International Solar Alliance Expert Training Course

In partnership with the Clean Energy Solutions Center (CESC)

Dr. David Jacobs

Session 30: Solar PV and Storage

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International Energy Transition

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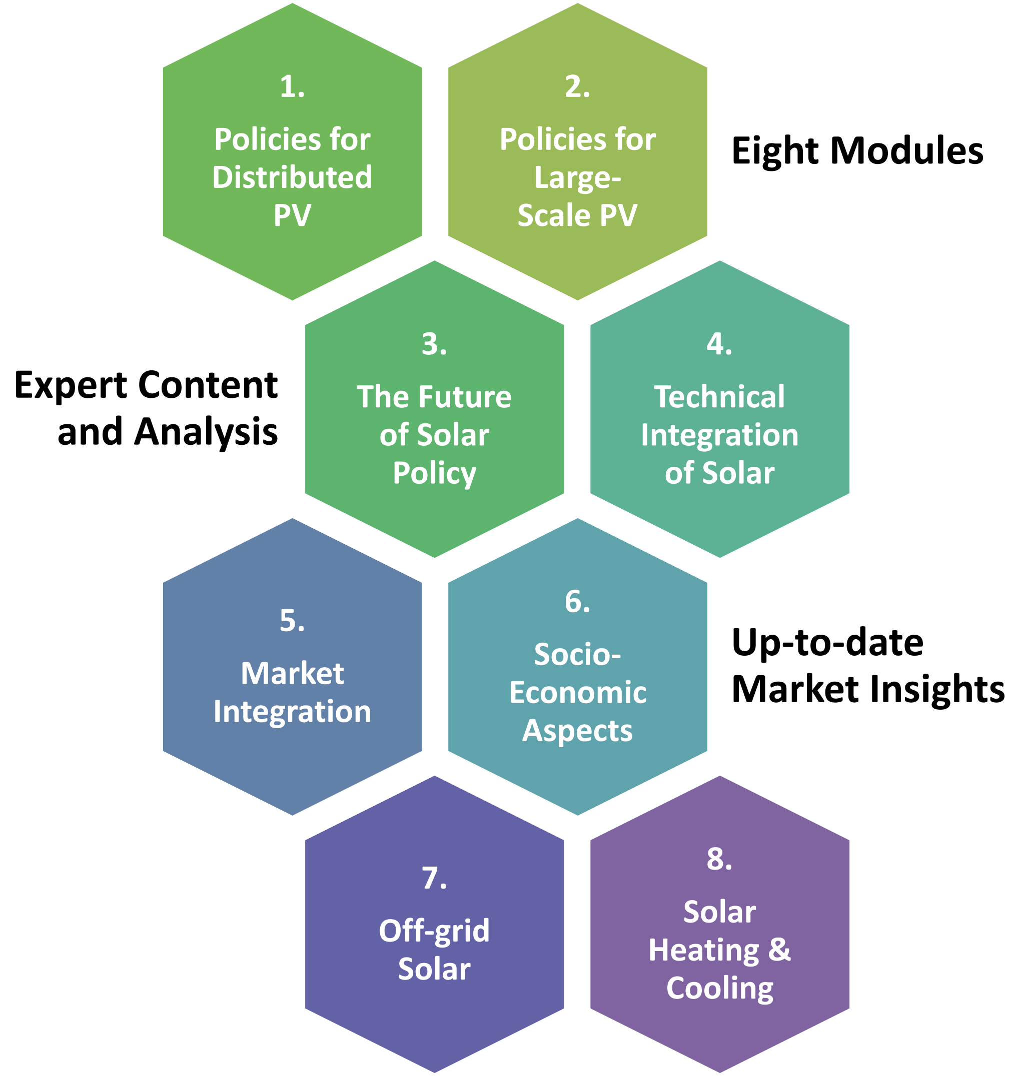
IET – International Energy Transition GmbH

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

This Training is part of Module 5, and focuses on solar PV market integration



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

- ✓ Session 3-9 (distributed solar).
- ✓ Session 10-13 (large-scale solar)
- ✓ Session 14-18 (future policies)

Overview of the Training Session

1. Introduction: Learning Objective

2. Understanding the application of storage in electricity systems and the use of solar+storage

3. Further Reading

4. Knowledge Check: Multiple-Choice Questions

Introduction:

