CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

INTERNATIONAL SOLAR ALLIANCE

International Solar Alliance Expert Training Course

In partnership with the Clean Energy Solutions Center (CESC)

Dr. David Jacobs

Session 27: System Integration of Solar PV

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Supporters of this Expert Training Series

International Energy Transition

INTERNATIONAL SOLAR ALLIANCE

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ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

An Initiative of the Clean Energy Ministerial

IET – International Energy Transition GmbH

Dr. David Jacobs

- Founder and director of IET
- Focus on sustainable energy policy and market design
- 14+ years experience in renewable energy policies
- 60+ publications on energy and climate
- 40+ countries work experience (consulting and presentations)

Training Course Material

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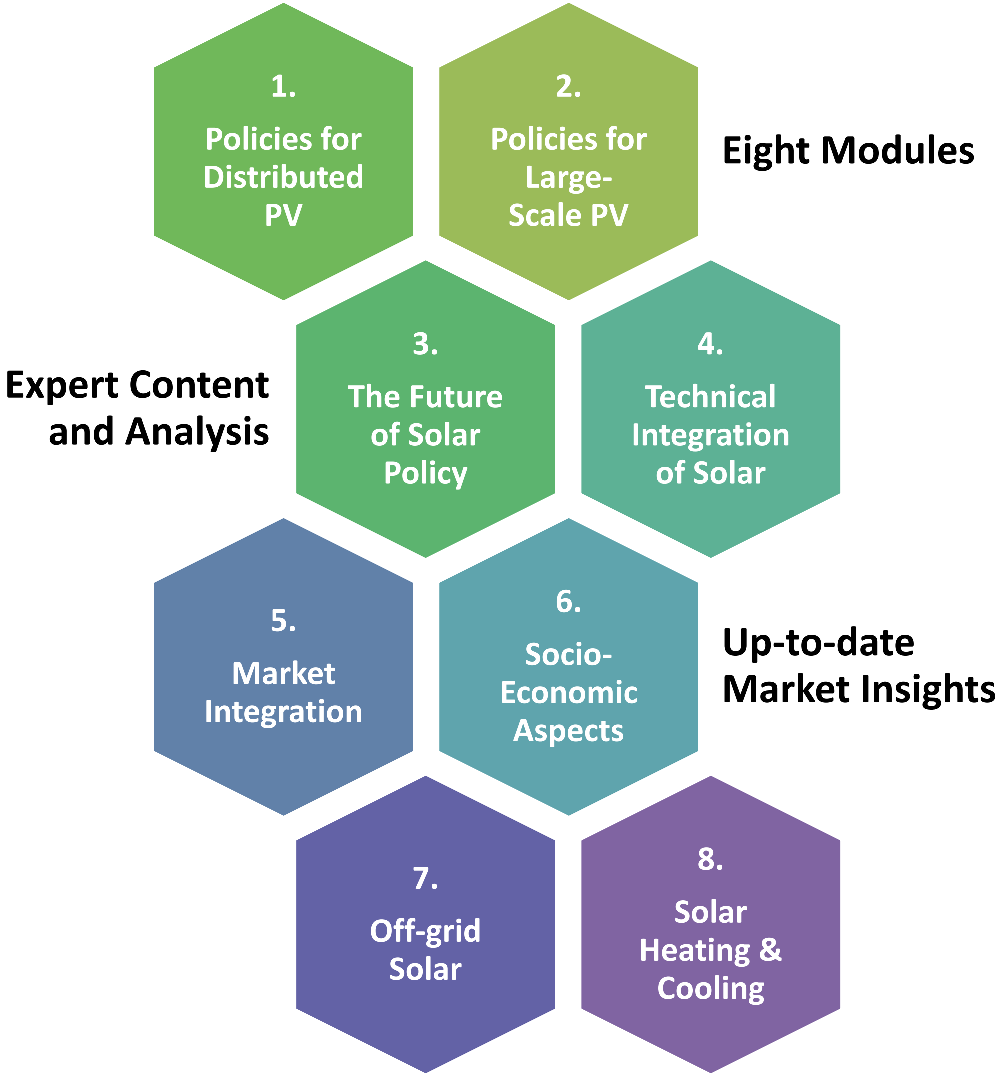
This Training is part of Module 5, and focuses on maket integration

<u>Related training units are:</u>

- ✓ 28. PV integration and the merit order effect
- ✓ 30. Solar PV and the Role of Storage
- ✓ 31. Sector coupling: Using solar power for the heating/cooling and transport sector



Overview of the Training Session

1. Introduction: Learning Objective

2. Understanding features of solar PV and its impact on power systems

3. Understanding flexibility options to integrate PV in modern power systems

4. Further Reading

5. Knowledge Check: Multiple-Choice Questions

Introduction:

Learning Objective

Learning Objective

- Understand the benefits of solar PV to the electricity system
- Understand the decisive features of solar PV (and its impact on electricity systems)
- Understand options to make the electricity system more flexible in order to integrate solar PV

Features of Solar PV and the Impact on Electricity Systems

Benefits of solar PV deployment for the electricity system

- Fuel cost savings
- Reduced short-run marginal system costs and reduced wholesale market prices (merit-order effect)
- Displacement of most expensive generation (merit-order effect)
- Reduced emissions

Features of solar PV

1. low short-run cost
2. Variability
3. Uncertain
4. Locational variations

Features of solar PV

1. low short-run cost = finance mechanism/support mechanism

2. Variability = market and system design

3. Uncertain = market and system design

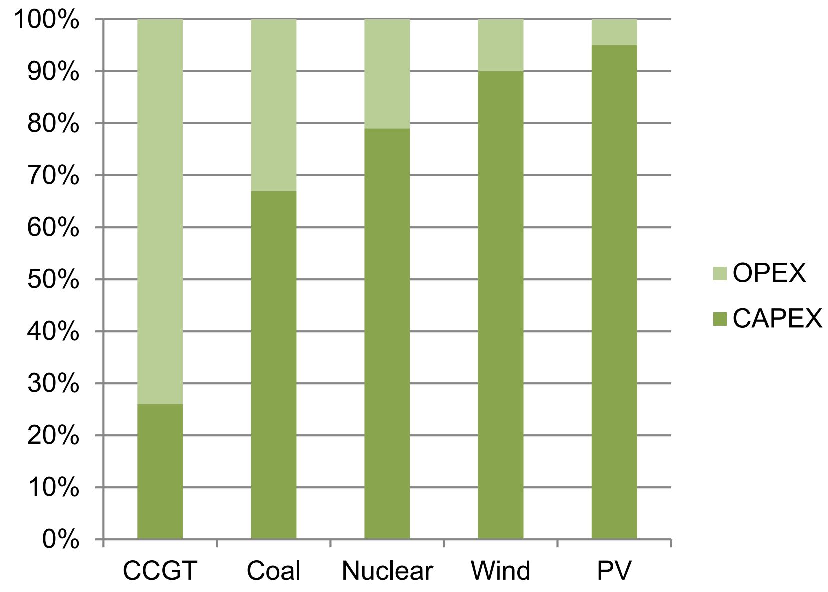
4. Locational variations = grid expansion planning

