- PV Project development case study

- Types of Solar developments
  - Utility scale (ground mounted, floating PV)
  - Rooftop PV
  - Mini-grids (hybrid minigrids)

- Environmental and social impact of solar projects

Solar PV technologies

Solar Photovoltaics (PV)

- Fastest growing renewable power technology
- Highest modularity between technologies: from solar lanterns to utility-scale plants
- Most “democratic” technology: small-scale systems within reach of individuals, communities, small businesses, etc.

Source: IEA

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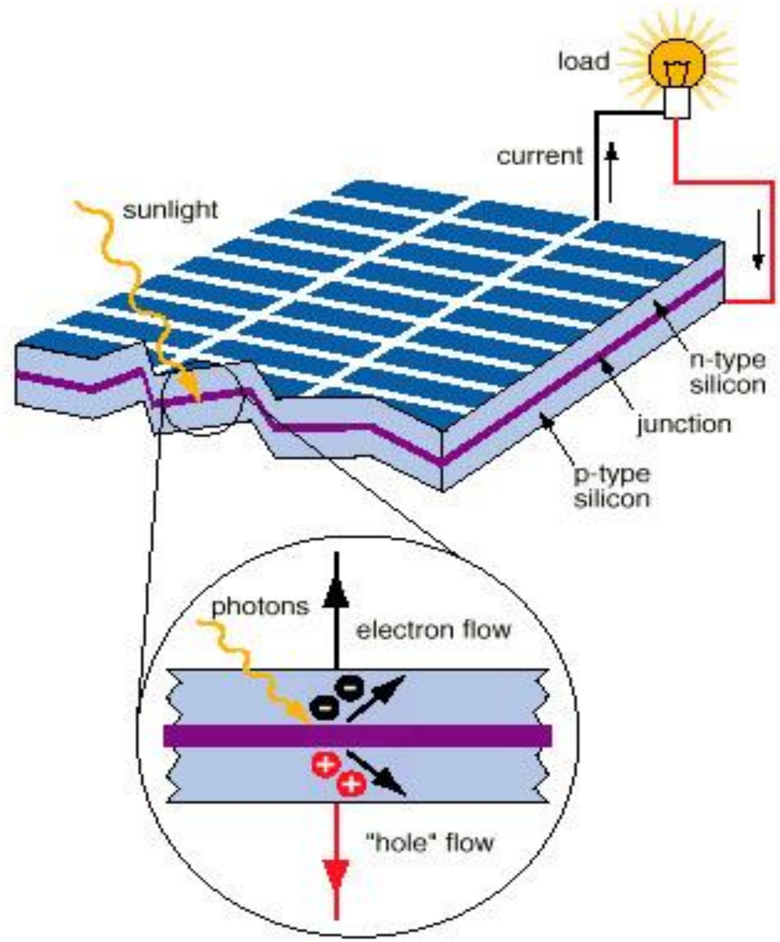
What is Solar PV?

- Photovoltaic (PV): Photo = light, voltaic = electricity
- The photovoltaic effect is the conversion of light into electricity
- Solid-state: no moving parts!
- A single 1 cm^2 cell produces about W at 0.5 V



Solar cells produce DC current

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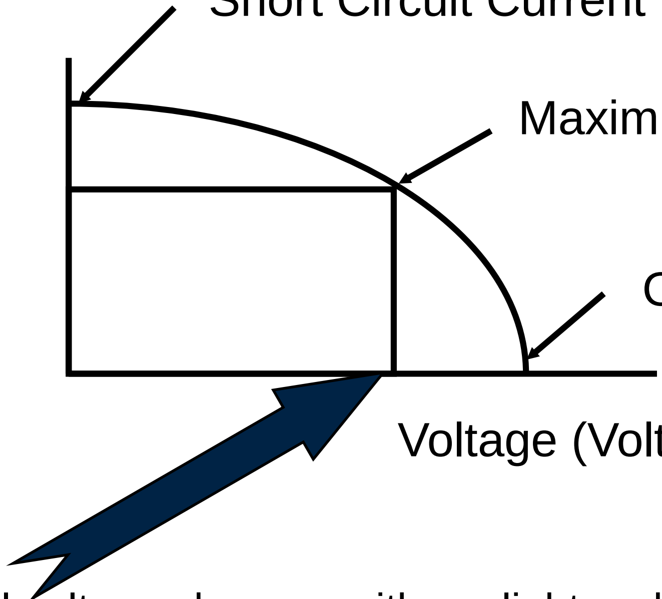
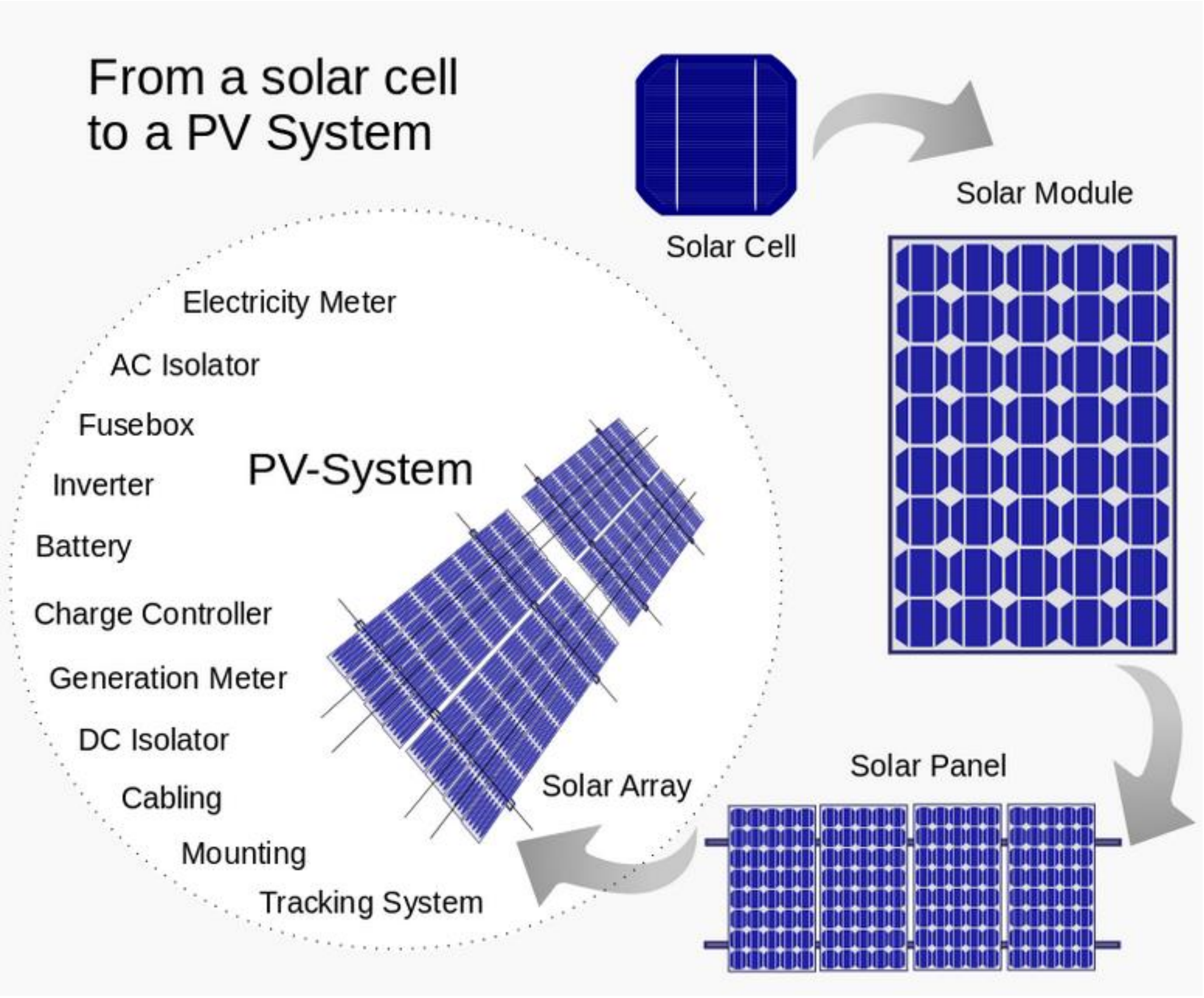
Current-Voltage (I-V) Curve

- Voltage
  - Depends on PV material's band gap: 0.5 eV for silicon
  - Decreases as temperature increases
  - Operating voltage determined by system voltage (battery)
- Current
  - Depends on surface area and intensity of incident light



Optimal voltage changes with sunlight and temperature

PV system components



Source: Wikipedia, Photovoltaic System,
http://en.wikipedia.org/wiki/Photovoltaic_system#mediaviewer/File:From_a_solar_cell_to_a_PV_system.svg

Types of PV cells

Crystalline Silicon (mono- and poly-)

15-23 % conversion efficiencies

Long lifetime

Thin film

CdTe

Amorphous Silicon

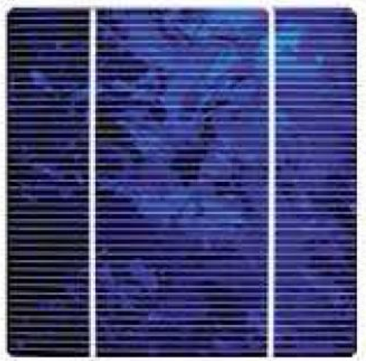
10-15 % conversion efficiencies

Potentially lower manufacturing cost

New technologies

- Multijunction: multiple layers of amorphous films (to increase efficiency)
- Flexible
- PV in concentrating modules
- Perovskite cells
- Organic cells

Monocrystalline cell



Polycrystalline – polysilicon cell

Amorphous silicon (T – Solar)

CdTe cadmium telluride (First Solar)

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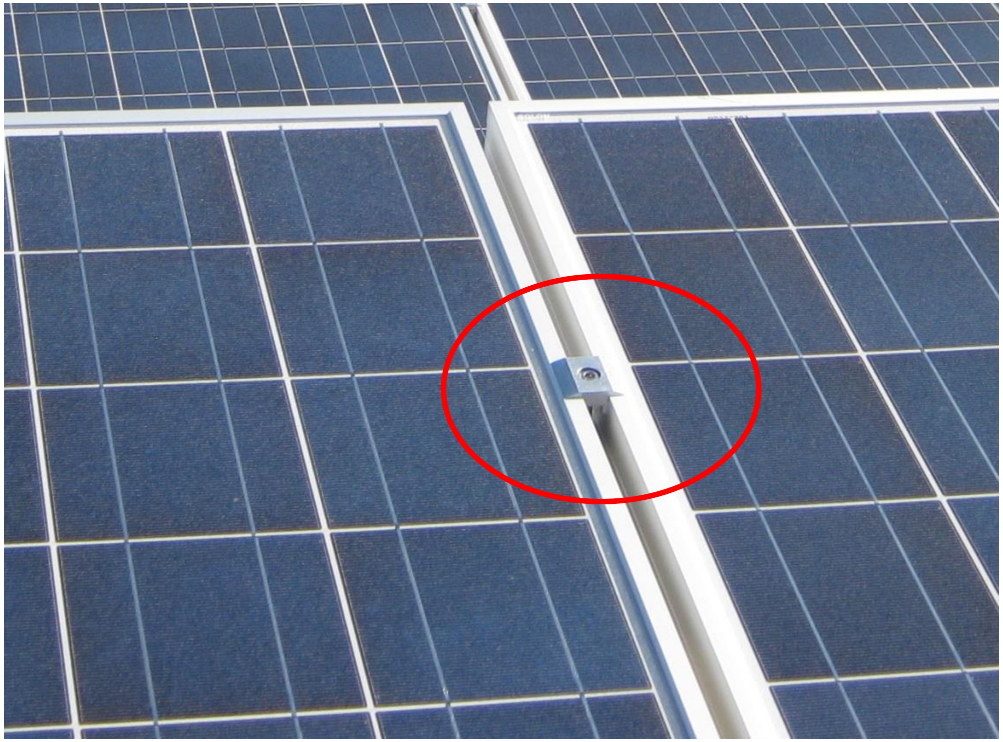
Mounting systems

Security of foundations

- Security of modules



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Tracking Systems

Mecasolar, 2011

Acciona, 2010

Mecasolar, 2011

PV Hardware, 2013

Reference: Enrique Serrano, S2M/

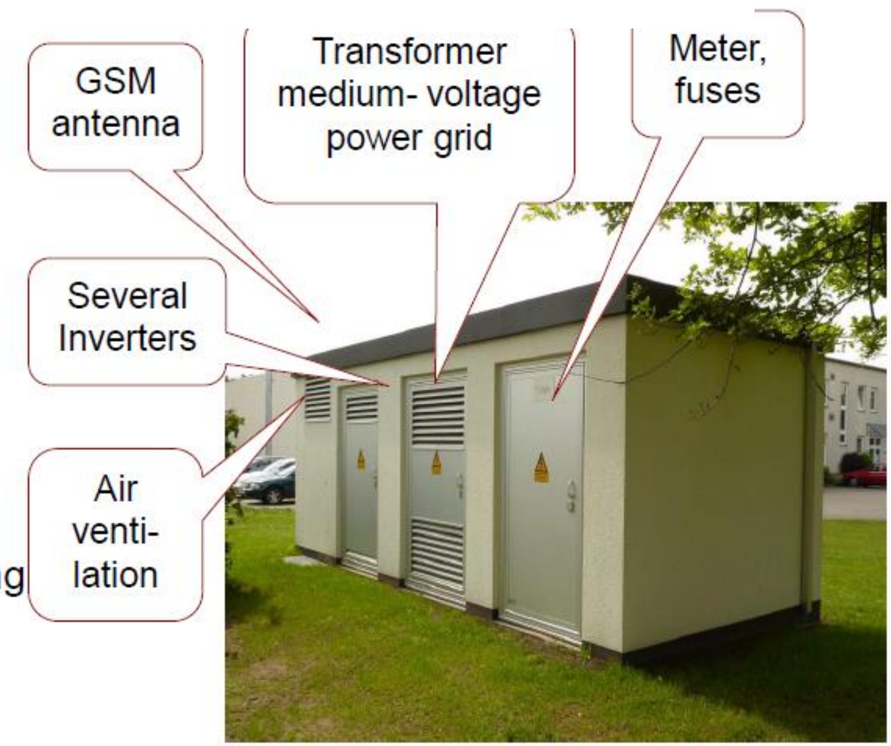
Inverters

Residential/commercial inverters

Note this illustration:

- One inverter (100kWp):
  - Air ventilation in summer: (2 x 150 W),
  - Heating in winter
- Own–consumption (1 MWp)
  - In Summer: 3 kW
  - In winter: 10 kW
- => If all ventilators are running there will be a high own-consumption:
- about 10.000 kWh /a)

Utility-scale inverters

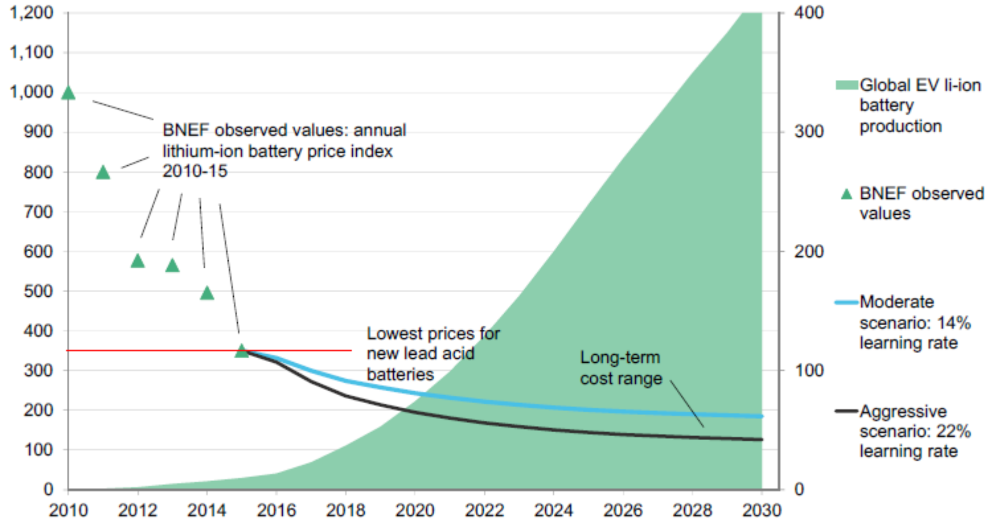


Monitoring System

- 24 hours data collection on Server
  - online
  - telefone line
- Direct communication with inverters
  - current, voltage, power, temperature
- Radiation measuring → Performance ratio
- Failure and theft indication by SMS or e-mail
- Maintenance reports

Batteries expected to play a major role by 2020

Lithium-Ion Battery Price Trends ($/kWh)



- Electric battery storage now deployed commercially for (1) minigrids, (2) ancillary services, (3) replacement of peaker plants, (4) T&D deferral and (5) commercial / industrial consumers demand charge avoidance
- Economics already positive in specific niches The key for project viability may be combining several revenue streams in a single project (e.g. T&D deferral and ancillary services)
- Battery prices experienced 40% cost reductions in 2016. Further reductions expected.