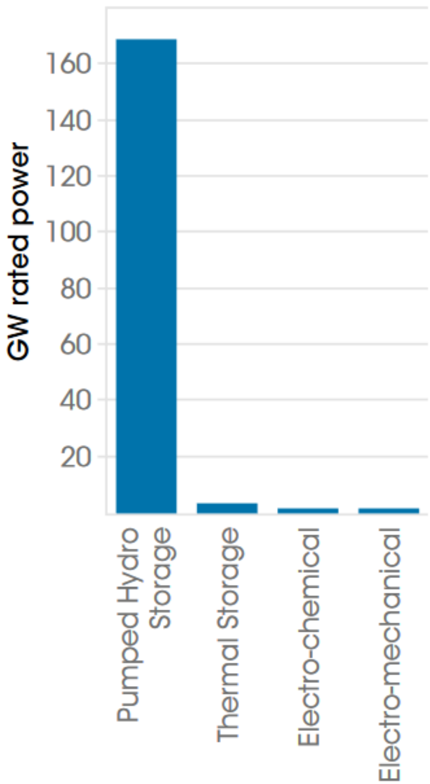
Learning Objective

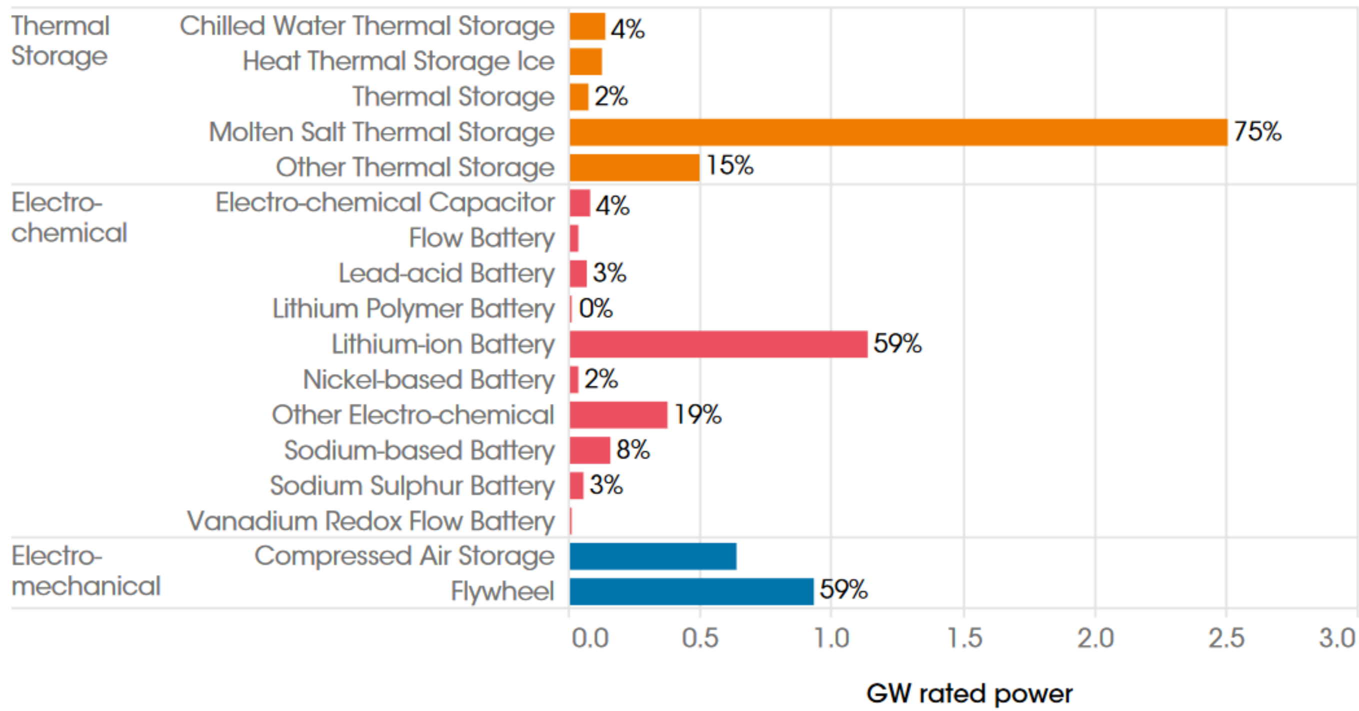
Learning Objective

- Understand the services that storage technologies can provide to power systems.
- Understand the effects and benefits of combining (residential) solar PV system with battery storage.
- Learn about market trends of lead-acid and lithium-ion storage technologies.
- Understand the recycling challenge related to an increasing roll-out of electro-chemical storage technologies.