Features of solar PV

1. **low short-run cost**, i.e. once solar PV is installed it can generate power at very little cost (zero marginal costs)

- High upfront investment (capital costs)

Share of fixed versus variable costs of selected power generation technologies



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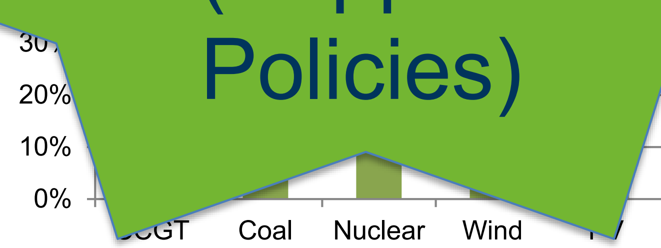

Check out Session 28 (Merit Order Effect)

Check out Session 3-9 (Support Policies)

Features of solar PV

1. low short-run cost = finance mechanism/support mechanism
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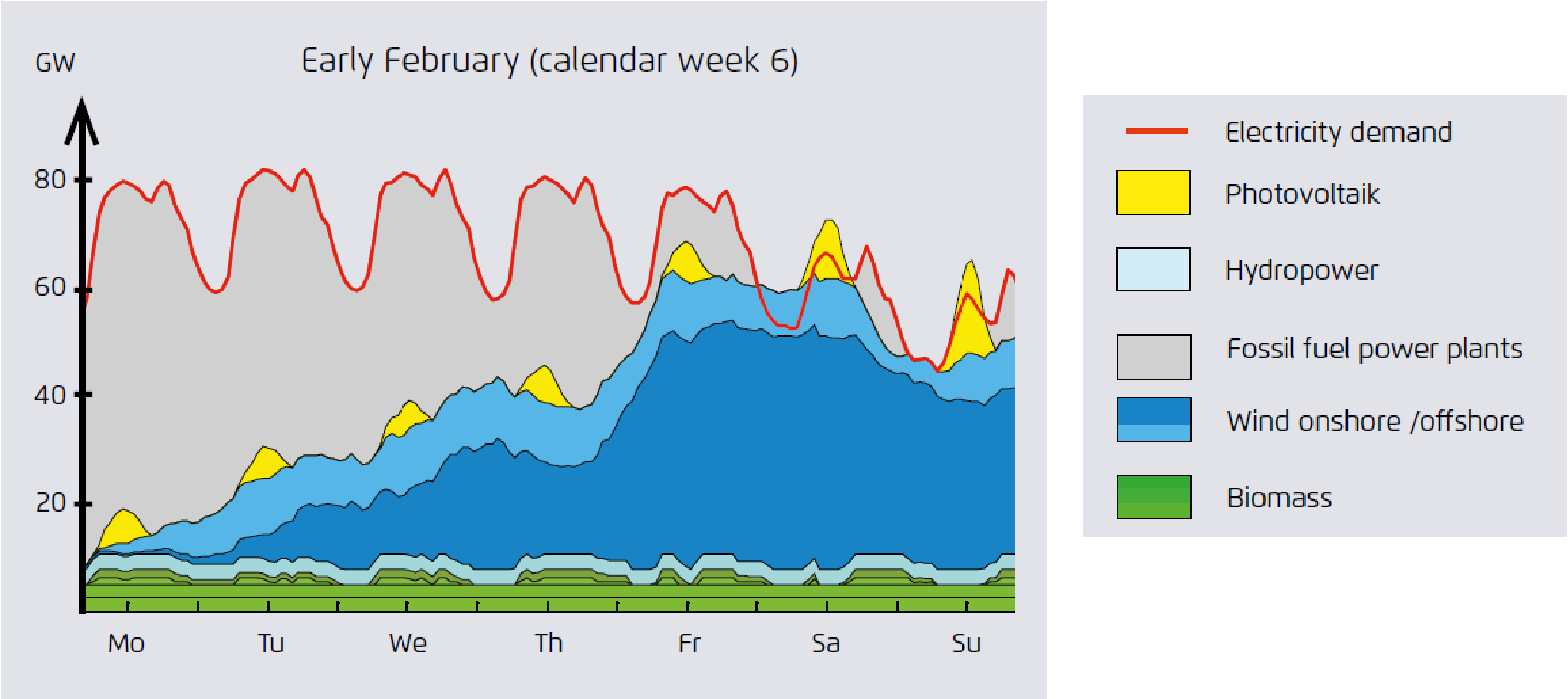
Many electricity markets will be determined by wind and solar PV