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Key Parameters

Wp (watts peak): In the context of PV sector that means the nominal power of total amount of modules

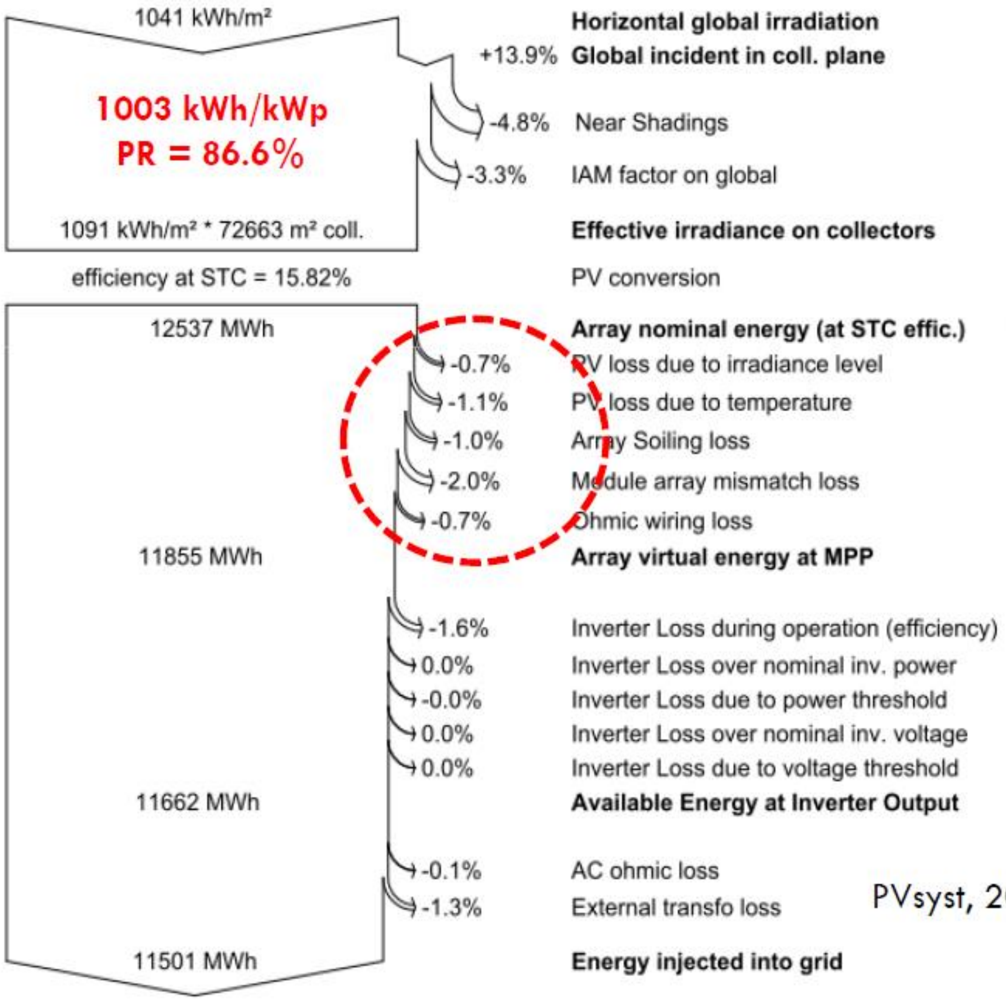
We (watts nominal electric): In the context of PV sector that means the nominal power of total amount of inverters

Energy yield (kWh/kWp) (specific production)

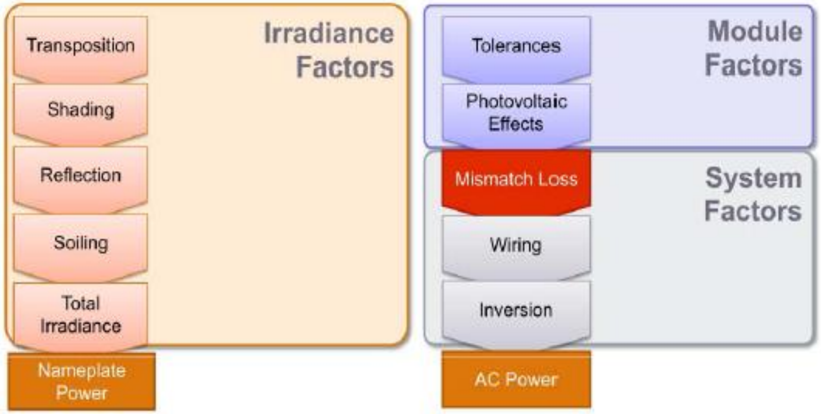
PR (Performance ratio): The performance ratio, often called "Quality Factor", is independent from the irradiation (however is dependent from weather conditions on site) and therefore useful to compare systems. It takes into account all pre-conversion losses, inverter losses, thermal losses and conduction losses. It is useful to measure the performance ratio throughout the operation of the system, as a deterioration could help pinpoint causes of yield losses

CUF (Capacity Utilization Factor): how much of the stated capacity a plant actually generates compared to its total possible capacity.

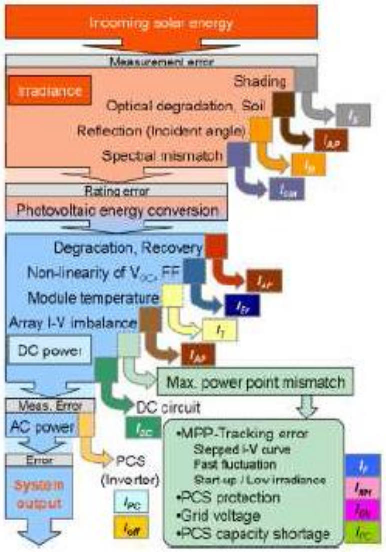
Energy yield



PVsyst, 2013



FolsonLabs, 2013



Tokyo Electric, 2013

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Case study: PV Project Development

Case Study:
20 MW PV Power Plant, El Salvador

Methodology

■ Methodology Techno-Economic Feasibility Study

Technical Assessment

Site Assessment
- Geotechnical-
- Environmental-
- Social-
- Climatic aspects

Technology Assessment
- PV Module Selection
- Inverter Concepts
- O&M Requirements

Permitting process
- Validation of grid connection
- Legal Framework Report

Technical Design

Financial Assesment

Evaluation of CDM Revenues

Yield Verification

Evaluation revenue and operating expenditures
- Feed-in tariff analysis
- Demand analysis

Assessment capital expenditures
- Investment costs incl. decommissioning

Financing Plan and Structure
- Co-operation with international financing Institutions

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A. Technical Assessment

Site Assessment

Objective Site Assessment

- **Evaluation of the site suitability based on:**

  1. **Meteorological data**
  2. **Terrain usability**
  3. **Area accessibility**

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A. Technical Assessment

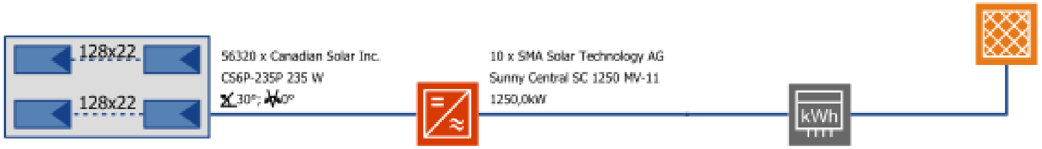
Technology Selection

Objective of Technology Assessment

- **Identification** of potential technological solutions

- **Evaluation** of the following technical components :

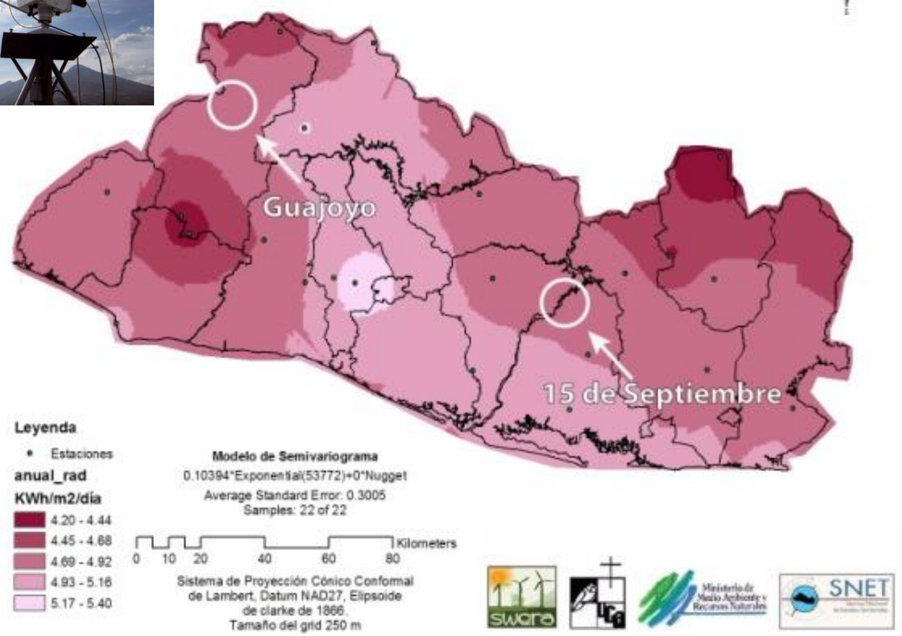
    1. **PV Modules**
    2. **Mounting Structure and Foundations**
    3. **Tracking vs. fixed tilt**



Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Irradiation El Salvador



<u>S/W yield verification</u>:

PV Sol, PV Syst, Insel, ILF inhouse

<u>Solar Data resources</u>:

-local rooftop plant:
-local measurement station

- data supplier such as:

SoDA , Meteonorm, SolarGIS, NASA , DLR, RETscreen, …

Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Environmental and Social Evaluation

Objective

•**Identification** of sensitive environmental and social features

•**Consideration of impacts** during

- Site preparation
- Construction
- Operation
- De-commissioning

•**Development of mitiga… ures**

Result

•**Both sites are feasible for development of a PV plant**

Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Module Selection

Description	Thin Film Technology		Crystalline Technology	
Module Technology	Amorphous Silicon a-Si	Cadmium Telluride CdTe	Monocrystalline	Polycrystalline
Total Number of Modules / MW	10,020	12,528	4,008	4,008
Module Area / MW	14,329 m^2	9,020 m^2	6,447 m^2	6,447 m^2
Total Area	1.9 ha - 3.1 ha	1.3 ha - 2.2 ha	0.8 ha - 1.5 ha	0.8 ha - 1.5 ha
Max Power El Salvador / ha	0.5 MW	0.75 MW	1.25 MW	1.25 MW
Yield / Year	****	1,528 kWh/kW	1,419 kWh/kW	1,420 kWh/kW
PR	****	79.8 %	74.1 %	74.2 %
Turnkey Price in Euro per kW	2,300 € - 2,600 €	2,300 € - 2,600 €	2,500 € - 2,800 €	2,300 € - 2,600 €

Result: Poly-crystalline

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Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Structural Design

2. Objective Mounting Structure

- **Elaboration** of cost and time efficient adequate mounting structure
- **Identification** of geological requirements

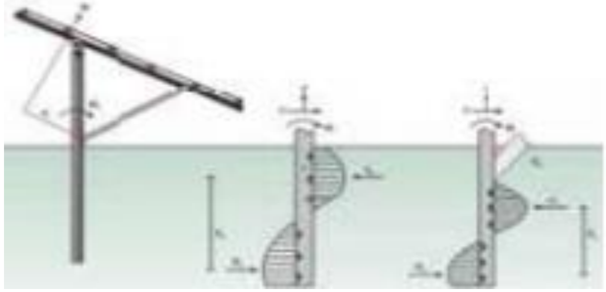
Results

- **15 de Septiembre:**

→Pile driven foundations sometimes pre-drilling required

- **Guajoyo:**

→Pile driven foundations often pre-drilling required



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Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Technology Selection

3. Objective Inverter Concept

- **Elaboration** of adequate inverter technology based on availability of maintenance and cost- efficiency
- **Identification** of costs and service availability

Results

String inverter concept

→ No on-site maintenance services required
→ Maintenance for central inverter concept are not available in El Salvador
→ Less operation costs

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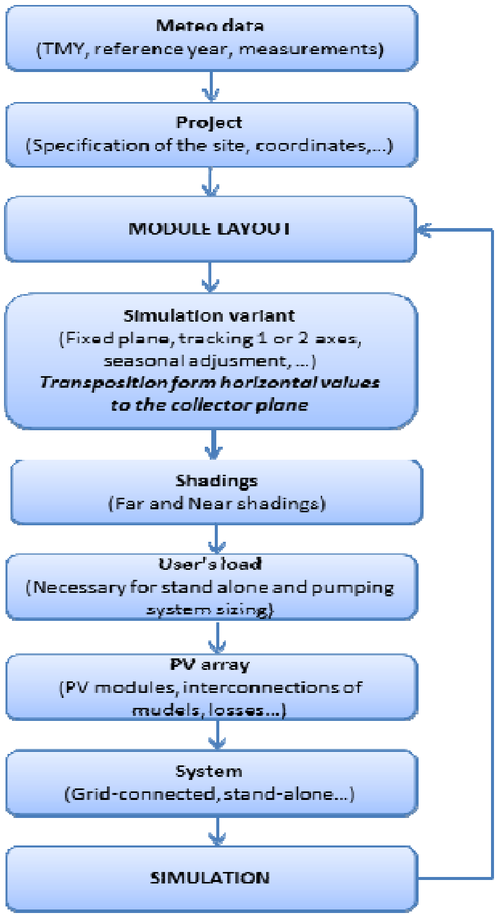
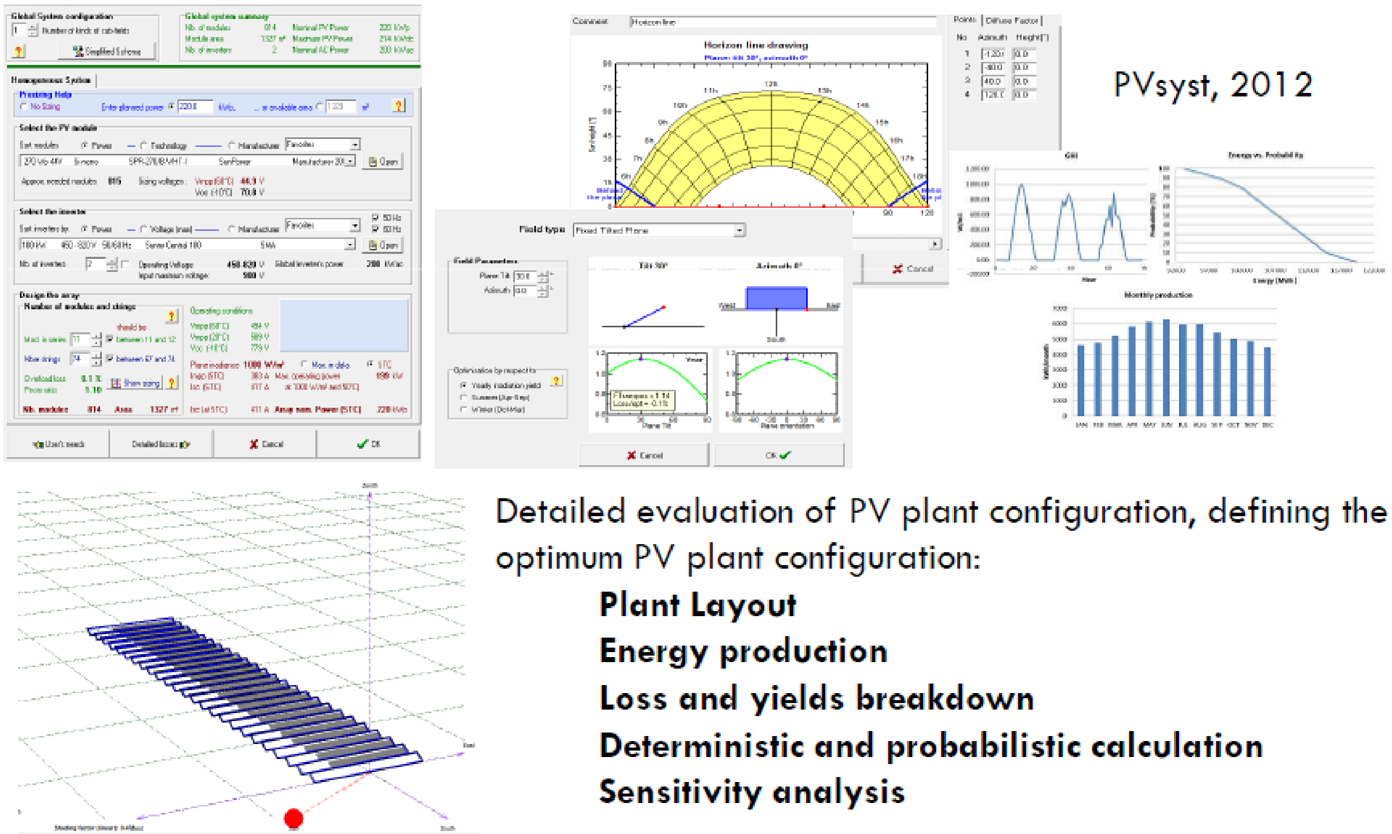
A. Technical Assessment

Technology Selection





PVsyst, 2012

Detailed evaluation of PV plant configuration, defining the optimum PV plant configuration:

- **Plant Layout**
- **Energy production**
- **Loss and yields breakdown**
- **Deterministic and probabilistic calculation**
- **Sensitivity analysis**

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Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Operation & Maintenance evaluation

Status Operation & Maintenance

Extremely low O&M

No rotating equipment

Results

→ O&M Concept

- **24 h security service**
- **Cleaning of modules**
- **Maintenance main components**
- **Maintenance low and medium voltage system**
- **Visual inspection**

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Case Study of a 20 MW PV Power Plant in El Salvador

A. Technical Assessment

Permitting Process

Results of Legal Framework

- **Permits and Authorizations**
  - Environmental Permit Process
  - City Hall Permit
  - Working Establishment regulation

  } Dialogue with Authorities

- **Connection to Grid**
- **Contract and Pricing**
- **Tax Benefits**

B. Financial Assessment

Financial Analysis:

- Irradiation/ Net Generation
- CAPEX/ Investment
- OPEX
- Electricity Tariff
- CER Certificates
- Start of operation
- Operation period/ Project Lifetime
- Financing/ Funding Structure
- Expansion Plan