Storage and Services for the Energy System

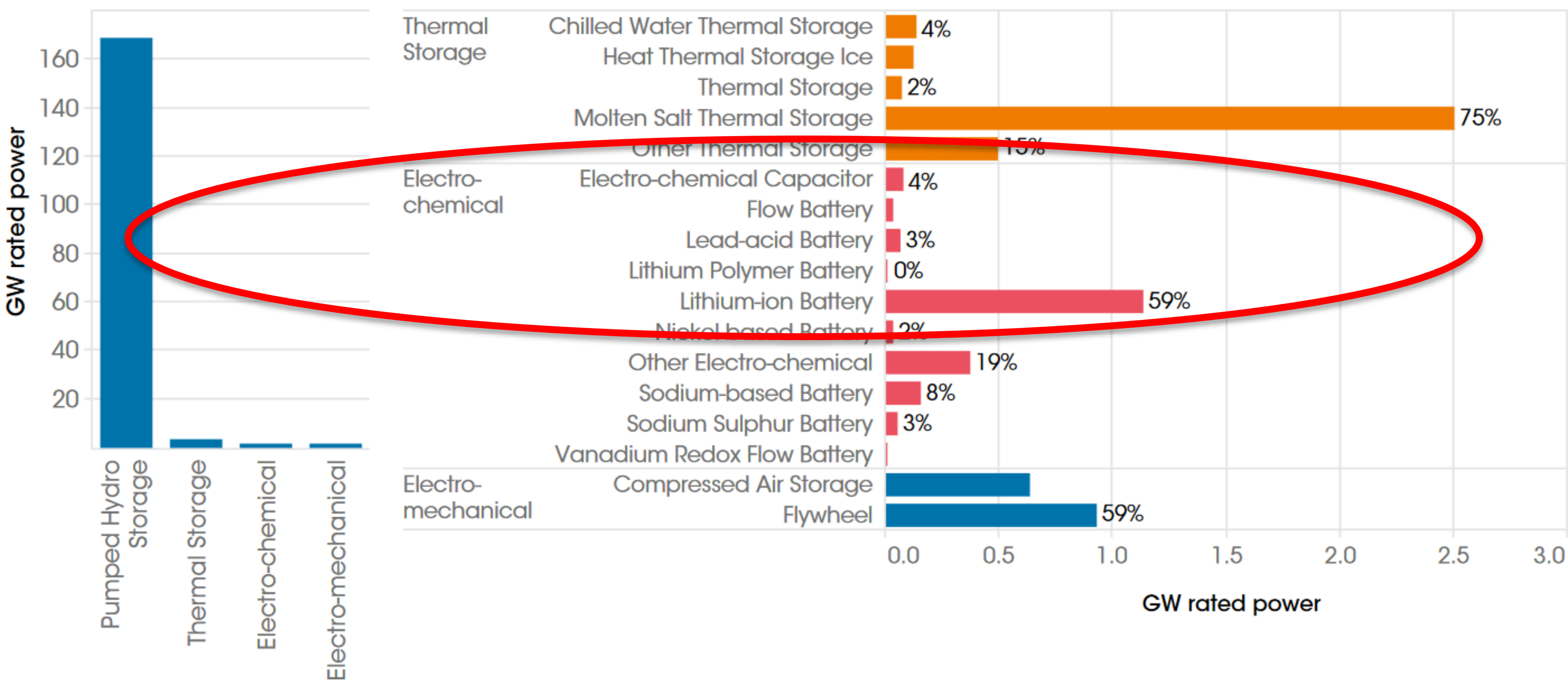
Global Operation Electricity Storage





Source: IRENA (2017), Storage report

Global Operation Electricity Storage



Source: IRENA (2017), Storage report

Storage: Understanding the Bucket

International Energy Transition

- Storage = A bucket that moves energy from one time period to another
- When to use the bucket:
  - When to fill the bucket
  - When to empty the bucket
- Features of the bucket/storage unit:
  - How fast can the bucket be filled or emptied?
  - How much does the bucket cost?
  - How big of a bucket to buy?
  - How long will the bucket last?
  - Will using the bucket in a certain way cause it to fail faster?
- The value of the energy must be worth more at the time you empty the bucket than it was at the time you filled the bucket