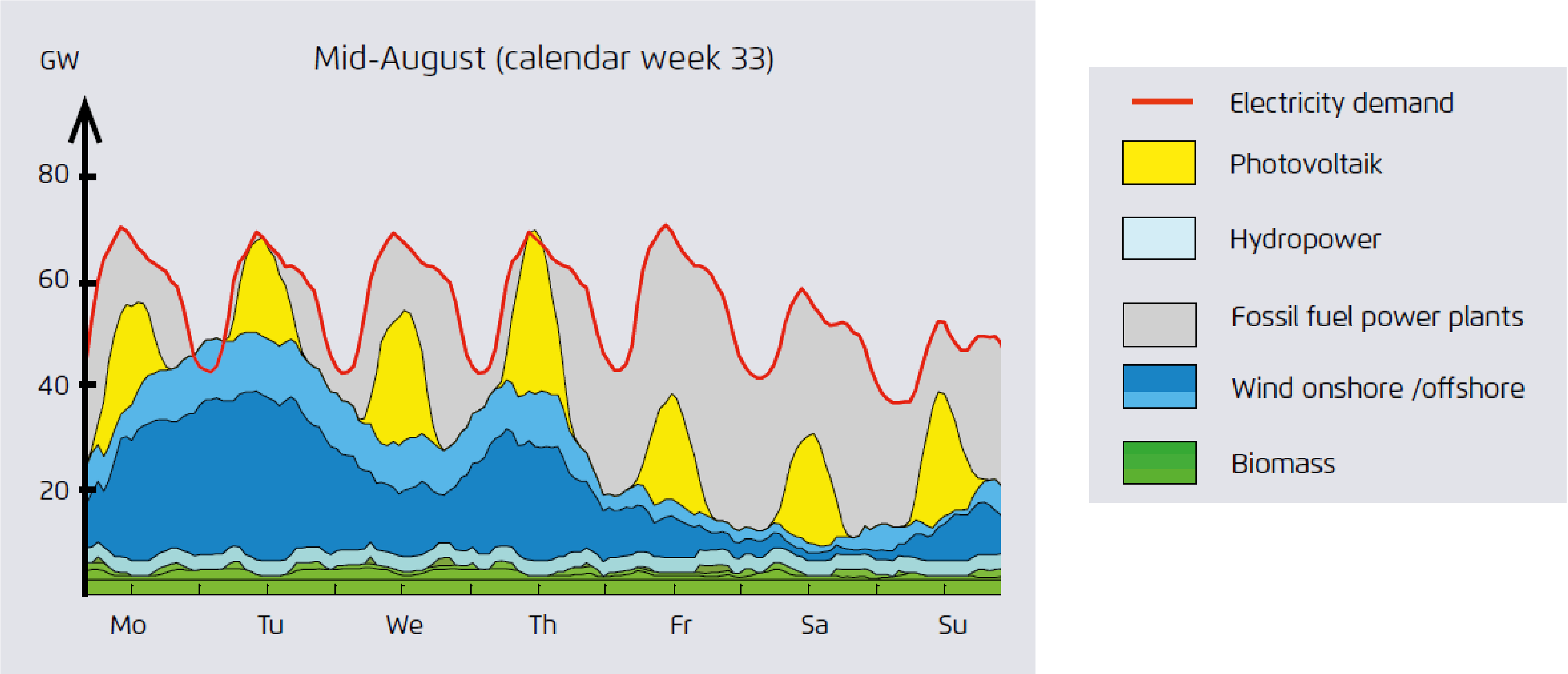
Electricity demand and renewable power generation in 2022



Source: Agora Energiewende 2012

Many electricity markets will be determined by wind and solar PV

Electricity demand and renewable power generation in 2022



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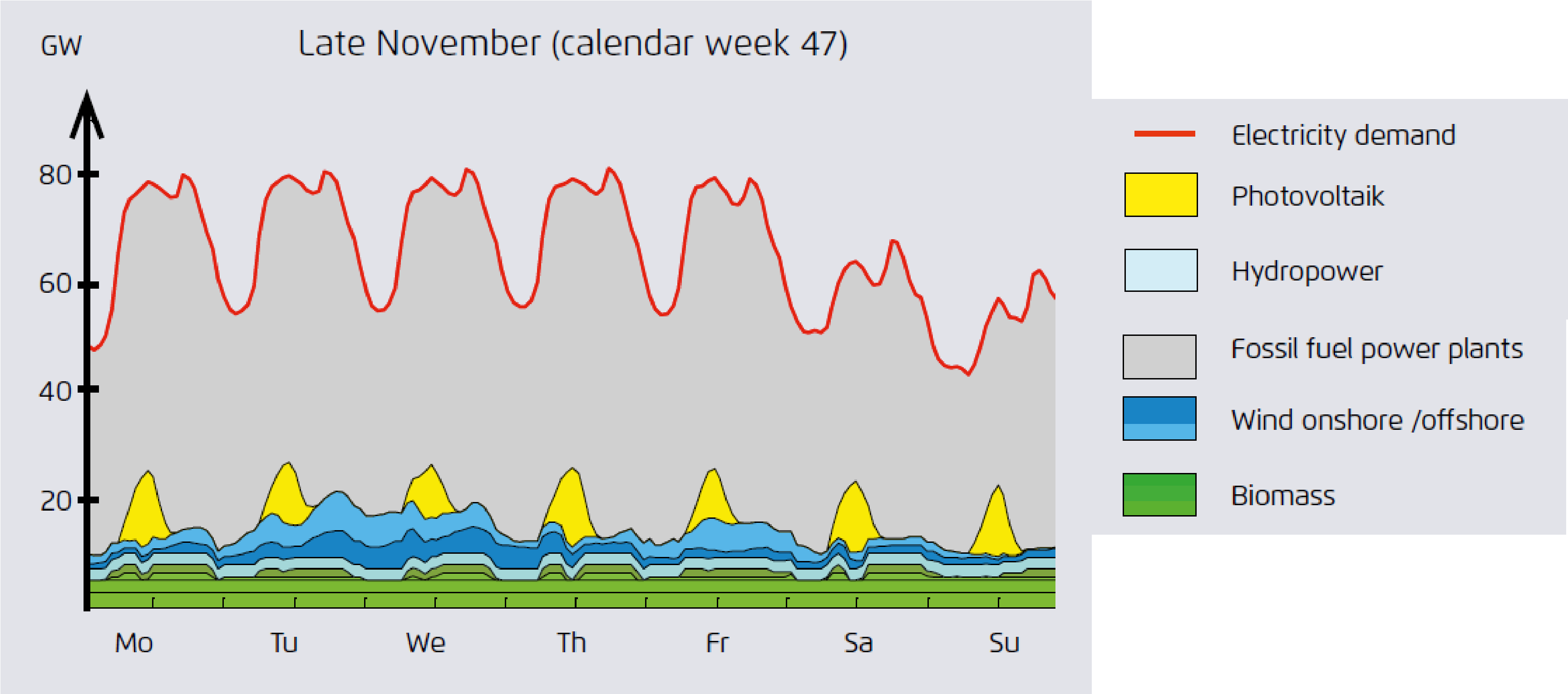
Electricity demand and renewable power generation in 2022