→

- Financial Rate of Return
- Levelized Electricity Cost
- Debt Service Coverage Ratio
- Net Present Value
- Avoided Emissions

Case Study of a 20 MW PV Power Plant in El Salvador

B. Financial Assessment

Cost Estimation

	15 de Septiembre Initial	15 de Septiembre Extension	Guajoyo
	6.1 MW	8.1 MW	3.6 MW
Modules	**8,612.68**	**11,485.24**	**5,169.11**
Inverter	**1,375.00**	**1,825.00**	**822.50**
Civil material and construction	**760.00**	**207.00**	**459.75**
Electrical Material	**3,894.80**	**4,832.90**	**2,394.13**
Grid connection	**717.50**	**-**	**567.50**
Engineering, tendering, site supervision	**840.00**	**655.00**	**460.00**
Insurances	**81.00**	**95.03**	**49.36**
Contingencies	**1,628.10**	**1,910.02**	**992.24**
	TEUR	TEUR	TEUR
Specific Investment Costs (EUR/kW)	**2,522 (3,556 USD)**	**2,340 (3,299 USD)**	**2,701 (3,808 USD)**

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C. Economic Assessment

Definition

Economic Analysis	Financial Analysis
• Quantification of costs and opportunity cost of compared to conventional thermal power generation • Focus is on a macro-economic and national level • Costs and Benefits adjusted to market structure and government intervention	• **Focus on interest of shareholders** of the project infrastructure • Application of market prices, exertion of factors i.e. inflation and taxes • Application of Funding Scenarios
Performance Indicators	**Performance Indicators**
•Economic Rate of Return **•Benefit – Cost Ratio** **•CO_2- Avoiding Costs**	**•Internal Rate of Return (IRR)** **•Net Present Value (NPV)** **•Levelized Energy Cost (LEC)**

C. Economic Assessment

Impact Parameters on Economic Ratios

- Irradiation/ Net Generation
- CAPEX/ Investment
- OPEX
- Avoided Energy Input
- Avoided CO2 Emissions
- Diesel Price
- Operation period/ Project Lifetime
- Local Market Distortions

→

- Economic Rate of Return
- CO2 Avoiding Costs
- Amount of Avoided Emissions
- Cost Benefit Ratio

Case Study of a 20 MW PV Power Plant in El Salvador

C. Economic Assessment

Impact Parameters on Economic Ratios

Irradiation/ Net Generation;	9,878 MWh/a
CAPEX/ Investment;	26,083 TUSD
OPEX;	297 TUSD
Avoided Energy Input;	2,069.4 TUSD
Avoided CO2 Emissions;	7,083t CO2/a
Diesel Price;	718.13 USD/t
Operation period/ Project Lifetime;	25 years
Grid Emission Factor El Salvador;	0.717 t CO2/ MWh

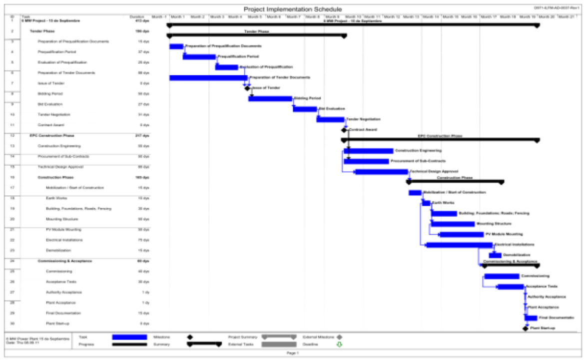
ERR:	6.01%
CO2 Avoid. Costs:	59.99 USD/ t
Avoided Emissions:	7,083 t/a
Cost Benefit Ratio:	0.7

Case Study of a 20 MW PV Power Plant in El Salvador

Project Planning and Scheduling

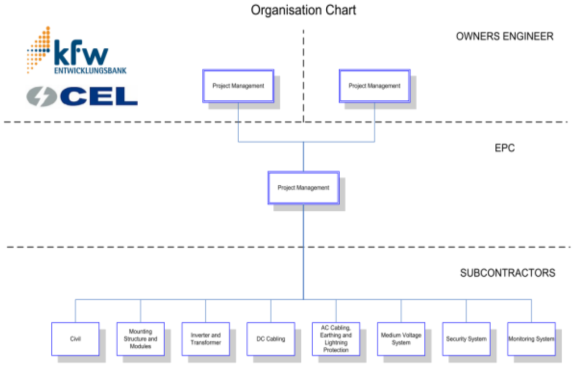
Objective

- **Elaboration** of project time "initial phase"
- **Identification** of milestones



Results

- **Initial project phase** >19 months
- **Tender phase** > 9 months
- **Construction phase** > 10 months



Construction

Procurement and Transport

- PV is modular, therefore special transport is not required
  - Standard trucks
- Since no very large items are being transported, no special preparation of the roads is needed
  - Like in wind blade transport
- Largest items are:
  - Transformers
  - Standard housings for inverters
  - DC cable drums

Source: SMA Solar Technology AG

Source: Betonbau

Photo: A. Tiedemann, RENAC

Construction

Construction: PV plant installation

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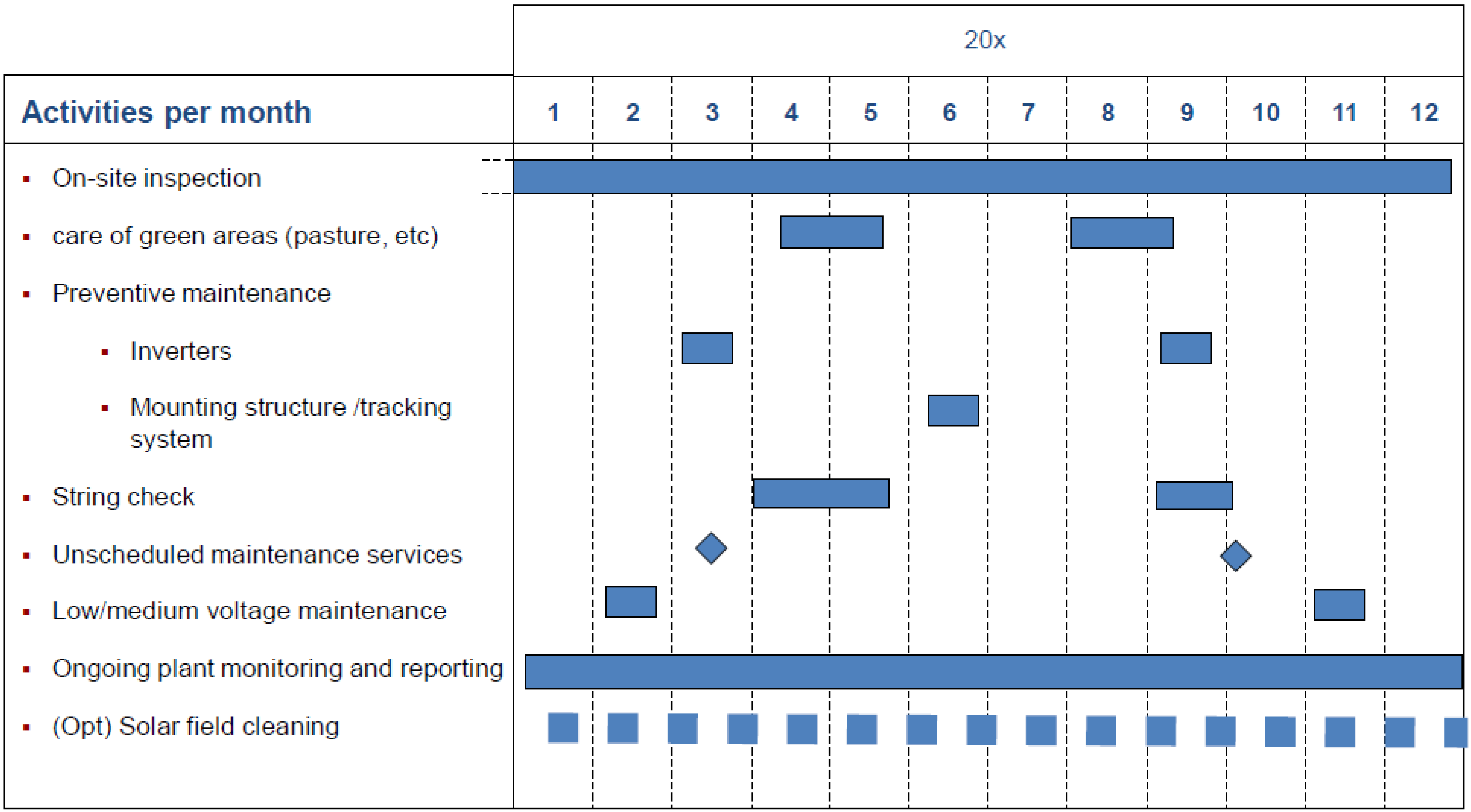
Operation and Maintenance



Types of Solar Developments

Ground mounted Utility Scale PV Plants

Top 5 US utility-scale PV project owners

gtmresearch

Rank	Owner	Contracted Pipeline (MWdc)	Projects Operating (MWdc)
1	First Solar	1992	392
2	Southern Company	546	1507
3	NextEra Energy Resources	298	1727
4	Cypress Creek Renewables	1229	578
5	NRG Energy	929	823

Largest Utility-Scale solar up to date:

- India's Tamil Nadu project
- 648 MW capacity
- Connected with the 400kV substation
- Completed construction in eight months
- Robotic waterless panel cleaning by Israel's Ecoppia

Some large PV plants in development:

- China's 2 GW project under construction in Ningxia
- India's three 500 MW projects planned in Maharashtra
- India's 600 MW Odisha project planned by Sonthalia
- Morocco's two 400 MW 'sister' projectsUkraine's four 1 GW Chernobyl projects,

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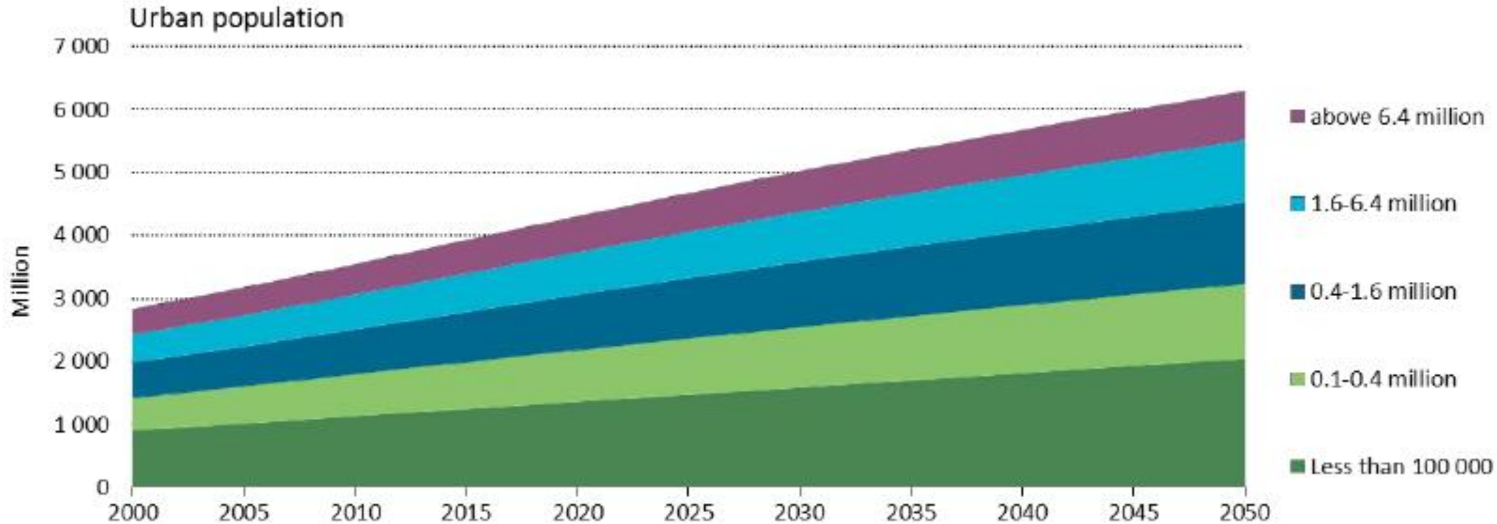
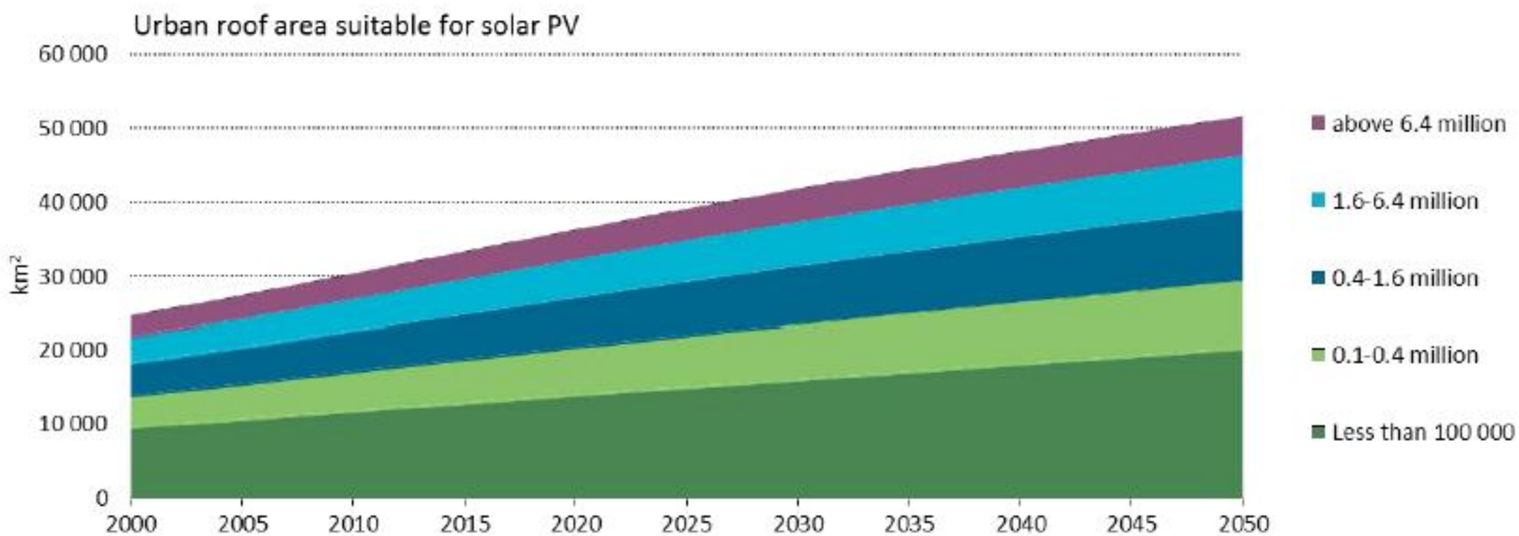
Reference: Green Tech Media: https://www.greentechmedia.com/articles/read/India-Holds-The-Crown-For-Worlds-Largest-Solar-PV-Project.-For-Now

Global Rooftop PV Potential





Reference: IEA

Rooftop PV at large scale

- Can provide quick scale up without substantial modifications to the regulatory framework
- Establishment of an aggregator is a prerequisite for success

Gandhinagar Project

- City population: 200,000
- 'Rent-a-roof' PV project: 5 MW
- 38 firms submitting expressions of interest.
- Azure Power and SunEdison each won one of the two 2.5 MW projects and the power purchase agreements were signed in April 2012.

Vadodara Project

- City population: 2,000,000
- 'Rent-a-roof' PV project: 5 MW
- Over 40 firms purchasing the bid documents.
- Madhav Solar (Vadodara Rooftop) Private Limited won the 25-year concession and the power purchase agreement with the distribution utility was signed in June 2014.