Source: IET based on Elgqvist (2017)

Range of Services Provided by Storage in Power Systems

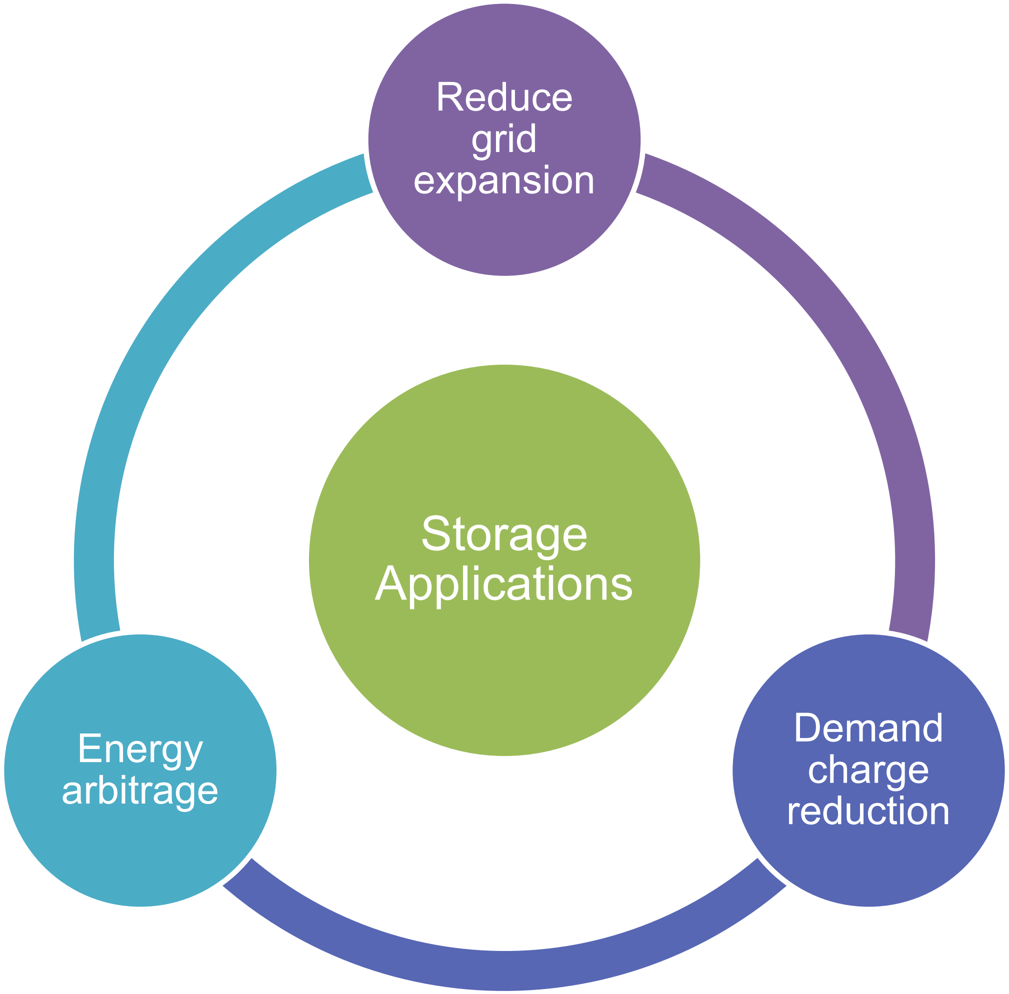
International Energy Transition

Bulk energy services	Ancillary services	Transmission infrastructure services	Distribution infrastructure services	Customer energy management services	Off-grid	Transport sector
Electric energy time shift (arbitrage)	Regulation	Transmission upgrade deferral	Distribution upgrade deferral	Power quality	Solar home systems	Electric 2/3 wheelers, buses, cars and commercial vehicles
Electric supply capacity	Spinning, non-spinning and supplemental reserves	Transmission congestion relief	Voltage support	Power rellability	Mini-grids: System stability services	
	Voltage support			Retail electric energy time shift	Mini-grids: Facilitating high share of VRE	
	Black start			Demand charge management		
				Increased self-consumption of solar PV		