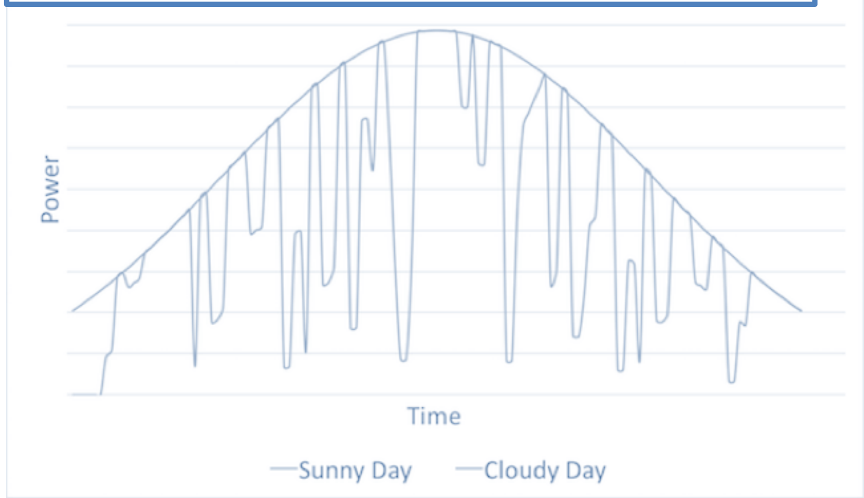


Source: Agora Energiewende 2012

Improved weather forecasting

- Weather forecasting systems have improved dramatically
    - Remaining problem: cloud casting

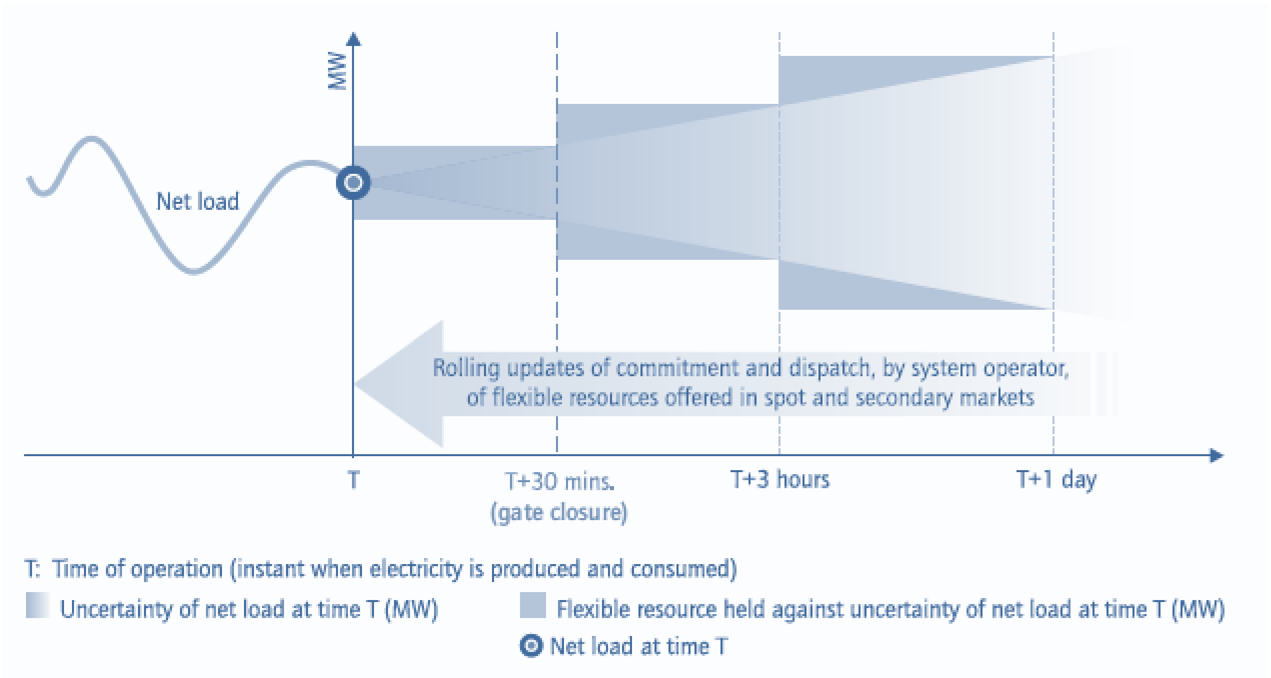
Solar output on a sunny and a cloudy day



Source: https://www.renewableenergyworld.com

PV friendly market design

- Gate-closure times in wholesale marked were move closer to the time of operation (15 minute before operation on intraday market).

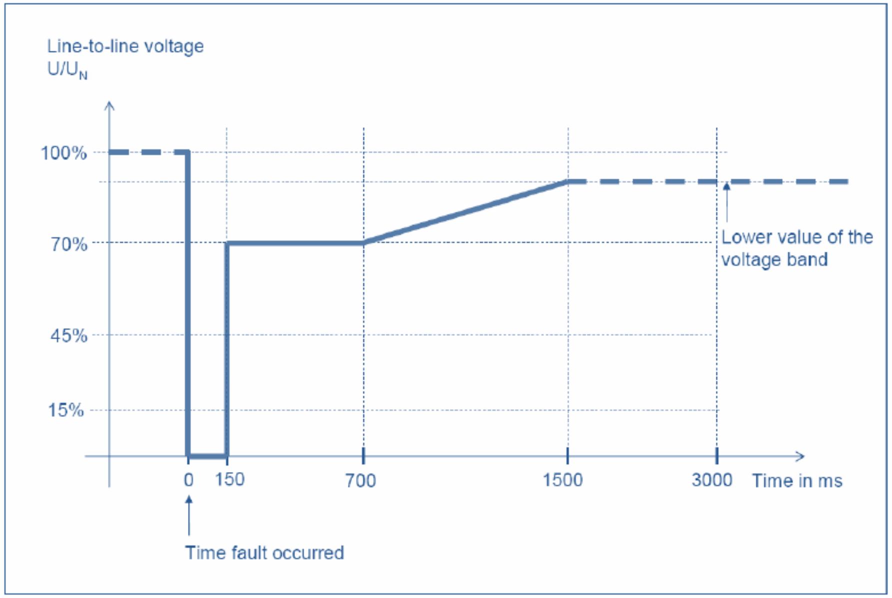


Source: IEA 2011

PV (inverters) can help to stablize the grid

- Grid Codes require PV to supply reactive power and support voltage dips (voltage ride-through capabilities)

- Allowing PV producers to participate in ancillary services markets (design might need to be modified: minimum bid size, time periods, etc.)