Floating Solar PV (FPV)

- **400 GW** of solar electricity can be produced covering only 10% of 50 largest dams in the world,
- **Approximately 40 floating PV projects** operational globally – in Japan (56.5 MW), UK (7 MW), South Korea (2.5kW), Australia, USA, India
- **First hybrid FPV and Hydroelectric Dam** Power Plant System (220kWp) in Portugal
- Total installed capacity by end of 2016 94MWp with projected installations to 150MWp by end of 2017

Supply Chain - Technology and Project developers

- Sunengy, Australia
- Kyocera, Japan – building 13.7MW farm
- Ciel et Terre, France – Hydrelio System
- Xiamen Mibet New Energy Co., Ltd. China
- Solaris Synergy, Israel

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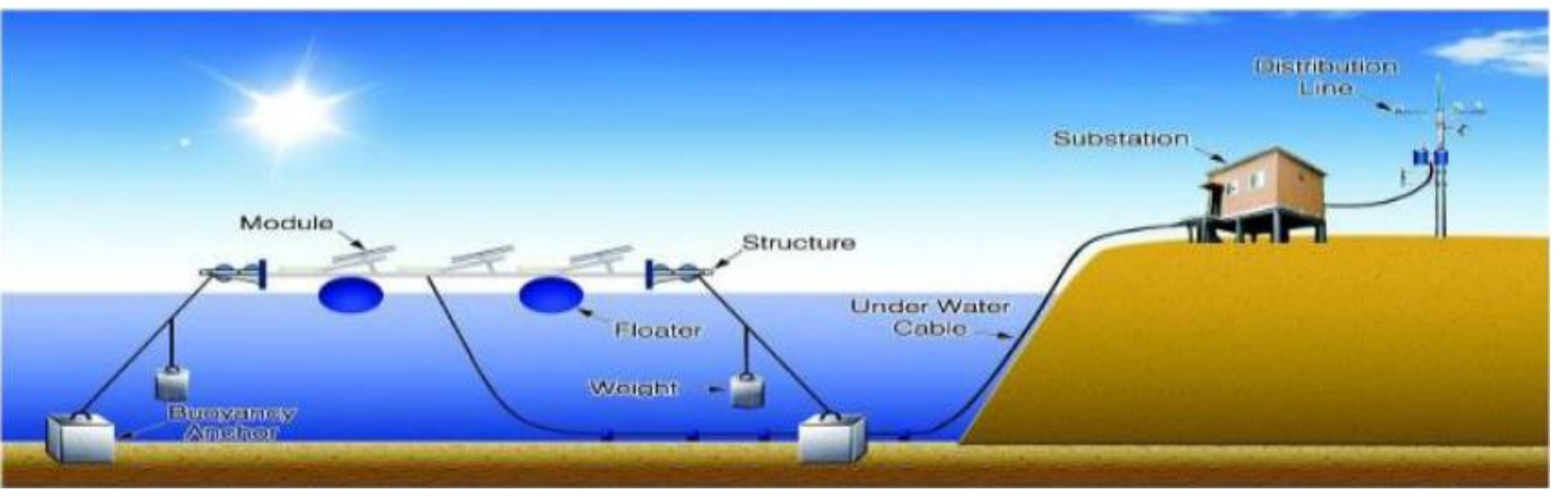
Reference: IEA

FPV Design Features (I)

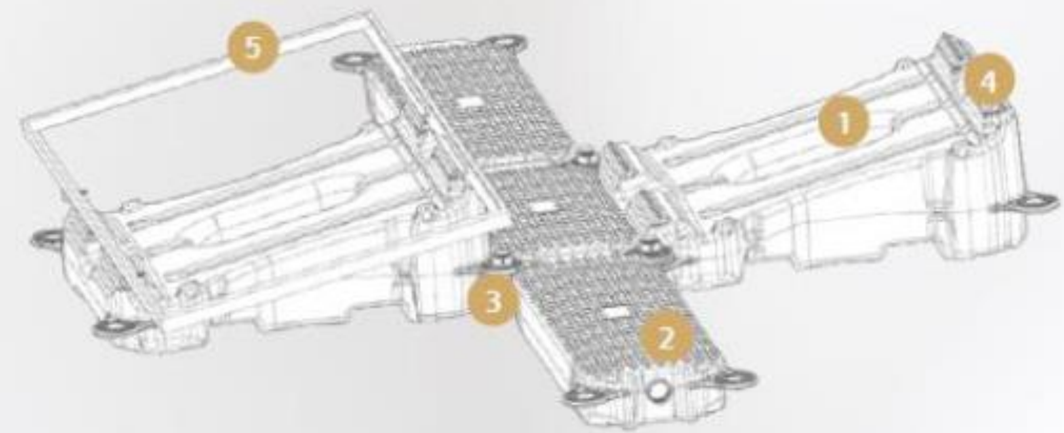
- Floats materials
- PV modules
- Seabed Anchors
- Mooring lines
- Inverter location
- Export cables and substation



Reference: IEA

FPV Design Features (II)

Innovations in floating materials (HYDRELIO by Ciel &Terre)



1. **MAIN FLOAT SUPPORTING THE PV MODULE**
   HDPE material
   Inclination angle: 12°

2. **SECONDARY FLOAT FOR MAINTENANCE/BUOYANCY**
   HDPE material
   Non-slipping surface

3. **CONNECTION PIN**
   Fiberglass + PP material
   Certification NFT 58 000

4. **RAIL TO ATTACH THE PV MODULE TO THE FLOATS**
   Aluminium or fiberglass + PP rail
   Certificated ISO 3302-1/1996

5. **STANDARD FRAMED 60 OR 72 CELLS PV MODULE**

60 CELLS

Length : max 1670 mm
Width : 991 ± 3 mm
Cable length : 1000~1200 mm
Connector : MC4 compatibility

72 CELLS

Length : max 1975 mm
Width : 991 ± 2 mm
Cable length : 1000~1200 mm
Connector : MC4 compatibility

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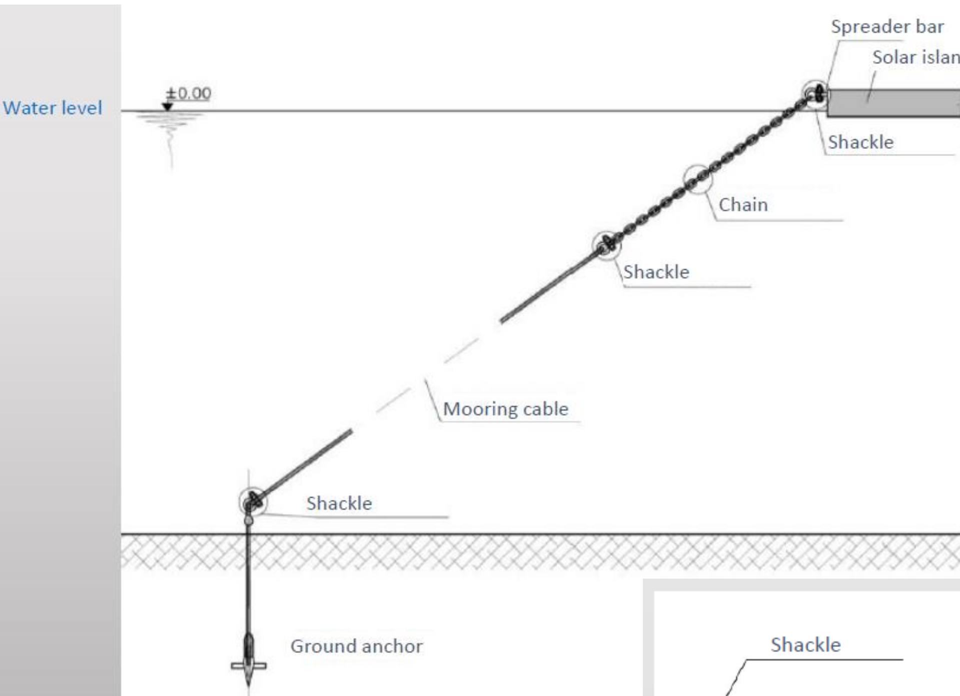
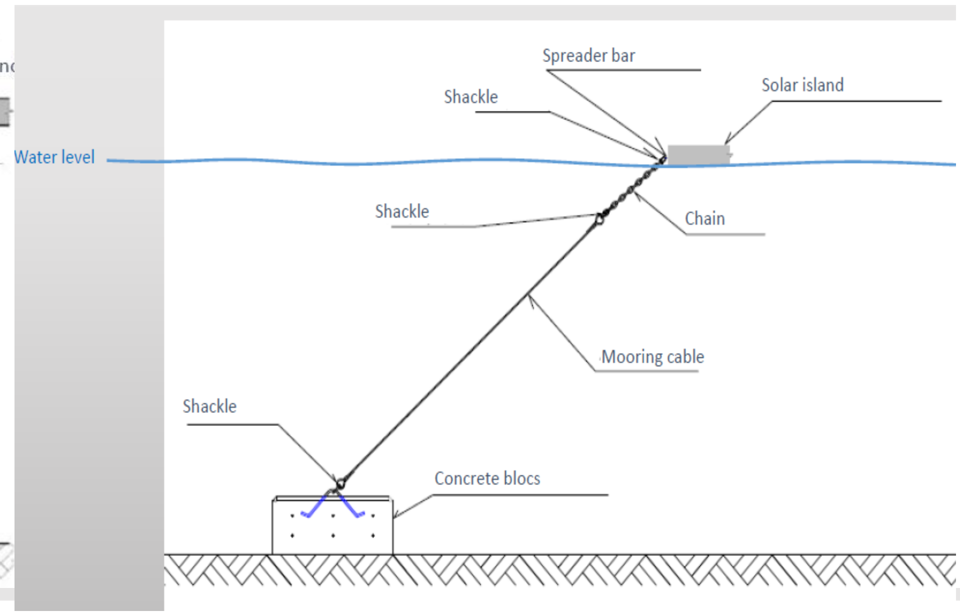
FPV Design Features (III)

Anchoring

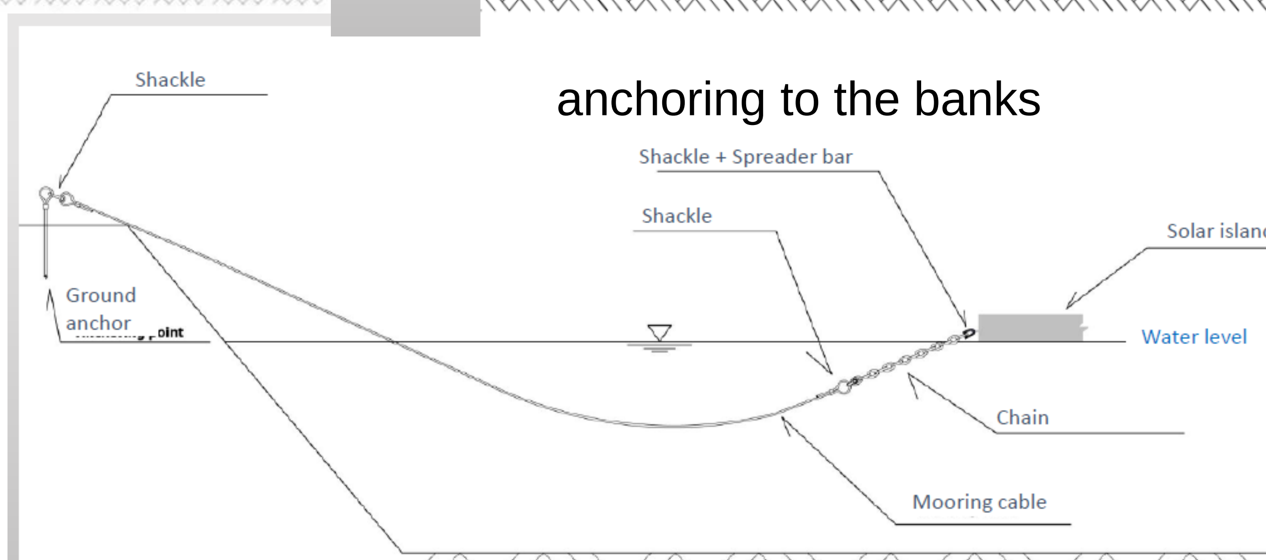
ground anchoring to the bottom



anchoring with concrete blocks



anchoring to the banks



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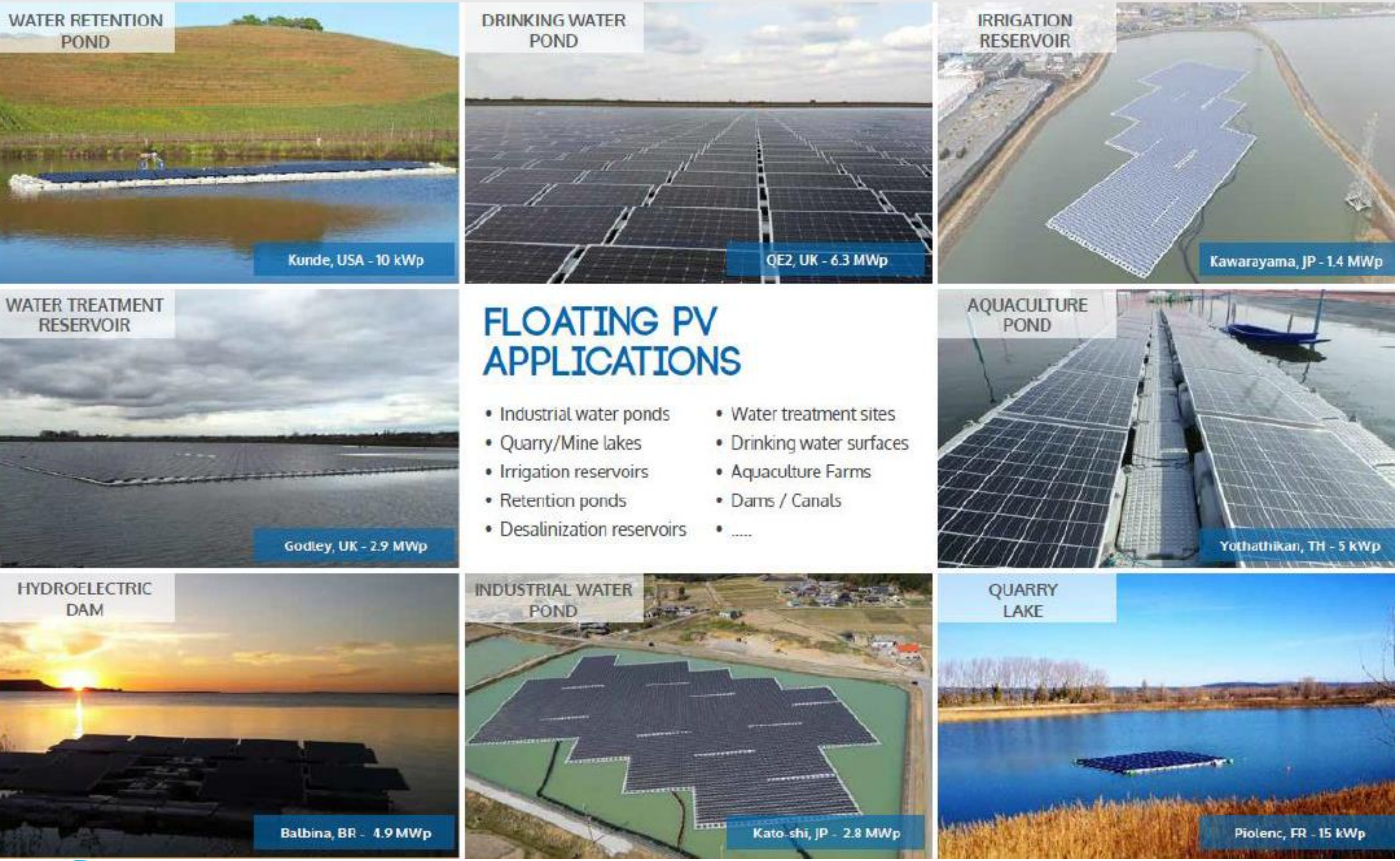
FPV Applications



How much capacity can be installed in a water body?

- Based on the experience in above installations & indication by various installers, a conservative estimate of 40 MWp capacity FSPV can be taken per sq. km of reservoir surface area covered

- The coverage of minimum 20% of total reservoir surface area can be considered with negligible impact on environment

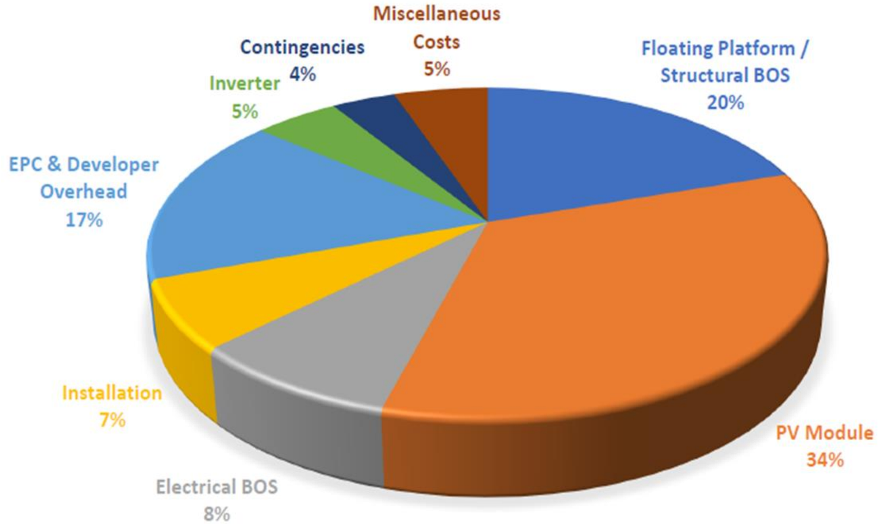
- One of the studies mention a potential of 909.05 GWh & saving of 16,233B liters of water per year exists if large reservoirs are used in India for Floating Solar PV power plants

Reference: https://www.nrel.gov/tech_deployment/state_local_governments/blog/floating-solar-photovoltaics-gaining-ground

FSPV – Indicative CAPEX Comparison

For example, India CAPEX can be around I million USD/MW for fixed and slightly higher for floating

In USA, utility scale costs are now <1.5M USD/MW



CAPEX Breakdown	Floating (USD/MW)			10MW Ground Mounted (USD/MW)		
Floating Platform / Structural BOS	$	370,000	20%	$	190,000	11%
PV Module	$	640,000	34%	$	640,000	36%
Electrical BOS	$	160,000	9%	$	160,000	9%
Installation	$	125,000	7%	$	190,000	11%
EPC & Developer Overhead	$	310,000	17%	$	310,000	17%
Inverter	$	90,000	5%	$	90,000	5%
Contingencies	$	67,800	4%	$	64,400	4%
Miscellaneous Costs	$	100,000	5%	$	100,000	6%
Land Acquisition	$	0	0%	$	30,000	2%
Total	**$**	**1,862,800**		**$**	**1,774,400**	