Boxes in red: Energy storage services directly supporting the integration of variable renewable energy

Source: IRENA (2017), Storage report

Storage Applications (Selection)



Source: IET

Storage Requirements and the Share of PV

International Energy Transition

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

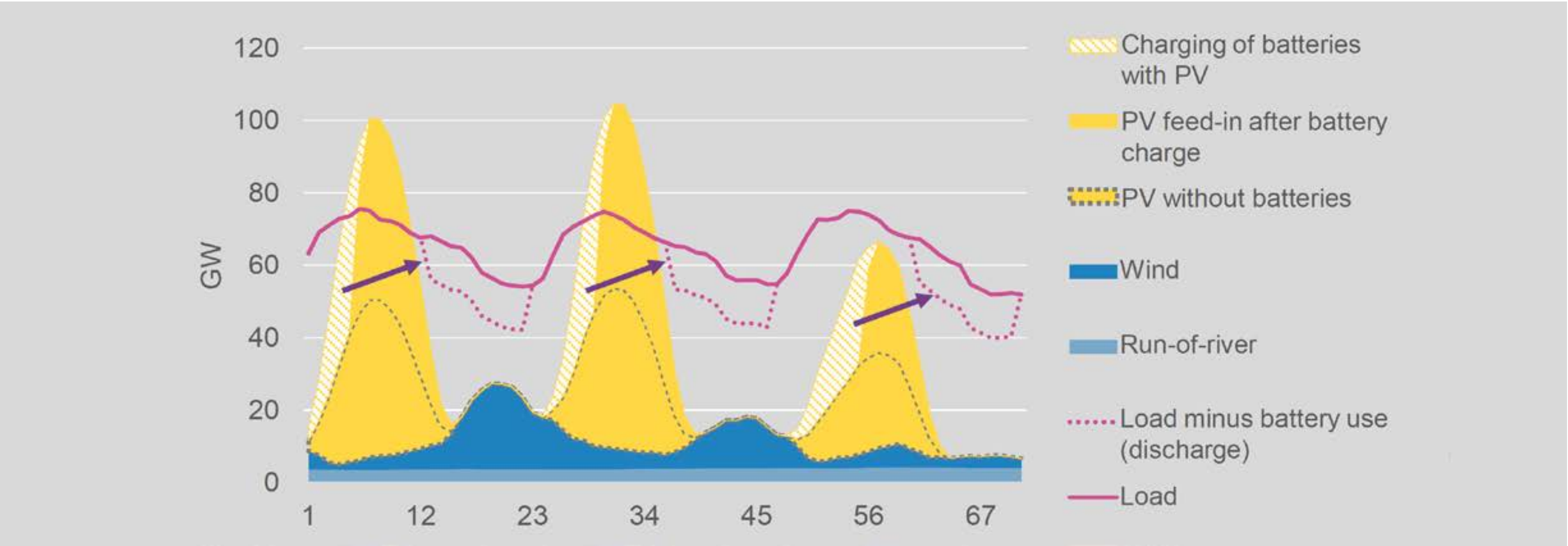
Storage Requirements and the Share of PV

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

Check out Session 27 (System Integration)