Source: Aryanezhad, M., et al. (2013).

Features of solar PV

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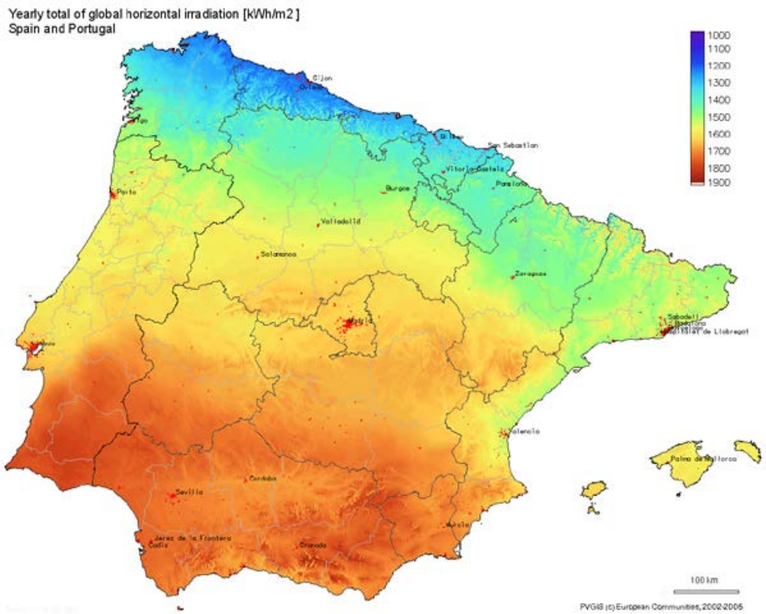
1. **low short-run cc** it can generate power at very littl

2. **Variability**, i.e. th ty of sunshine

3. **Uncertain**, i.e. th an only be predicted with high accurac



4. **Locational variations**, i.e. solar resources vary from one place to the next = grid expansion required

The expansion of the EU transmission grid

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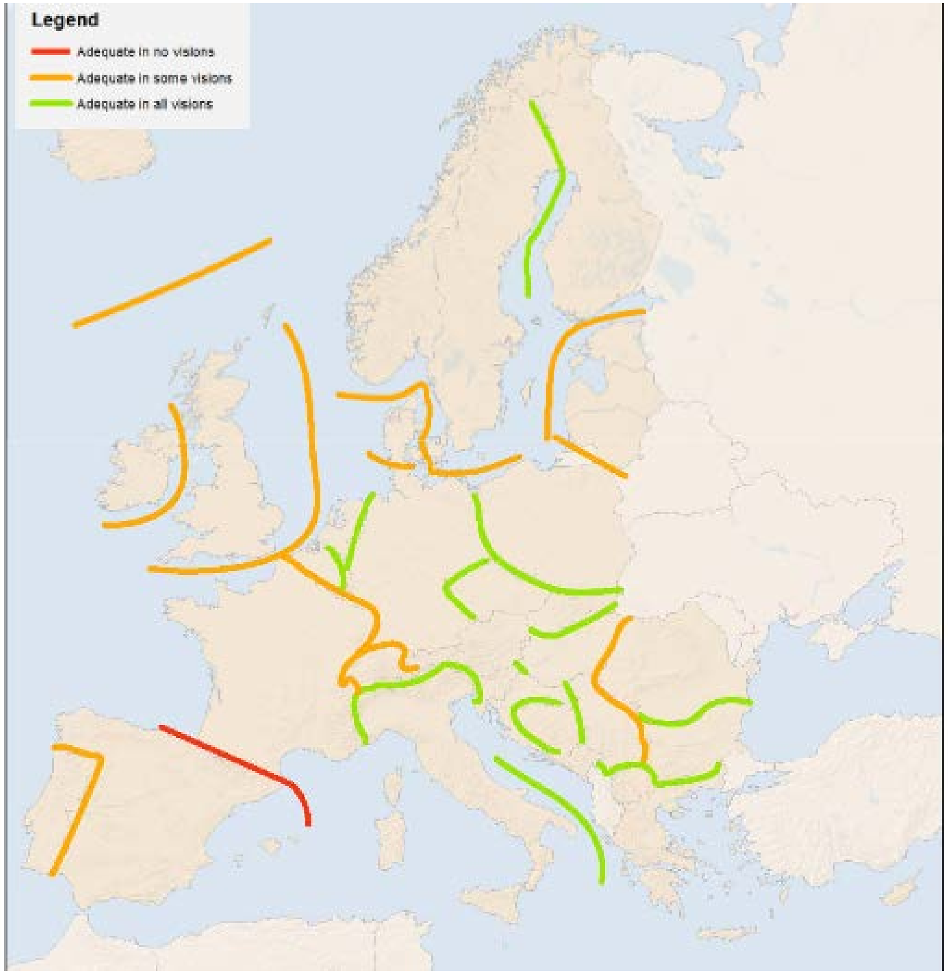
- Anticipate the future: 10-year network development plan from ENTSO-e
- Increasing interconnections: 10% by 2020; 15% by 2030
- Reducing bottlenecks: The latest report pinpoints about 100 spots
- Linking markets: Full market coupling with European neigbours (e.g. one merit order for Germany and Austria).