Reference: ITPENERGISED

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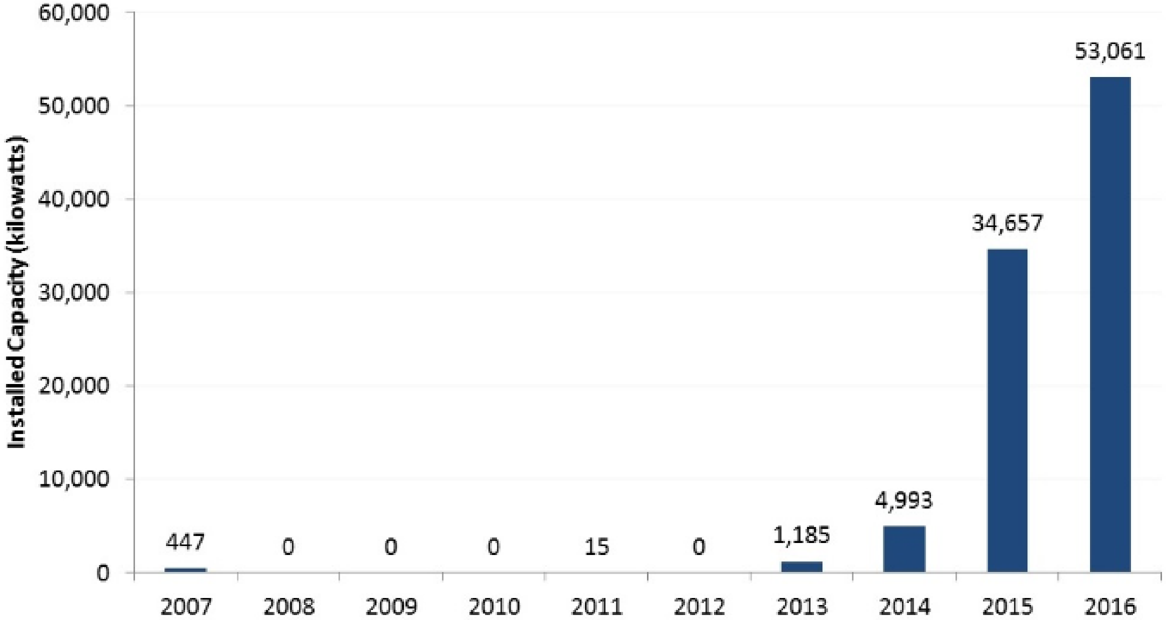
FSPV Development

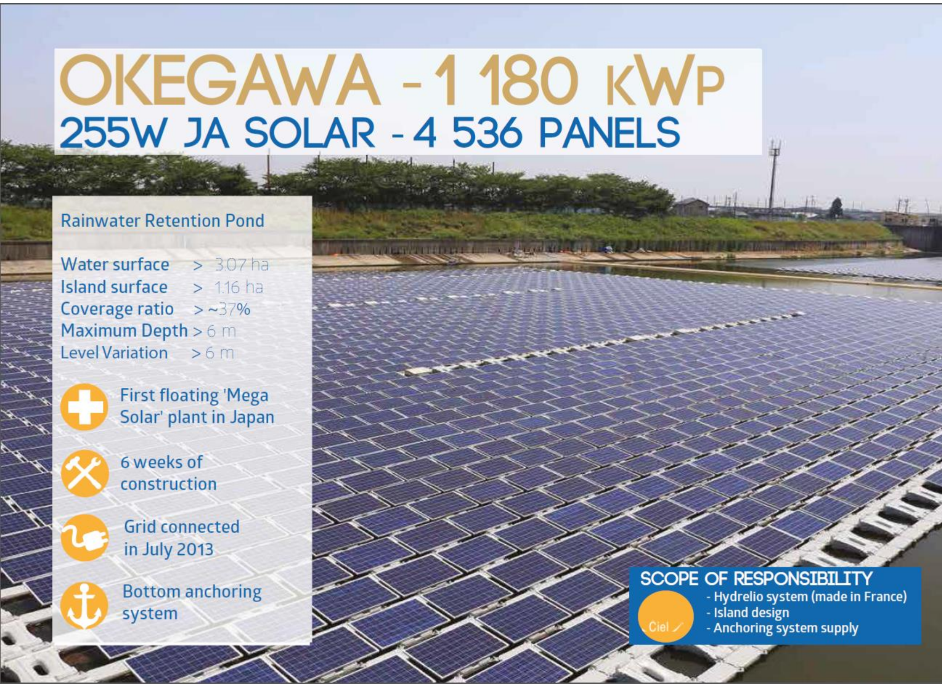
- Largest installation in Europe is the 23,046 panel, 6,337kWp Queen Elizabeth II plant in Eng, total cost of £6m, generates electricity equivalent to consumption of 1,800 homes
- In Brazil, a 350 MW pilot project is being planned at the Balbina hydroelectric plant in the Amazon



Reference: https://www.nrel.gov/tech_deployment/state_local_governments/blog/floating-solar-photovoltaics-gaining-ground

FSPV Projects

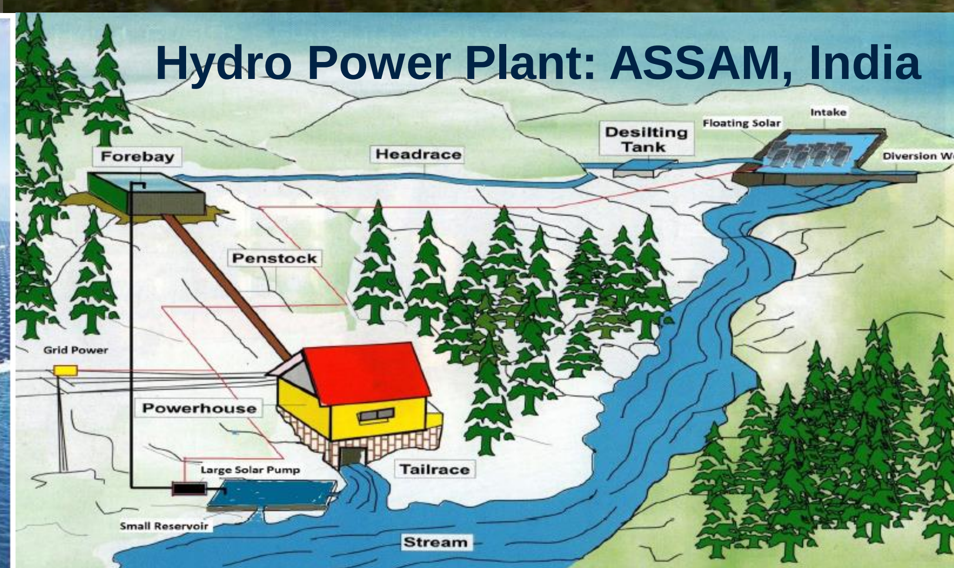
Rainwater retention pond, Japan



Irrigation reservoir, Japan

Flooded coal mining región Huainan, China

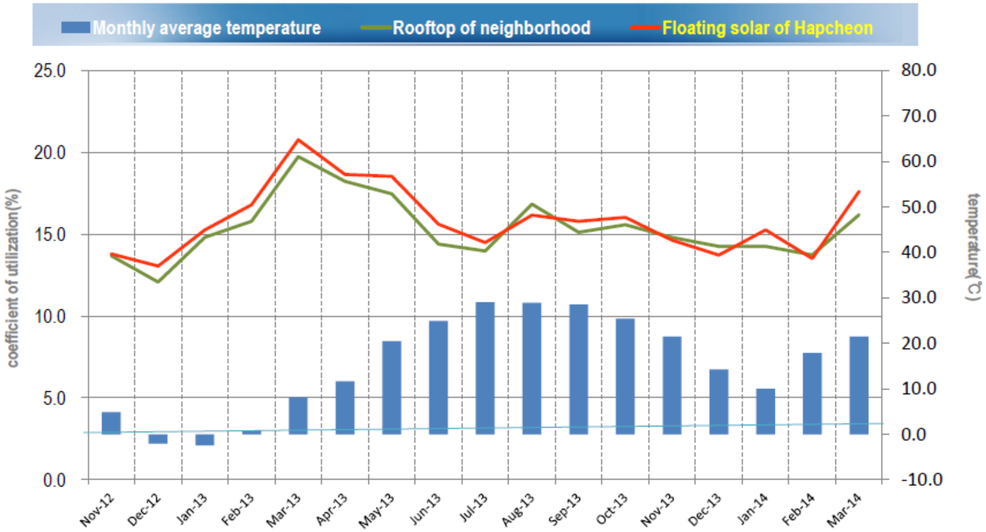
Hydro Power Plant: ASSAM, India



Advantages of FSPV

- Utilization of unused space of lakes, reservoirs, etc., preserving land for other uses
- If located in hydropower plants reservoir, it can use existing evacuation infrastructure.
- Land neutral – less space conflicts, lower plot acquisition cost
- Reduce evaporation by up to 70%
- Improved water quality – slow algae growth
- Maintenance benefits in dusty locations

- Higher capacity factor from a cooling effect: panels are naturally cooled hence automatically solves the issue of heating losses that occur during its operation



Reference: https://www.nrel.gov/tech_deployment/state_local_governments/blog/floating-solar-photovoltaics-gaining-ground

Challenges **for FSPV**

- Potential impact on livelihood.
- Though water bodies are not treated as forest but forest people claims water bodies are their property.
- Anchoring of the Floating platform may be challenging.
- Fisherman and Tourist boats movement may be restricted after installation of the plant.
- Access to the plant for O&M may be dfficult.
- Shadow Effect due to bird. Easy access for Marine animals to a stable structure.

Reference: https://www.nrel.gov/tech_deployment/state_local_governments/blog/floating-solar-photovoltaics-gaining-ground

PV/Hybrid Minigrids- Vietnam example

- ✓ 600 kW PV Capacity
- ✓ Utility application on resident island
- ✓ Commissioned November 2014
- ✓ Fuel Reduction: **292,000 Liter per year**
- ✓ CO_2 Reduction: **721,000 kg per year**

Environmental and social issues

Environmental impact of technologies

Energy technologies	Life-cycle impacts* (Pre- and post-generation)			Power generation impacts			CO_2 emissions (t/mWh)**
	Air	Water	Land	Air	Water	Land	
Coal: USC	*Baseline technology for relative assessments below*						0.777
NGCC	Positive	Positive	Positive	Positive	Positive	Positive	0.403
Nuclear	Positive	Variable / uncertain	Variable / uncertain	Positive	Negative	Positive	0.005
Solar: CSP	Positive	Positive	Positive	Positive	Negative	Minimal	0.017
Solar: PV	Positive	Positive	Positive	Positive	Positive	Minimal	0.009
Wind	Positive	Positive	Positive	Positive	Positive	Variable / uncertain	0.002

* Includes co-impacts from fuel extraction, processing and transport. Does not include co-impacts from plant construction or manufacturing.

** Based on NEEDS life-cycle estimates for year 2025. Does not include non-CO_2 greenhouse gases such as methane.

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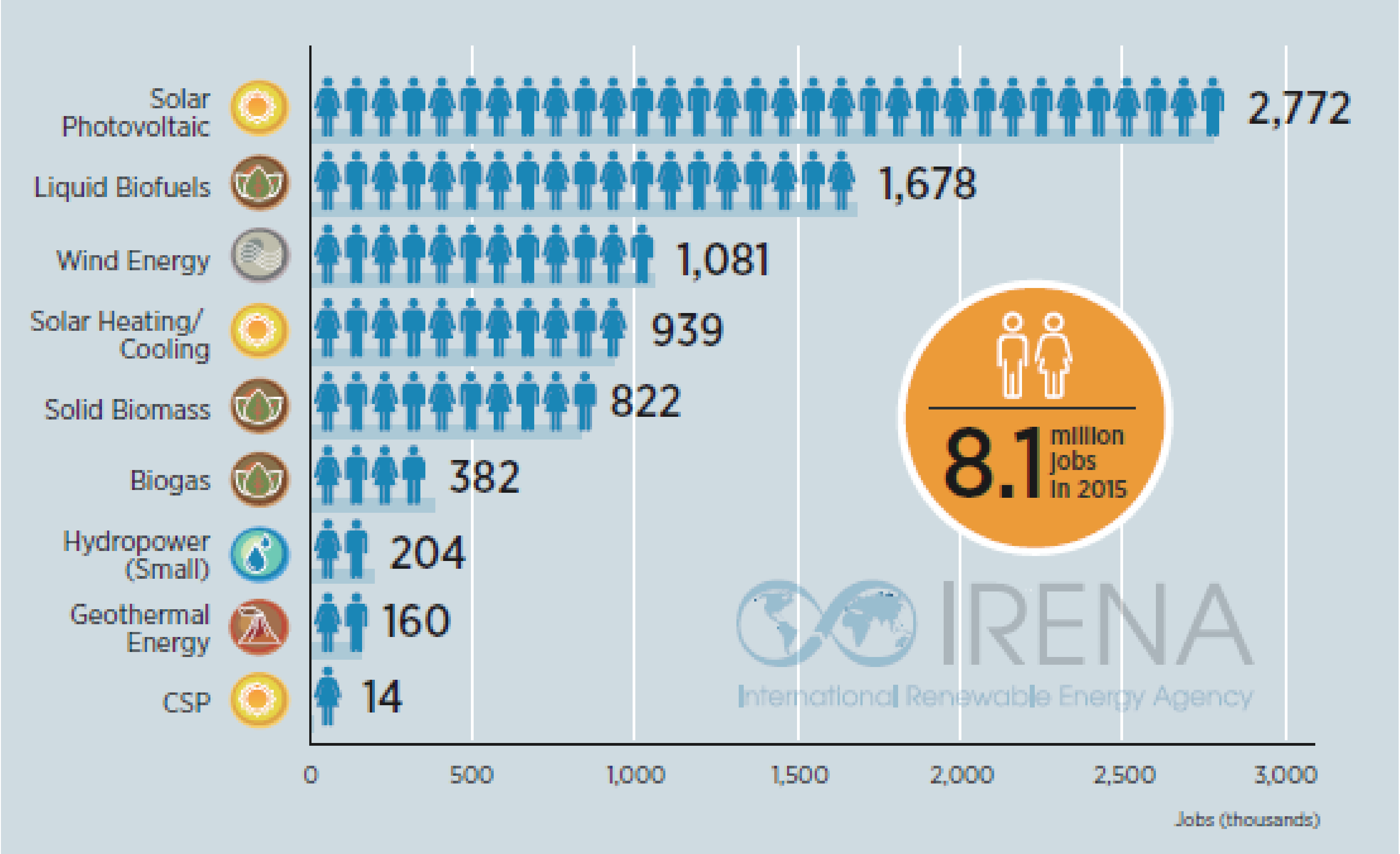
Reference: IEA, Energy Technology Perspectives 2010, http://www.iea.org/publications/freepublications/publication/etp2010.pdf

Social impacts - job creation

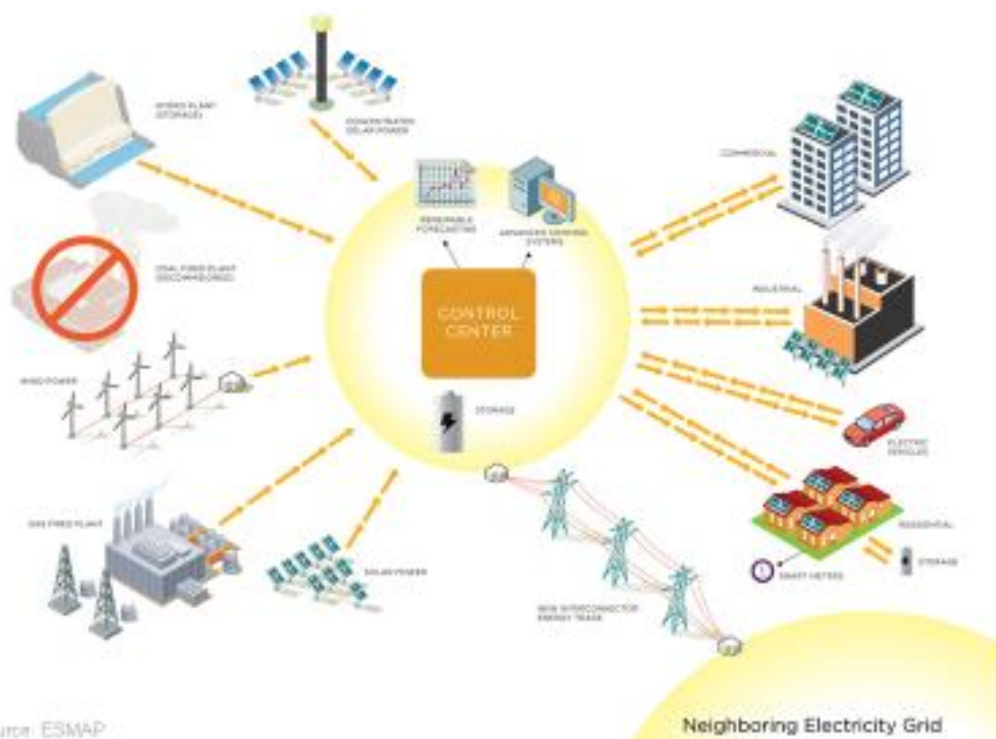
- Renewable energy sector has become a significant employer



Source: based on IRENA, Renewable Energy and Jobs, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Jobs_Annual_Review_2016.pdf

Session 4:
Solar PV Grid Integration

- **Defining the grid integration challenge**
- **Solar resource Variability and unpredictability**
- **Best practices to reduce grid integration issues**



Source: ESMAP

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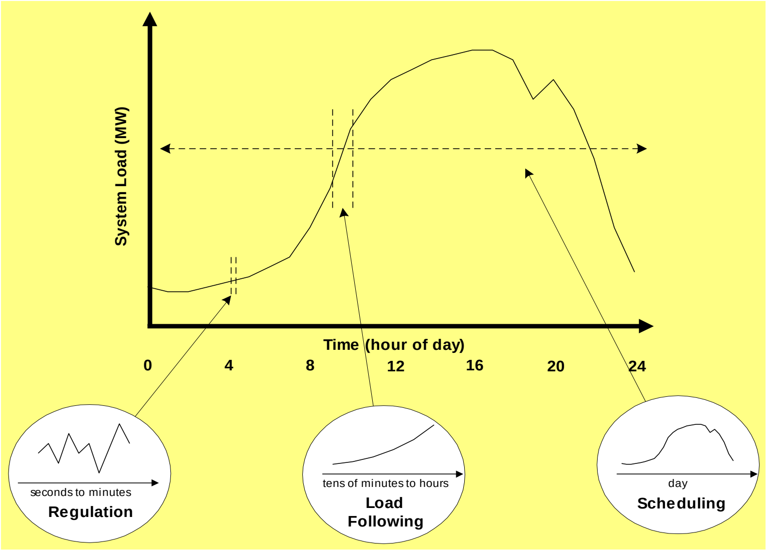
Defining the Grid Integration Challenge