Storage Requirements and the Share of PV

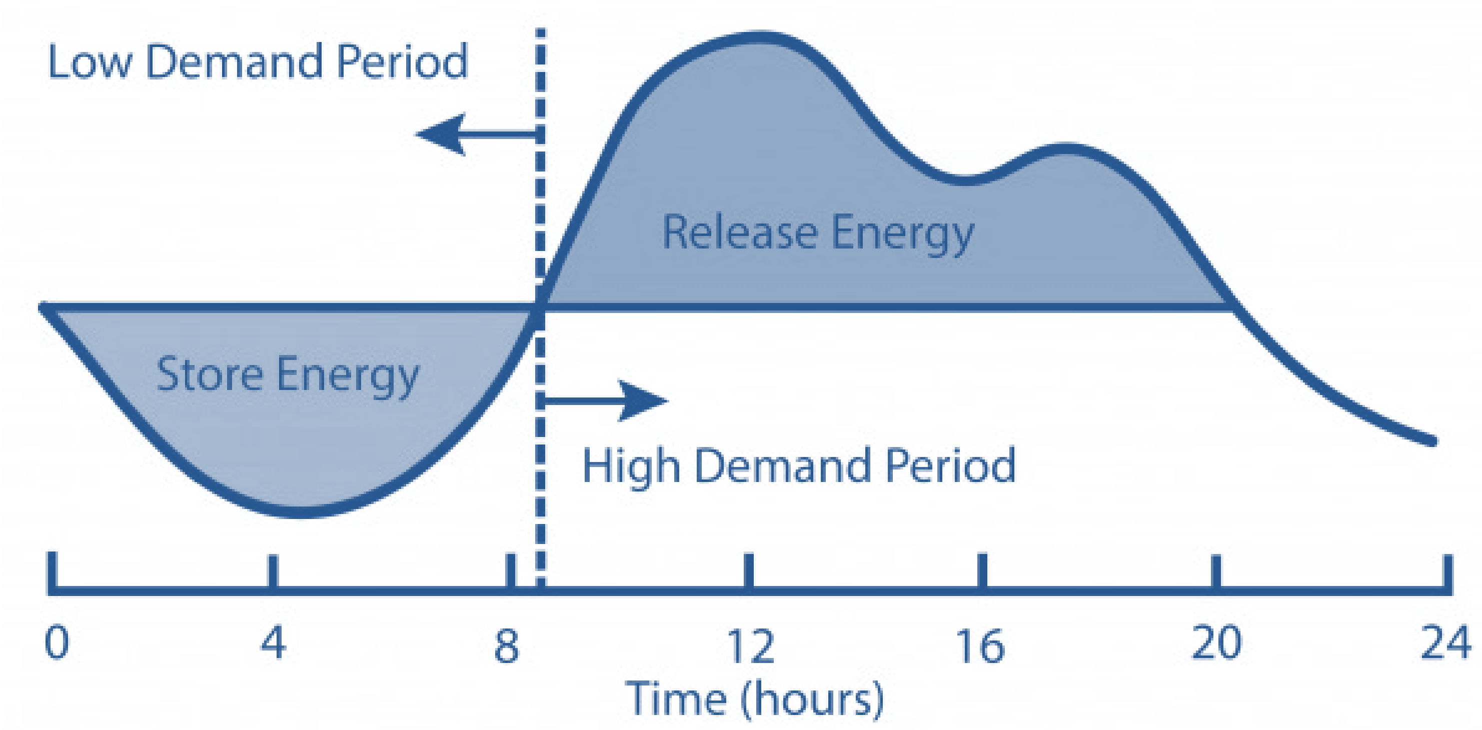
- System perspective: Several studies have shown that battery storage will only be required for RE shares higher that 80% (RE generation far exceeding demand)!
- Individual perspective: probably earlier!



Source: (Deutsch and Graichen 2015)

Energy Arbitrage

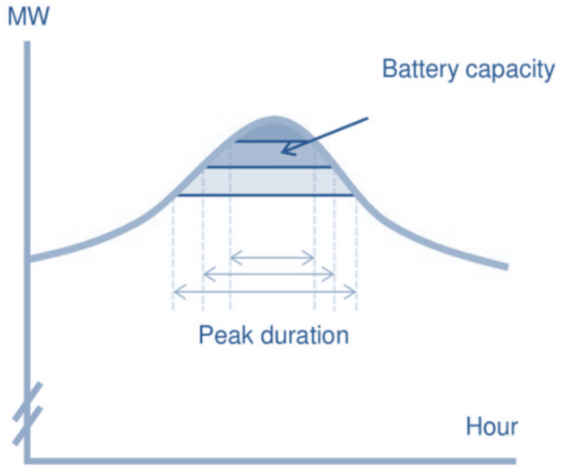
- Shifting kWh from low demand periods to high demand periods