Source: ENTSO-e 2014

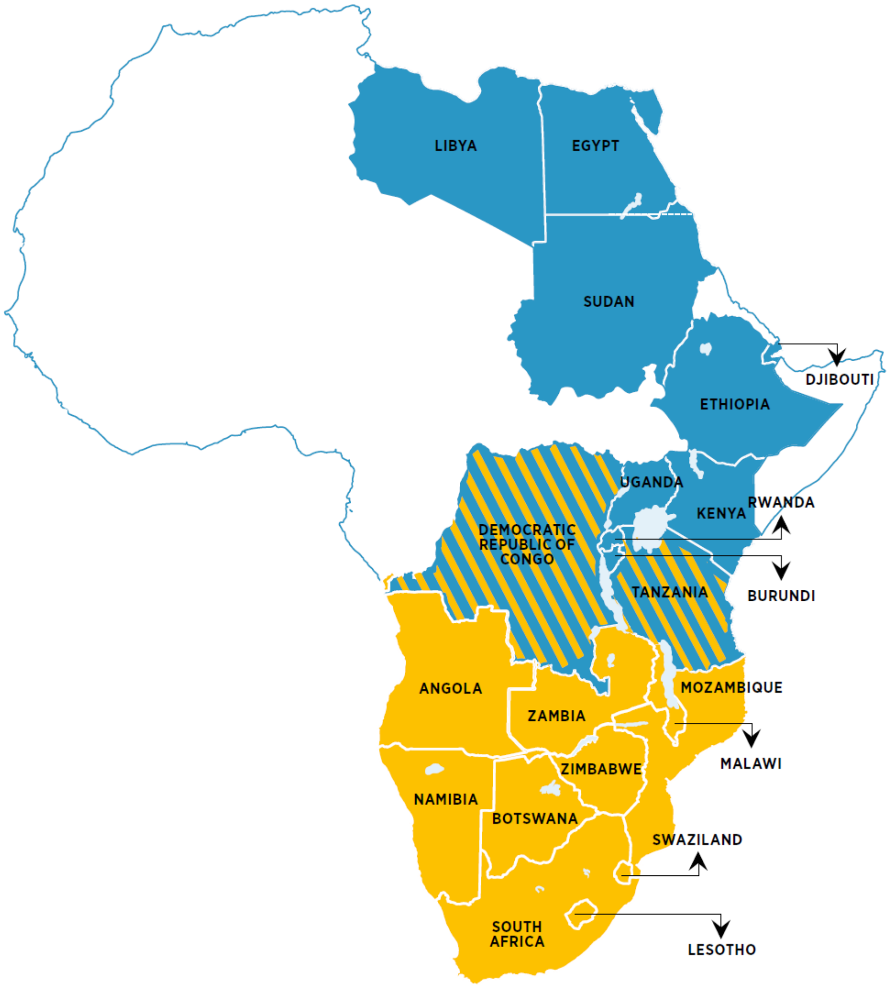
IRENA's Africa Clean Energy Corridor

African corridor countries

Eastern Africa Power Pool (EAPP)

Southern African Power Pool (SAPP)

The term "country" as used in this material also refers, as appropriate, to territories or areas



Source: http://www.irena.org/DocumentDownloads/Publications/ACEC_Africa%20Clean%20Energy%20Corridor_2015.pdf

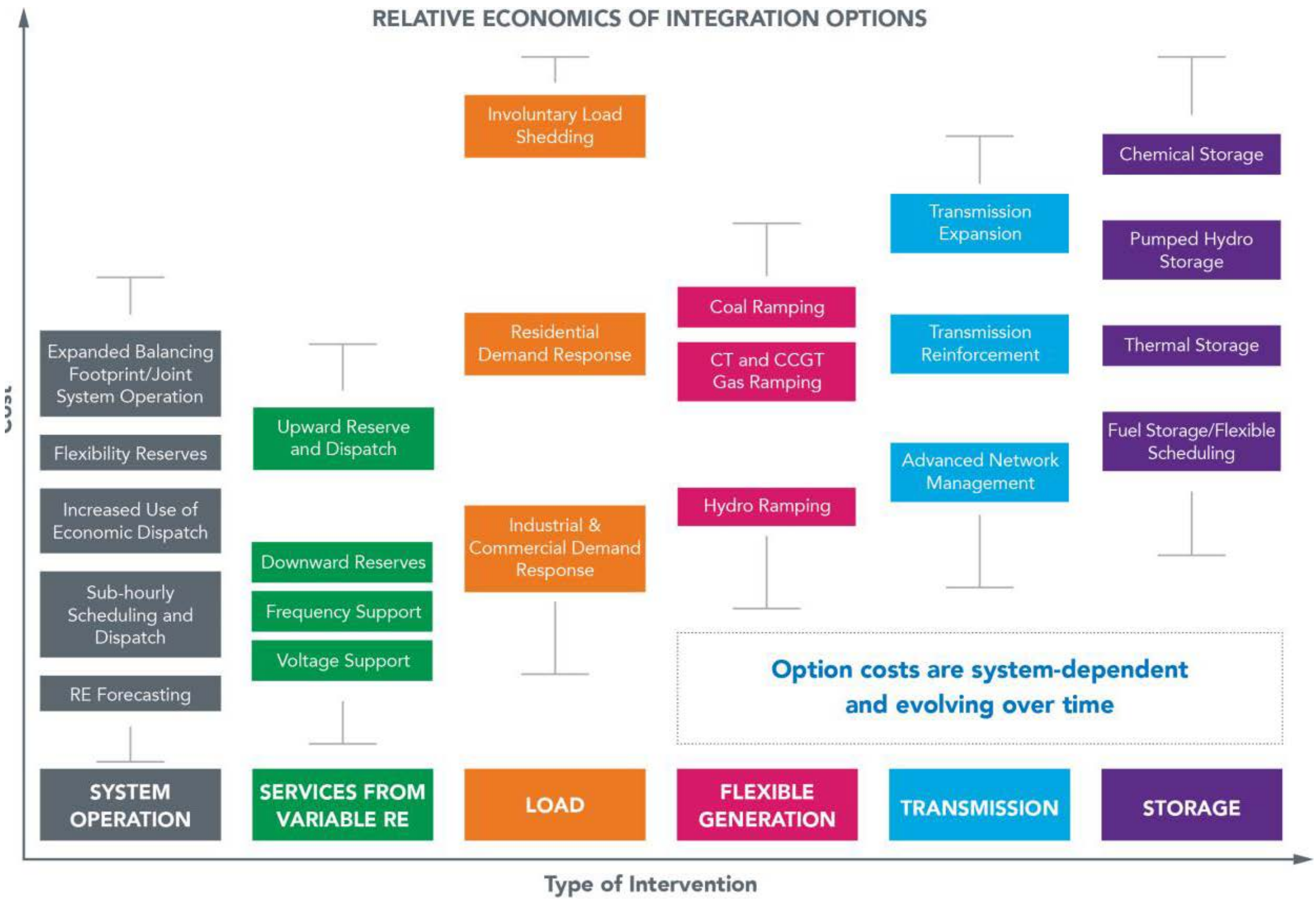
System Integration of Solar PV:

Options for Making the Power System more Flexible

Flexibility options for integrating high shares of wind and PV

1. Flexibility through grid expansion/interconnections
2. **Flexibility from conventional power plants**
3. **Flexibility from dispatchable RE technologies**
4. **Curtailment of RE**
5. **Flexible demand**
6. **Flexibility through storage**