Power System Operations

- The duty of the operator to ensure technically safe of the grid.
- Load fluctuates constantly
- System operators must constantly match generation and load

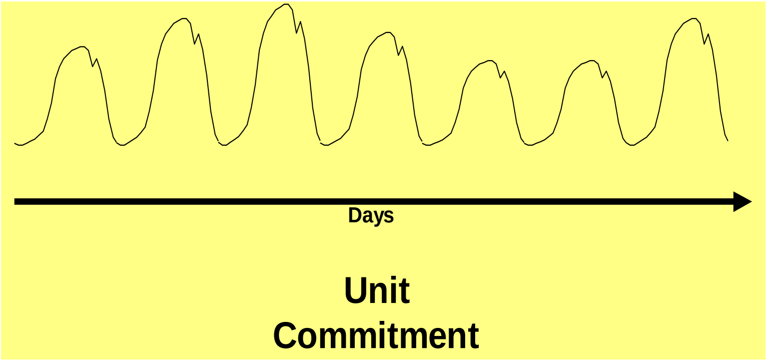


Power system operators must:

1) make minute-to-minute adjustments to match generation and load

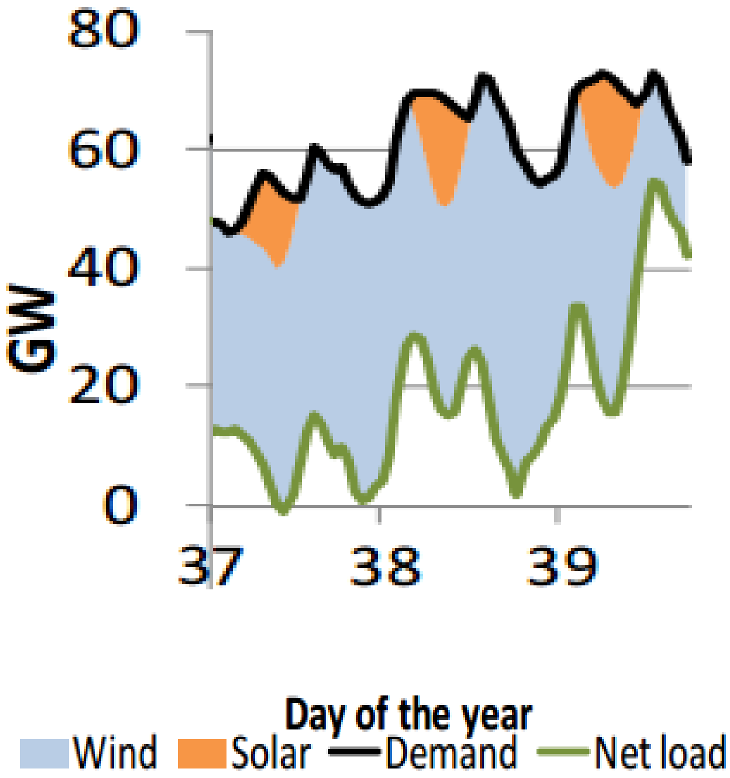
2) follow changes in daily load patterns (minutes to hours)

3) commit power plants to meet load (day-ahead)



Why is grid integration an issue?

- Some renewables are dispatchable (geothermal, bioenergy, most of hydropower and CSP), while the output of others (wind, PV, wave) are site specific, variable and less predictable – those are challenging to integrate
- Variability is not new - operators have always been dealing with variable demand but now also supply varies - the net load in presence of variable renewables has changed significantly



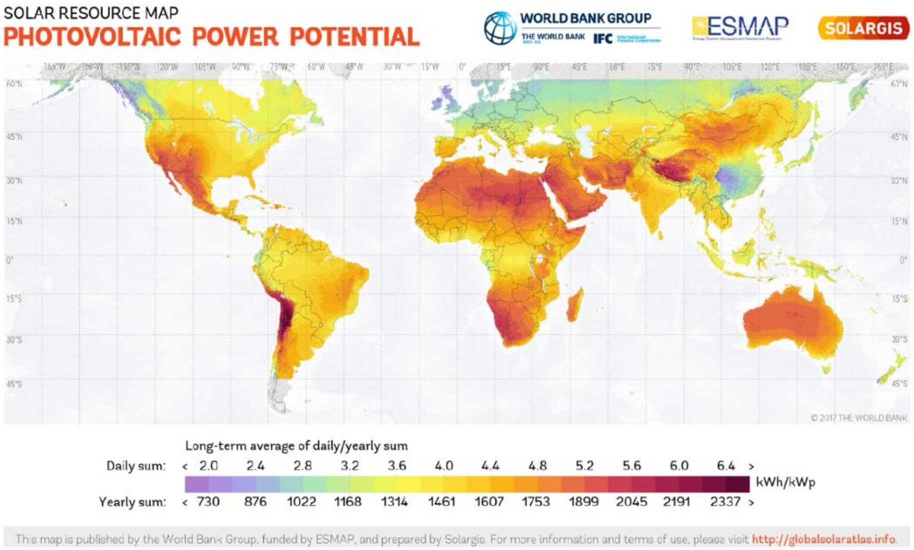
- More flexible reserves are needed to balance load & generation each day
- Each wind plant does not need to be backed up by a conventional plant
- Reserves are managed for the whole system; existing units can be used
- Conventional power plants may need to be ramped up and down or cycled more

Source: IEA

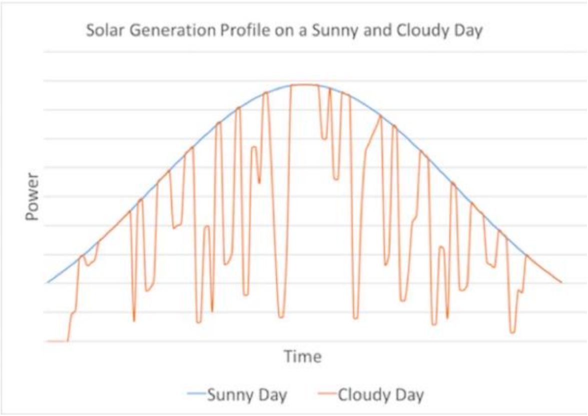
Solar resource variability and unpredictability

Resource Variability and uncertainty

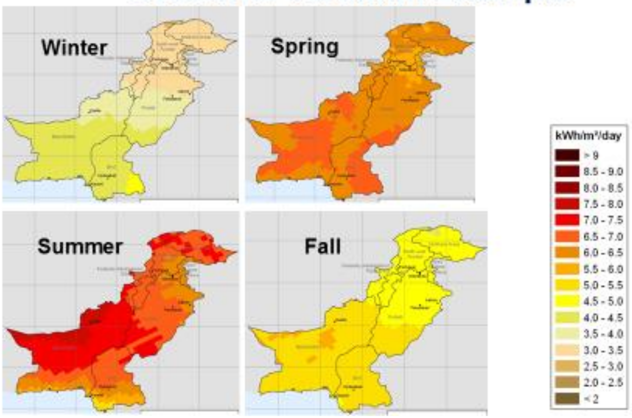
- Spatial variations
  - Climate and weather
  - Geography



- Time variability
  - Diurnal (daily)
  - Seasonal
  - Inter-annual variation (El Nino, La Nina, etc.)



Seasonal Variation Example



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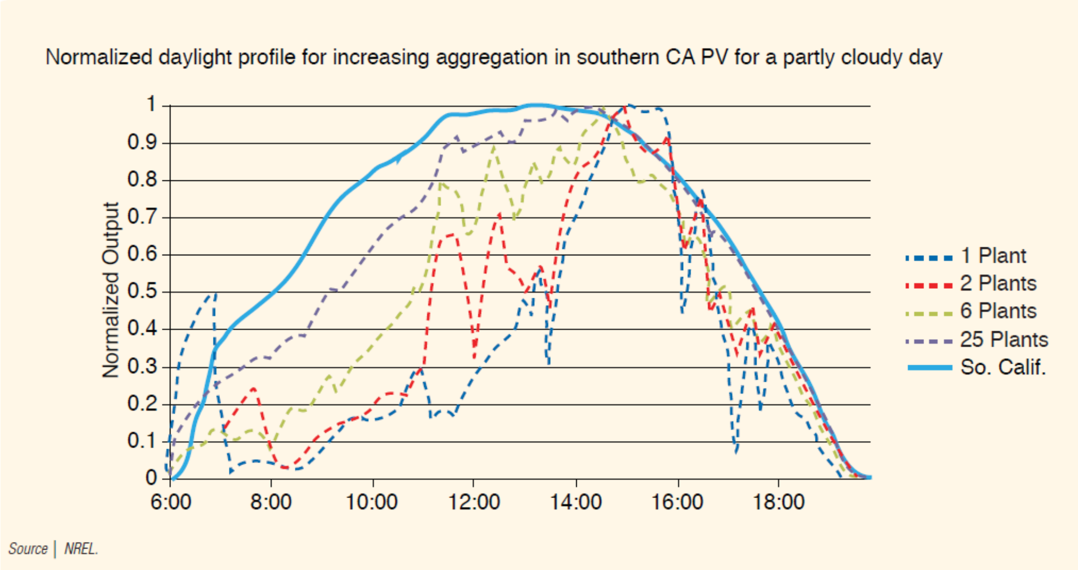
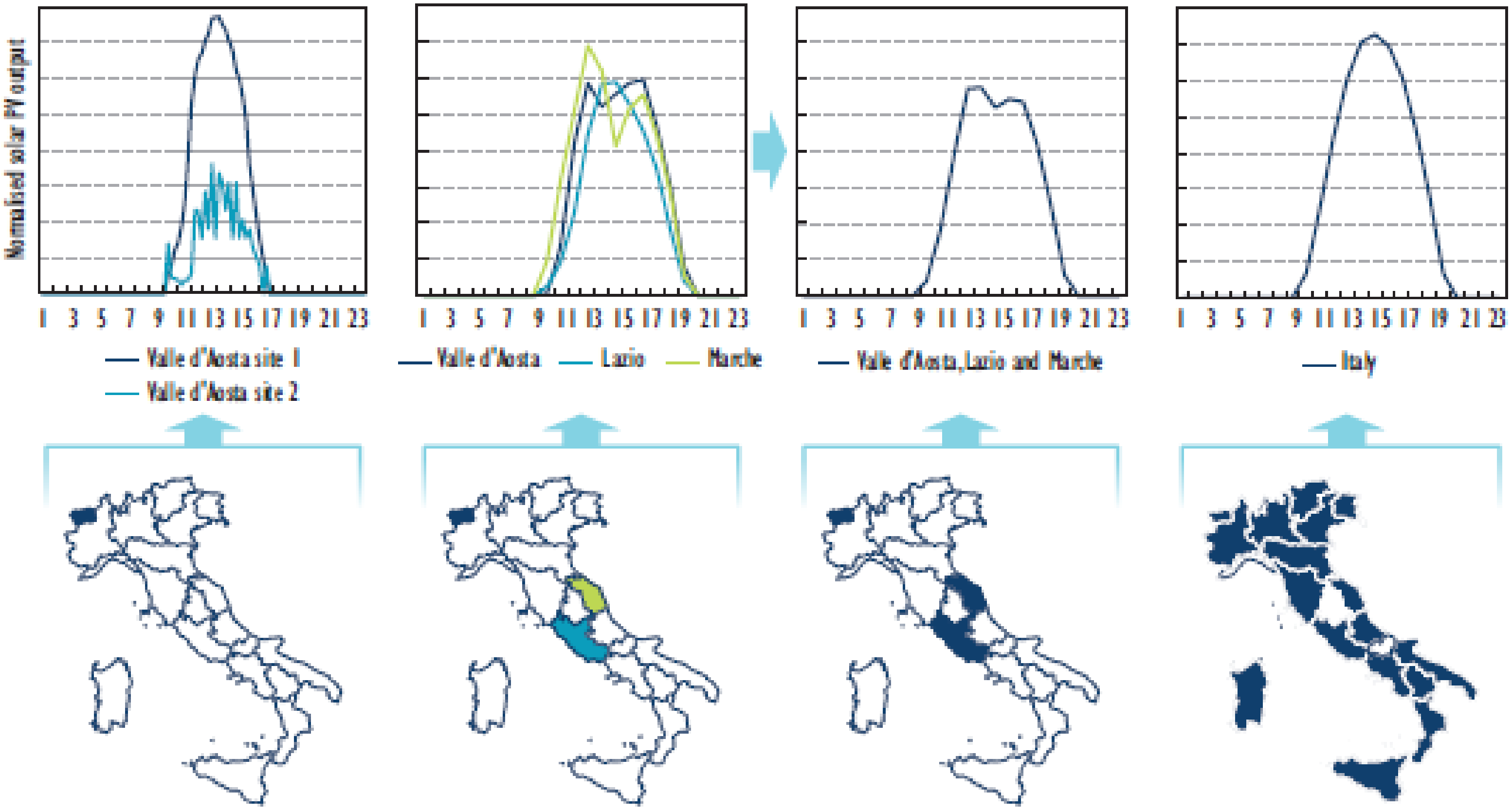
Aggregation helps with variability



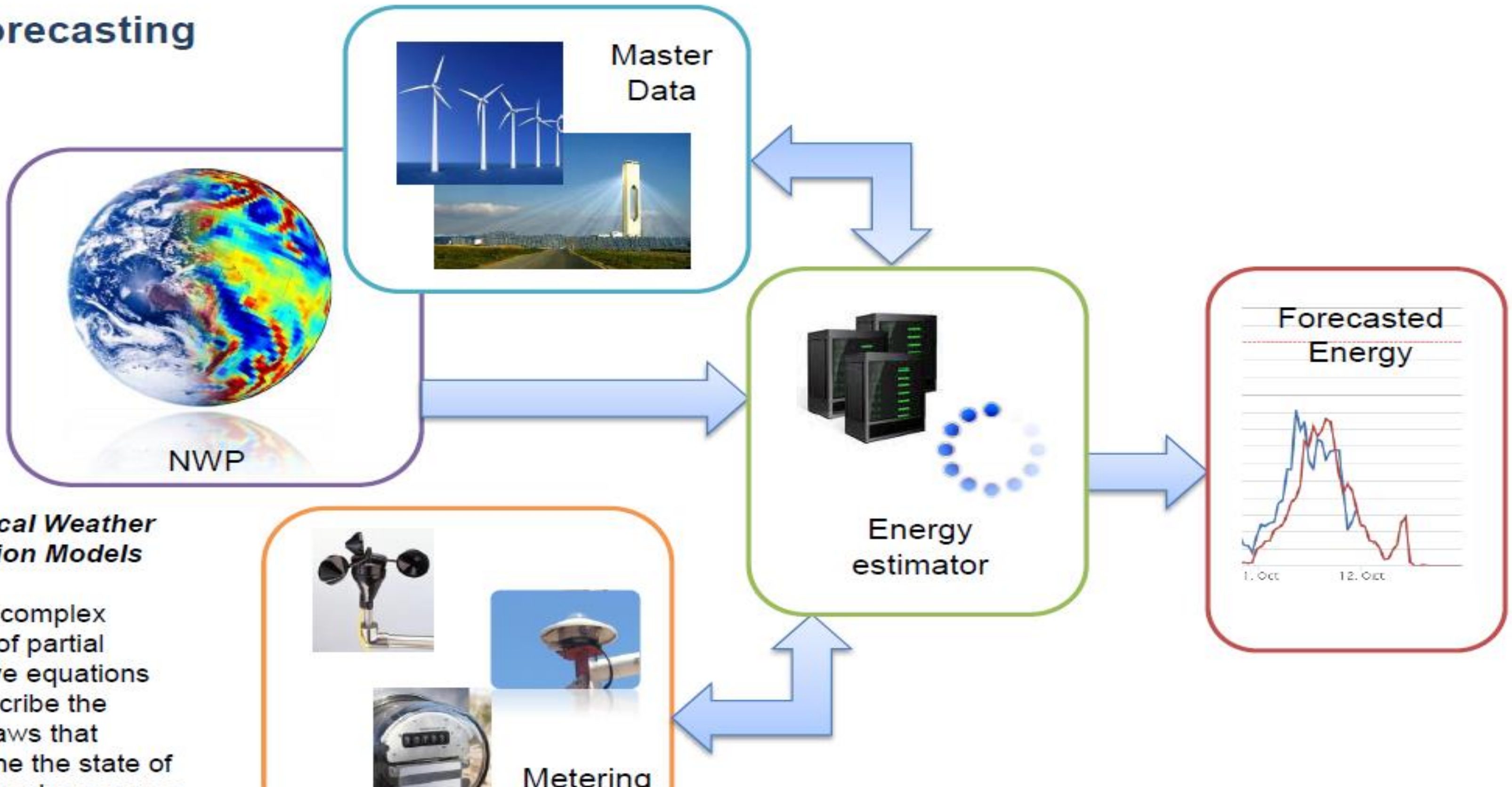


Source: IEA

Forecast helps with uncertainty

- Forecasting helps utilities and grid operators anticipate the amount of renewable energy generations – reduces uncertainty
- Every system holds reserves to provide supply in case of unexpected errors
- Regulation Encourage expanded use of solar forecasting by IPPs and utilities and balancing areas and encourage regional forecasts or exchange of forecasts among balancing areas

•Forecasting



Numerical Weather Prediction Models (NWP)
Solve a complex system of partial derivative equations that describe the physic laws that determine the state of the atmosphere across space and time.