Cost of Different RE Integration Options



Source: http://iea-retd.org/wp-content/uploads/2016/03/IEA-RETD_RE-TRANSITION.pdf

Flexibility options for integrating high shares of wind and PV

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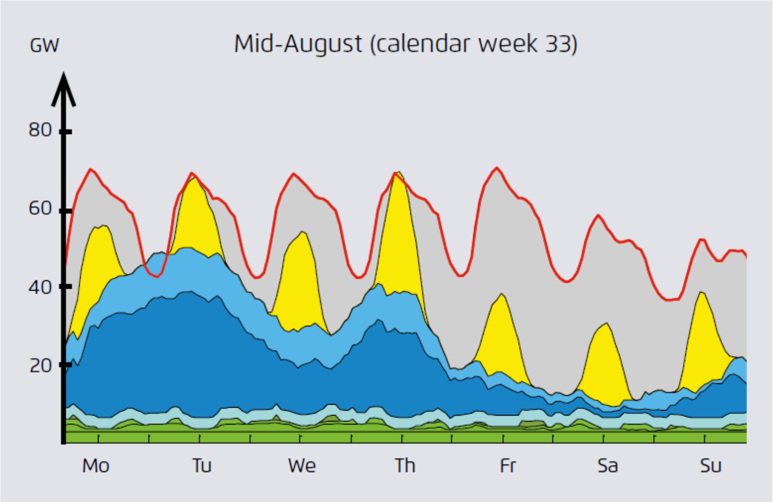
- Additional measures to optimally integrate rapidly increasing share of solar PV:

Check out Session 29 (The Duck Curve)

Conventional power plant need to become more flexible

- Base load power plants will disappear (fossil fuel power plants need to become more flexible)
- Reduce must-run requirements of conventional power plants
- Reduced full-load hours for coal and gas-fired power plants
- changing economics and additional revenue requirements via capacity markets?
    - Re-negotiate offtake agreements?

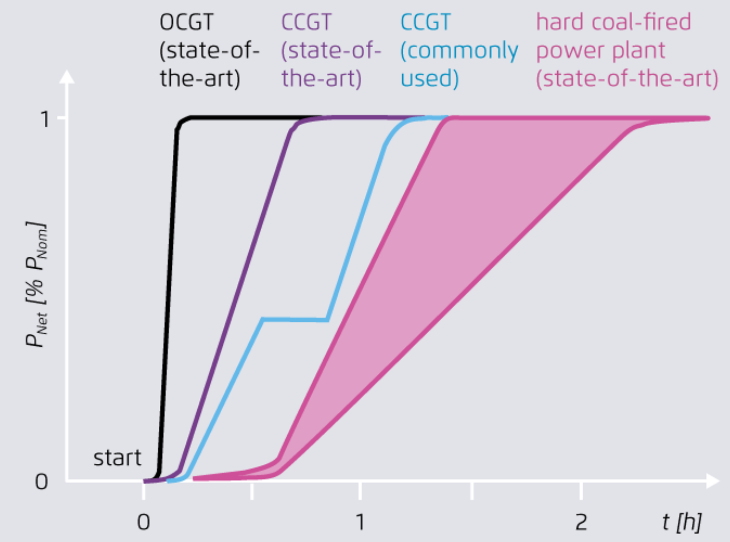


Source: Agora 2013

Conventional power plant need to become more flexible

- Increased ramping requirements and new ramping products
- Upgrade existing power plant in order to allow for better ramping capabilities (coal?, nuclear?)

Ramp rates and start-up times of different power plant technologies — Figure 19



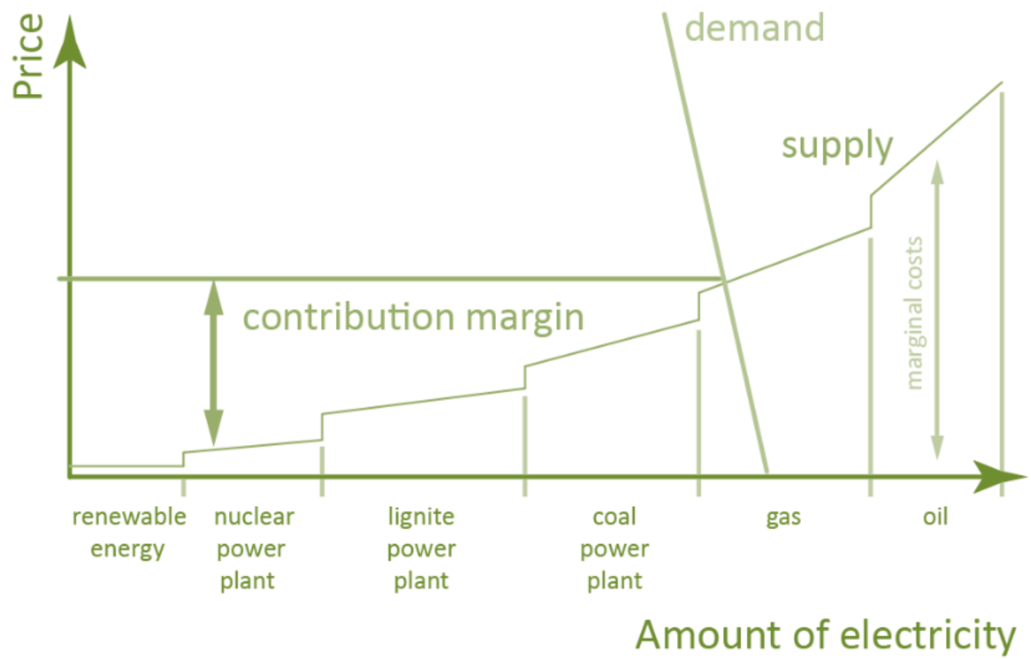
Fichtner (2016) based on VD, (2012)

Source: https://www.agora-energiewende.de/en/publications/a-word-on-flexibility/

Source: Milligan et al 2012 (NREL)

Moving from long-term PPAs to economic dispatch

- Inflexibility in many power markets stems from long-term contracts for gas- or coal-fired power producers
- Economic Dispatch: Power plants are dispatched according to their short-term marginal costs (fuel costs and CO2 costs)
- Wind and solar are only dispatched at times of negative prices on the spot market