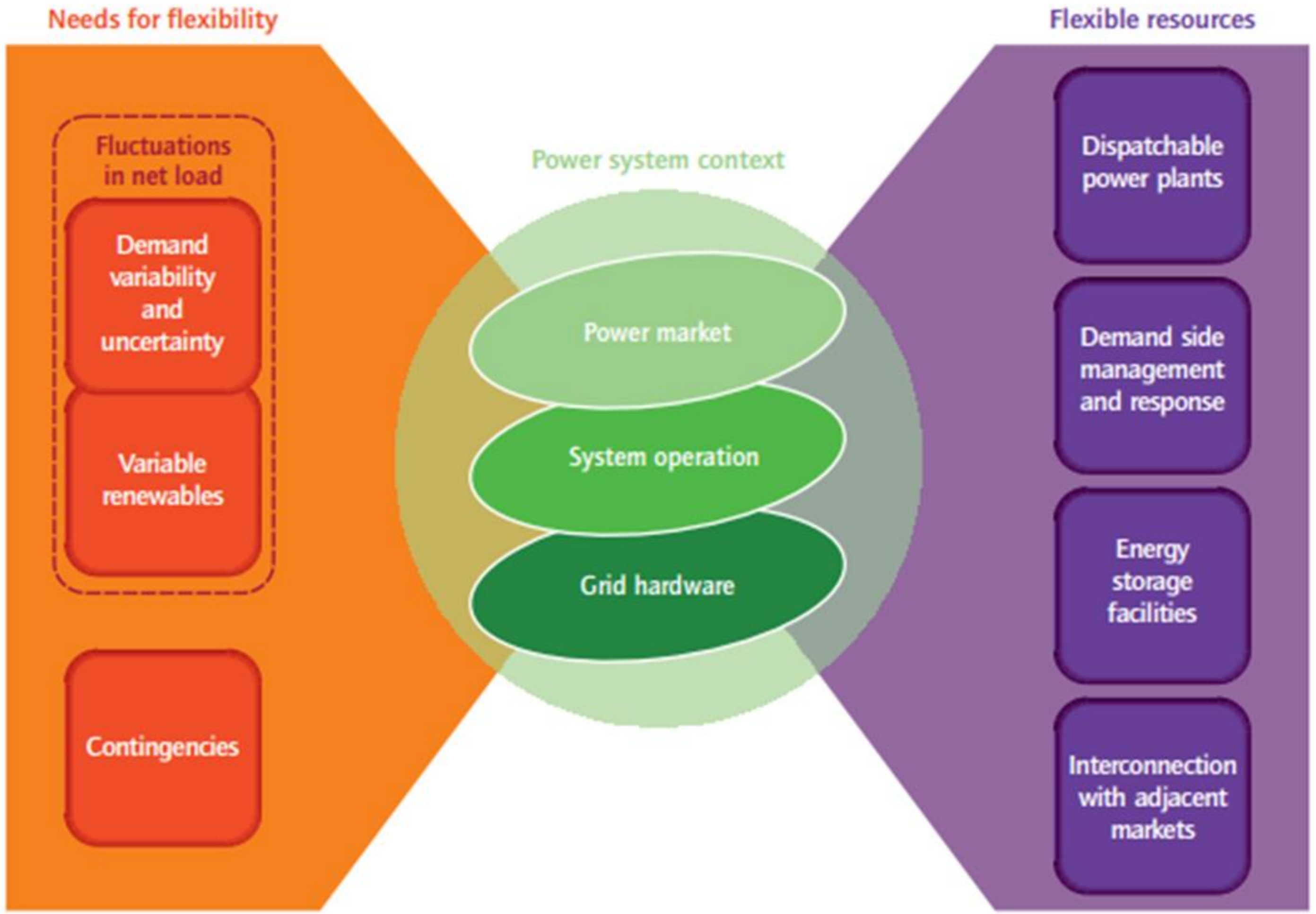
Source: Gnarum

Best Practices for VRE grid integration

How much renewables can be accommodated

(without additional investments)?

- It depends on system, operations and economics. Power systems already have flexible resources for balancing (to deal with the variability of the demand)
- RE can be integrated if adequate operational changes can provide additional flexibility



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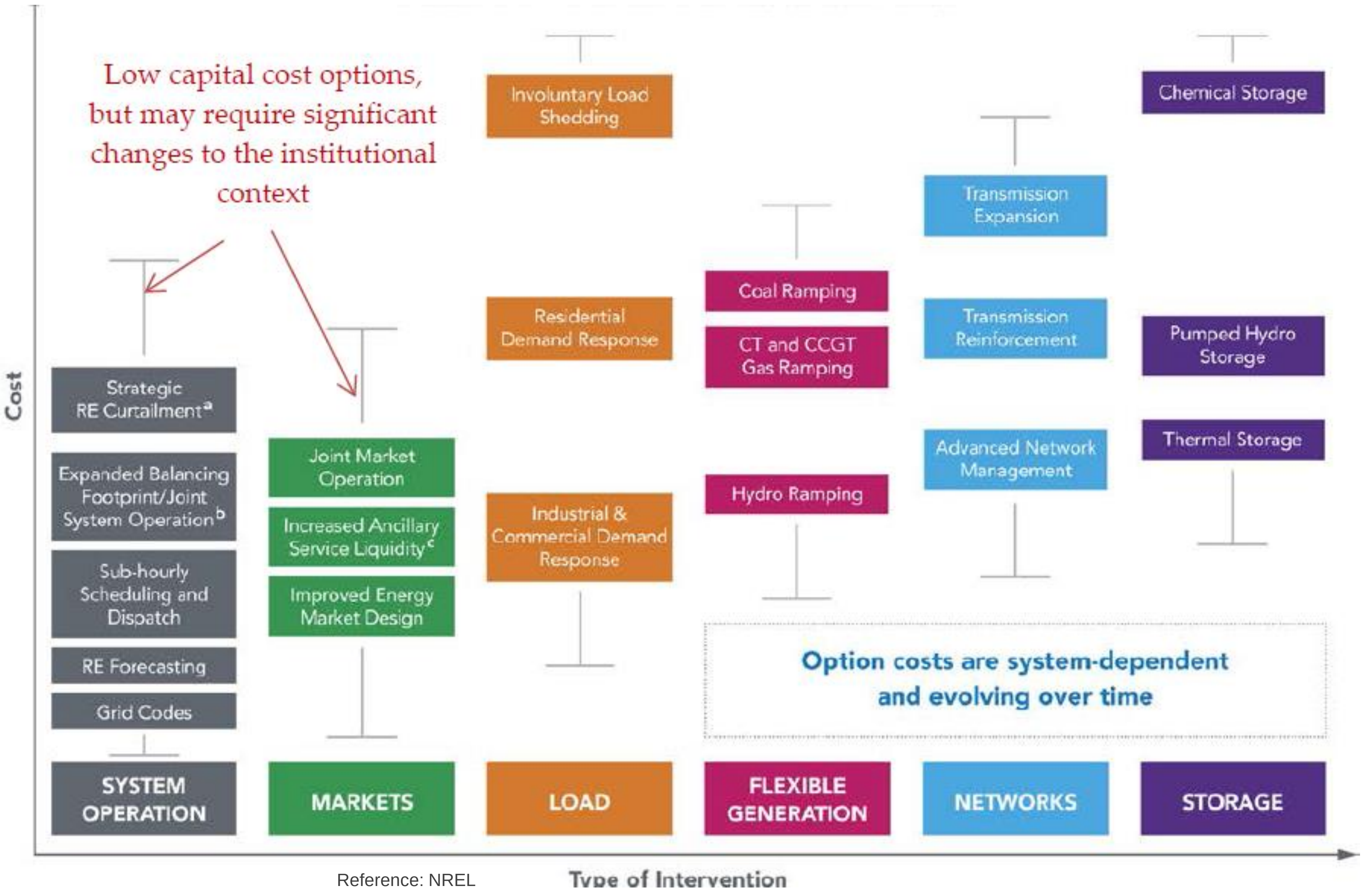
Economics of different Flexibility options



Reference: NREL

Encourage Geographic Dispersion of projects

Geographic diversity reduces variability

Variations in output from wind and solar plants are reduced over a large area

Diversity lowers aggregate variability and forecast errors, reducing reserves needed

Policy and Regulatory Options

- In transmission plans and utility resource plans/RFPs, consider siting wind and solar to minimize variability of aggregate output and better coincide with load profiles
- Support right-sizing of interstate lines (increasing project size, voltage, or both to account for credible future resource needs) that access renewable resources

Source: Dennis Schroeder

Increase Flexibility of Generation

Access greater flexibility in the dispatch of existing generating plants

Some plants can be retrofitted to increase flexibility by lowering minimum loads, reducing cycling costs and increasing ramp rates.

Focus on flexibility for new generating plants

Requires rethinking resource adequacy analysis to reflect the economic benefit of flexibility service

Changes to resource planning and procurement frameworks

Policy and Regulatory Options

Conduct a flexibility inventory for existing resources

Analyze the potential for retrofitting less flexible generating plants

Review incentives/disincentives for plant owners to invest in increased flexibility

Examine and amend guidance for evaluating flexibility needs in utility resource planning

Use competitive procurement processes to evaluate alternative flexible capacity solutions

Encourage Demand Response

Shift customer load up and down to complement wind and solar through direct load control and real-time pricing with automation

Demand response (DR) may be less expensive than supply-side resources and energy storage technologies

Policy and Regulatory Options

Allow DR to compete on a par with supply-side alternatives in utility resource planning and acquisition

Consider potential value of enabling DR when evaluating advanced metering

Examine ratemaking practices for features that discourage cost-effective DR – e.g., demand charges that penalize large customers for higher peaks when they shift loads away from periods of limited energy supplies

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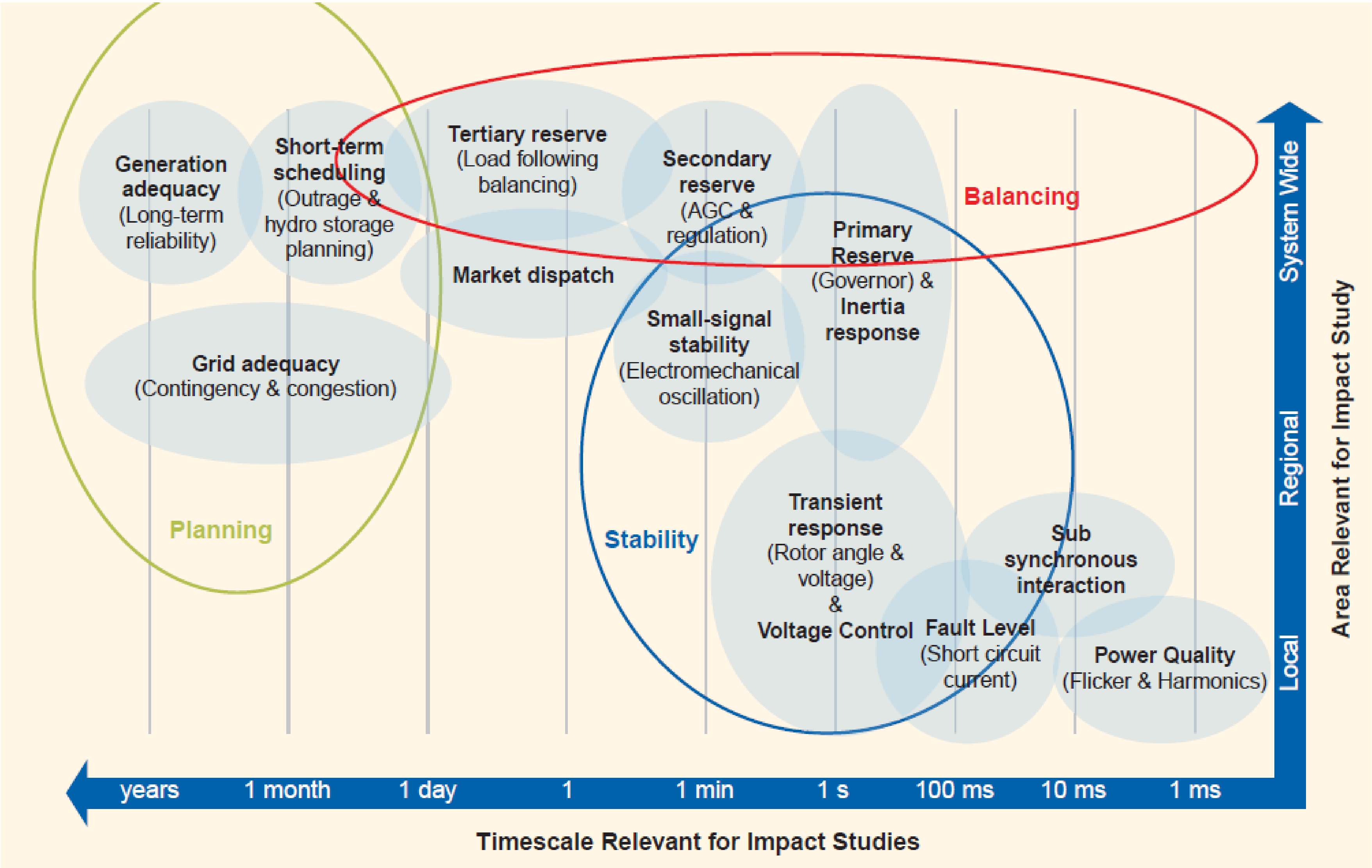
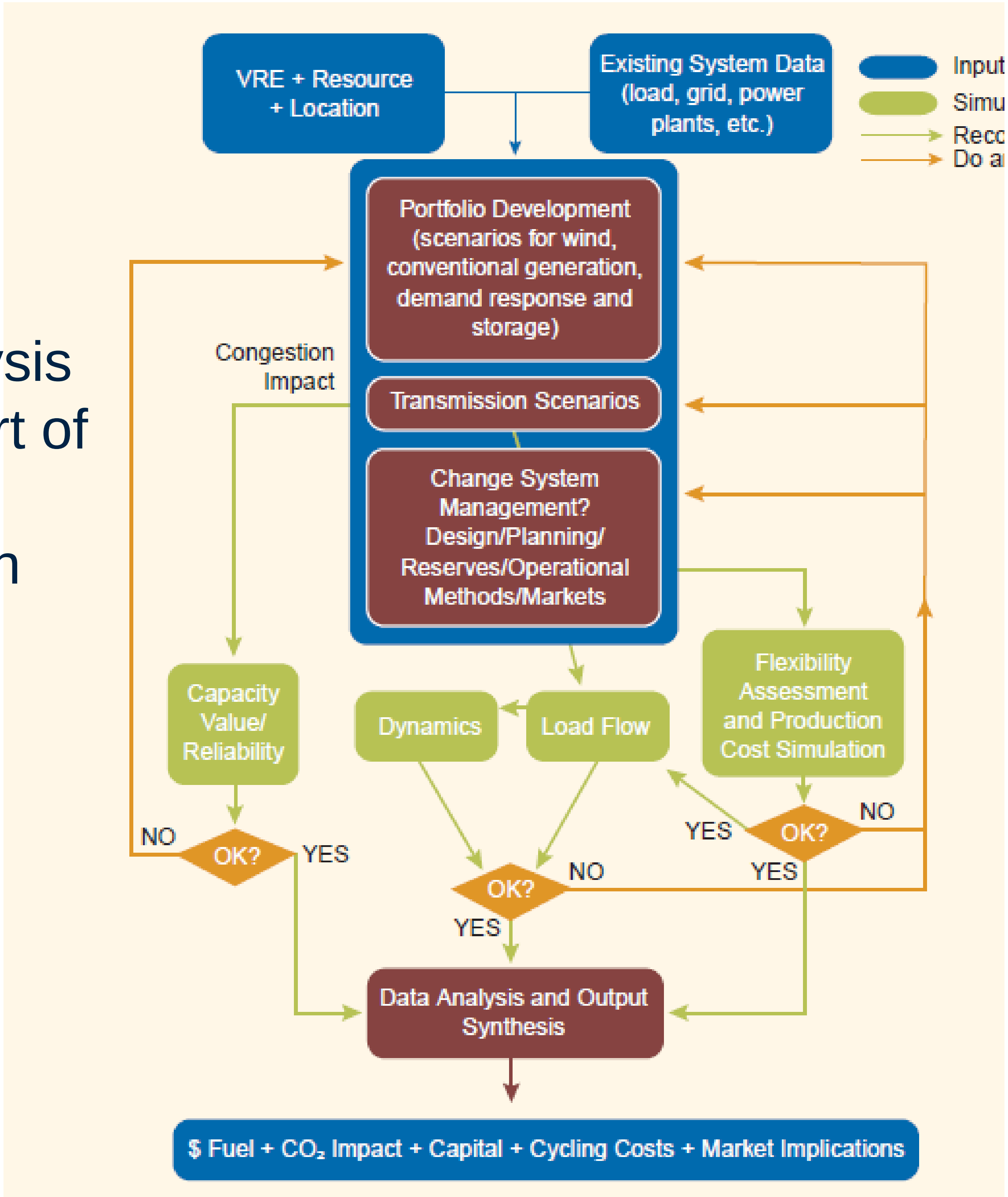
Grid Expansion Planning and grid studies for higher shares of VRE

Grid Studies



Reference: IRENA

Short term analysis as an integral part of the long term expansion plan



Source | Adapted from IEA Task 25 Report.

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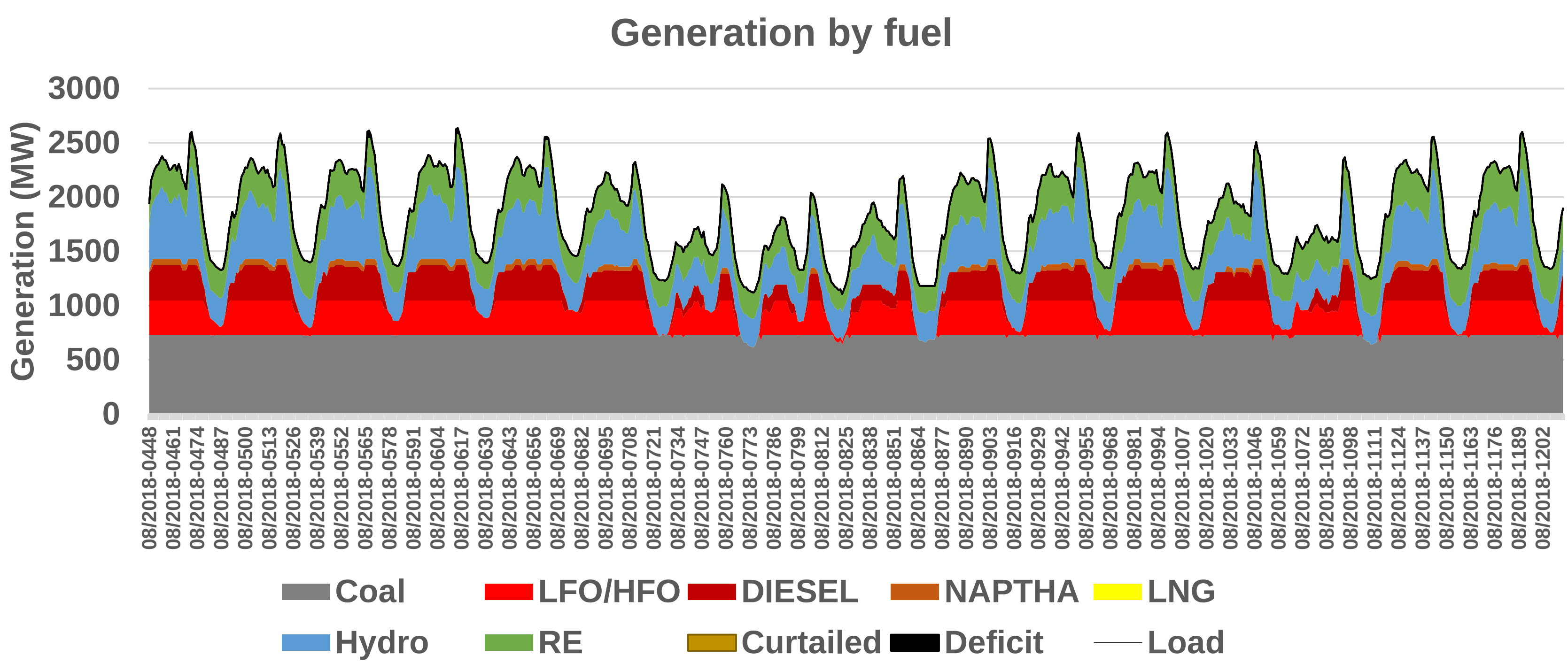
Grid Integration of Renewables in Hydrothermal systems

- The World Bank is supporting the Central Electricity board in Sri Lanka in short-term grid studies to evaluate:
  - VRE curtailment for different levels of VRE penetration
  - CO_2 emissions
  - Operational costs of the Sri Lankan system in different scenarios

- The short-term study was performed using PSR's planning software:
  - NCP (short-term dispatch scheduling) and
  - SDDP (medium term scheduling).

- The modeling exercise was performed to simulate dispatch for the 2017-2020 period, and will be used as input to the least cost expansion plan.

Detailed Results-Base Scenario (Half-Hourly Generation sample- 2018)



- The dispatch of units was optimized by NCP on a per 30 minute basis
- Base load capacity is provided by coal fired generators and the varying part of demand is balanced by hydro and Oil/Diesel generators

Summary of results

Scenario	NCRE penetration (%) (solar, wind, mini-hydro and biomass)	VRE curtailment (% of total wind and solar penetration)	CO2 emissions (million tons)	CO2 emissions savings compared to "no VRE" scenario (million tons)	Average system wide CO2 emissions (gr/kWh)	Total system operative costs ($ billion)	Total system operational costs savings compared to "no VRE scenario" ($ billion)	Average cost of electricity production ($/MWh)
Medium	17.9%	0.0%	33.72	1.84	527.1	2.75	0.37	43.21
Dry	17.9%	0.0%	34.63	0.94	540.5	2.94	0.19	45.99
Wet	17.9%	0.0%	31.96	3.61	499.0	2.39	0.73	37.56
No VRE	9.3%	0.0%	35.57		554.7	3.12		48.83

The results focus on three main areas:

- *On VRE curtailment*: The Sri Lankan grid can effectively absorb the amount of RE that has been proposed so far up to 2020
- *On emissions*: Integration of around 720MW of new solar and wind generation help reduce emissions by 1.84 million tons by the same year. The average emissions intensity of the grid over the same period will reduce by ~5%
- *On operational costs*: Integration of around 720MW of new wind and solar will reduce system-wide total operative costs by $370 million over the 2017-2020 period

Additional info: Examples of what strategies have been successful internationally

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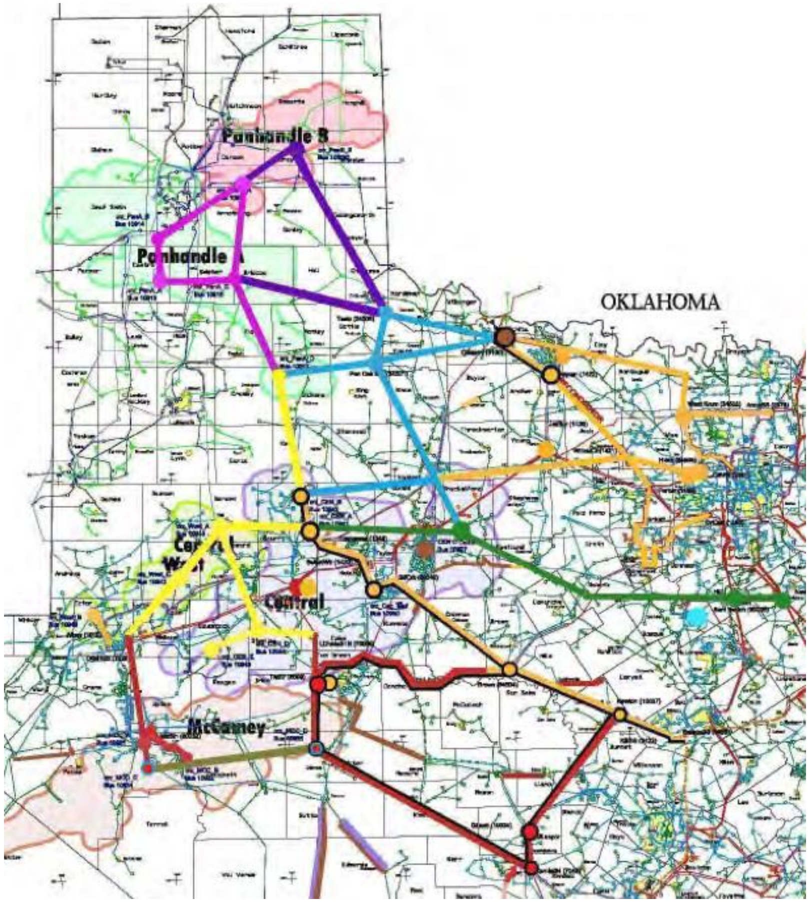
A. Lead Public Engagement, New Transmission



Source: Public Utility Commission of Texas, Docket No. 35665, Nov. 14, 2008. Public domain.

Examples

Texas: New transmission lines were key to integration; line construction, often resisted, was successful due to extensive and varied opportunities for public feedback

California's Renewable Energy Transmission Initiative—diverse, credible 30 person steering committee committed to achieving consensus and publicly supporting outcomes

Denmark, to address public concerns about aesthetics, plans to bury its entire high voltage grid by 2030

What Worked: Communicated to the public why new transmission is essential

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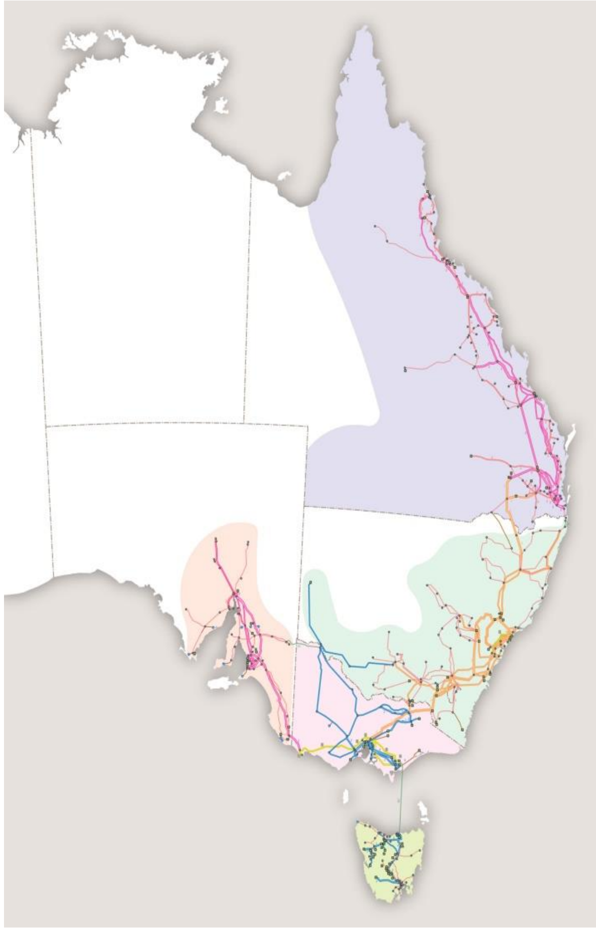
B. Coordinate and Integrate Planning



Source: Australian Energy Market Operator

Examples

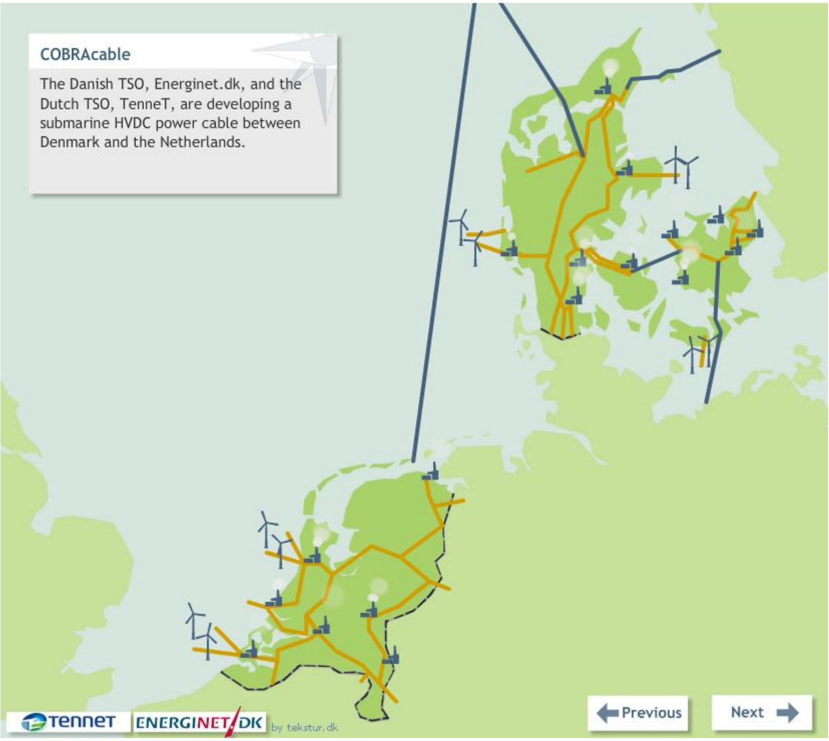
Australia: National-scale studies provide information, but complex spot market pricing has guided investment in both generation and transmission. Pricing includes

- Location-specific multiplier on regional price to reflect losses
- Connection costs
- Congestion-based pricing

Texas: Centralized planning has guided decisions. Competitive Renewable Energy Zones (CREZ) allow generation and transmission to be developed in coordination. Rate payers, not developers, absorb financial risk.

What Worked: Improved capacity of planners to handle added complexity

C. Market Design for System Flexibility



Source: Energinet.dk

Examples

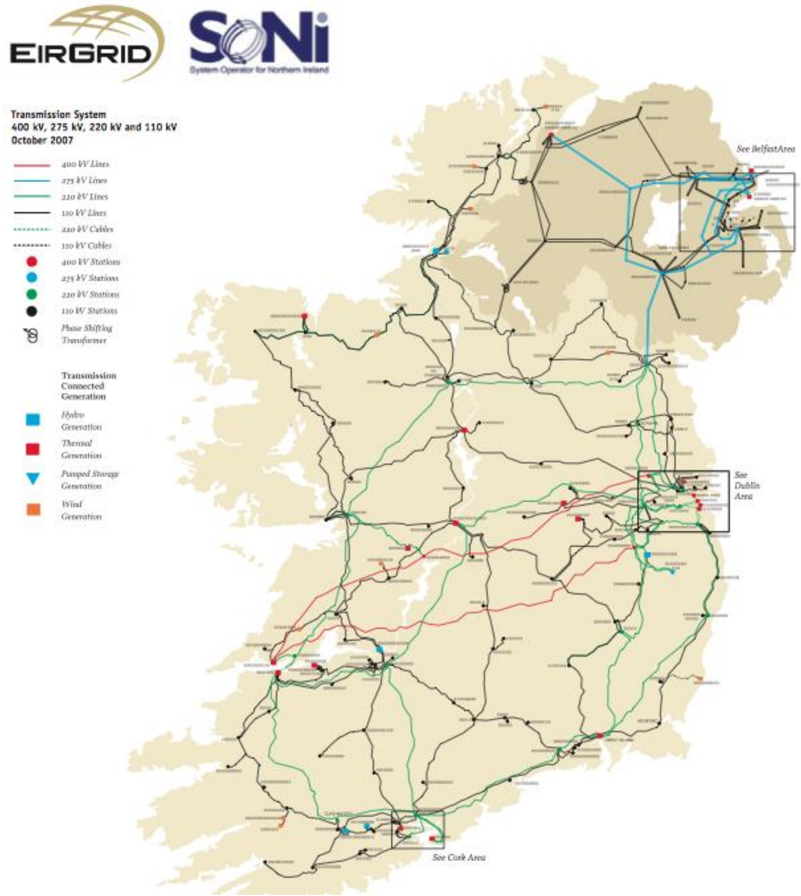
Denmark:

- Large power pool provides greater flexibility, e.g., Norway's hydro is critical to accommodating high wind penetrations
- Regulating Power Market operates up to 15 minutes before delivery
- Negative pricing provides economically efficient way to reduce output during excess generation
- Combined heat and power (CHP) required to participate in spot power market

Australia: Subhourly (5 min) dispatch intervals reduce need for ramping and improve forecast accuracy. Nodal and negative pricing encourage market efficient location strategies.

What Worked: Identified potential impacts of variable generation on electricity markets and generator compensation

D. Expand Diversity, Geographic Footprint



Source: Global Energy Network Institute

Examples

Ireland—has twice sought both to reduce its vulnerability to weather variability and also to strengthen its power system through expanding regional integration

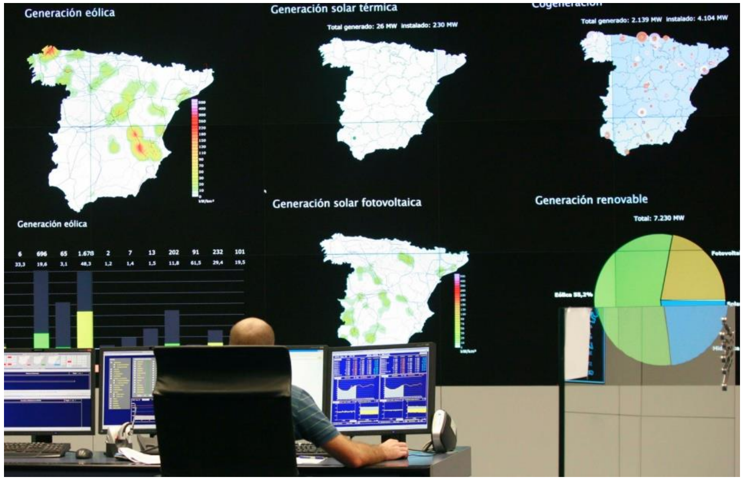
- Single Electricity Market with Northern Ireland: required for all electricity >10 MW sold and bought in Ireland; no bilateral transactions permitted
- 500 MW East-west interconnector to U.K. (under construction)

U.S. West lacks an organized wholesale electric market, but an Energy Imbalance Market has been proposed to allow balancing areas to share reserves, and—through this broader diversity—reduce the system-wide variability of RE

What Worked: Evaluated options to overcome institutional challenges in merging or increasing cooperation among balancing areas

Energy & Extractives

E. Improve System Operations



Source: Red Eléctrica Española

Examples

Spain's Control Centre for Renewable Energies

- Monitors RE installations real-time
- Wind farms >10 MW & PV>2MW provide reactive power support
- 97.5% of wind farms have fault-ride through capability
- New operational procedures proposed to maintain optimal voltage control

Australia: Market operators use forecasting model that integrates forecasts from a variety of sources

Denmark: System operator uses multiple, advanced forecasts in planning, congestion management, dispatch, and to assess need for regulating power

What Worked: Supported use of forecasting best practices; training on best practices for grid operators