Flexibility from dispatchable renewables

- Increased ramping requirements (e.g. hydro)
- Modified finance mechanism for dispatchable renewables (biomass):
- Reasoning: reduce operating hours of biogas plants and use them as back-up for wind and solar PV (biogas plus storage)

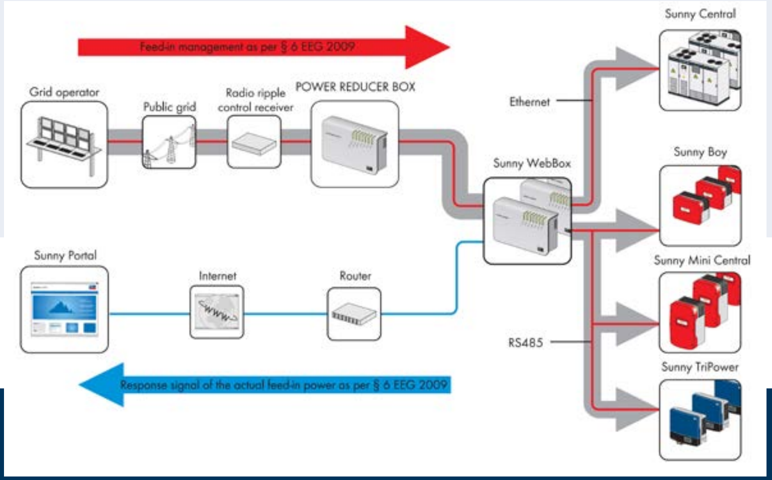
Source: https://www.suezwaterhandbook.com/degremont-R-technologies/sludge-treatment/digestion/digestion-with-integrated-biogas-storage-Digelis-Smart

Adopting new curtailment rules

- Curtainling RE producers in times of grid congestions
- Remote-controlled power plants
- Curtailing maximum output of RE producers (70% of PV nameplate capacity in Germany)
- (Full) compensation of RE producers?

Adopting new curtailment rules

Option 1:	Option 2:
Fixed curtailment of peak PV output	**Remote controlled operation via system operator**
• cap the maximum output of PV systems at a certain percentage of the nameplate peak capacity	• Remote control via ripple control receivers
• In Germany, PV output of such systems is capped at 70%	• can send signals to reduce the amount of electricity fed into the grid in 10% increments
• This regulation reduces the annual cumulative power generation of a PV system by about 1%	



Demand response – Examples of flexible load

- Lower hanging fruits: Flexibility of industrial consumers

INCENTIVE MECHANISMS FOR FLEXIBLE LOADS ON DAY-AHEAD AND INTRADAY MARKETS

Type	Incentives via
Load shifting	Regular price spreads (e.g. > EUR 50/MWh)
Load shedding	Occasional, very high prices (e.g. > EUR 1,000/MWh)
Load increase	Regular low prices (e.g. < EUR 10/MWh)

Source: IASS Potsdam on the basis of Gobmaier and von Roon 2010

Storage technologies can facilitate RE integration in various ways

1. Load shifting
2. Frequency response
3. Reduce grid congestions
4. Reduce RE curtailment
5. Ramping

Check out Session 30 (PV and Storage)

Source: IEA-RETD RE-STORAGE 2015

Summary

Summary of Key Findings

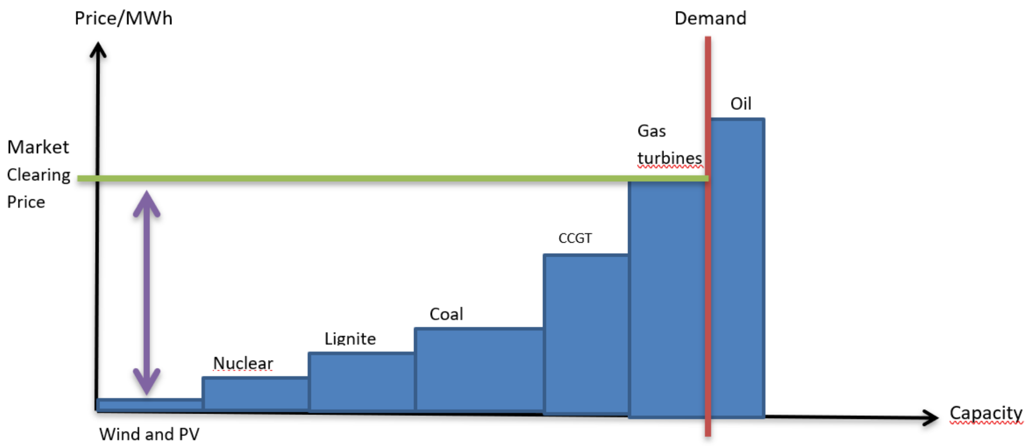
- The deployment of solar PV triggers important benefits for the electricity system
- Increasing shares of solar PV increase the need for flexible power systems
- There are numerous flexibility options, including grid expansion, flexible (dispatchable) power plants, flexibility from wind and PV, demand response and storage.
- Each region/countries needs to analyze and compare the costs of various flexibility options

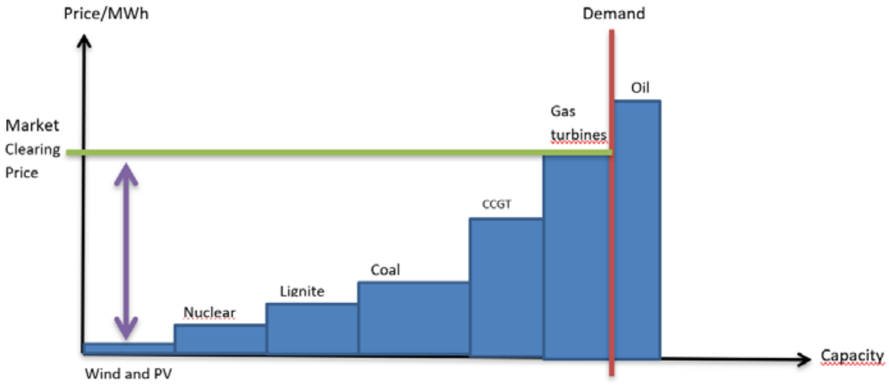
Outlook:

Solar PV and the Merit Order Effect (Session 28).

Solar PV and the Merit Order Effect

- Solar PV reduces the wholesale market price





Further Reading/List of References

List of References and Further Reading

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Thank you for your time!

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Factor
Ideas for change

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6. Knowledge Checkpoint: Multiple Choice Questions