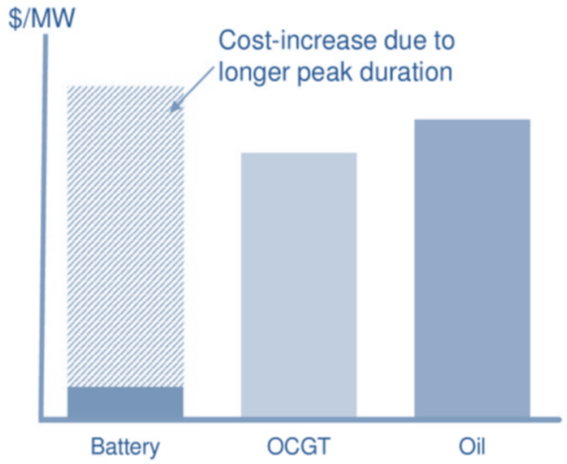


Source: http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

Meeting Peak Demand in Power Systems

- Grid services (ramping, balancing market, frequency control)
- Meeting peak demand
- Shift PV generation to peak demand in evening hours?
- Operating PV systems like coal fired power plants (not a good idea…)



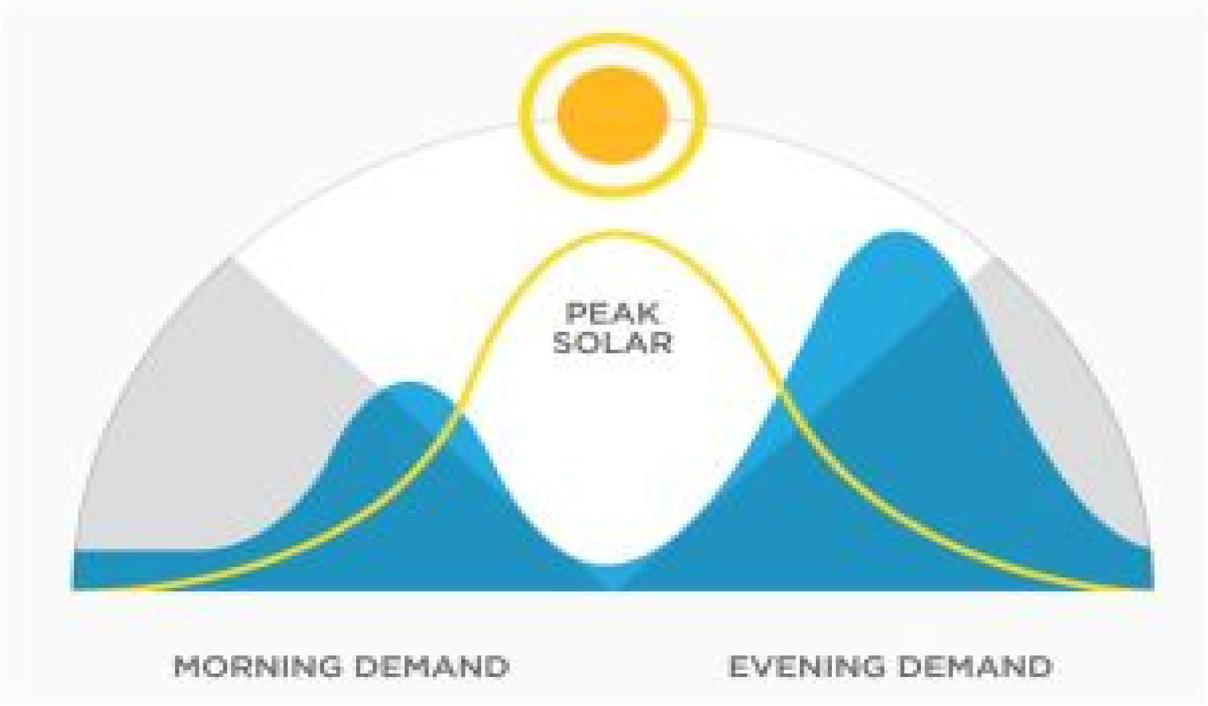


Source: Bloomberg New Energy Finance

Source: (BNEF 2018)

Meeting Peak Demand in Power Systems

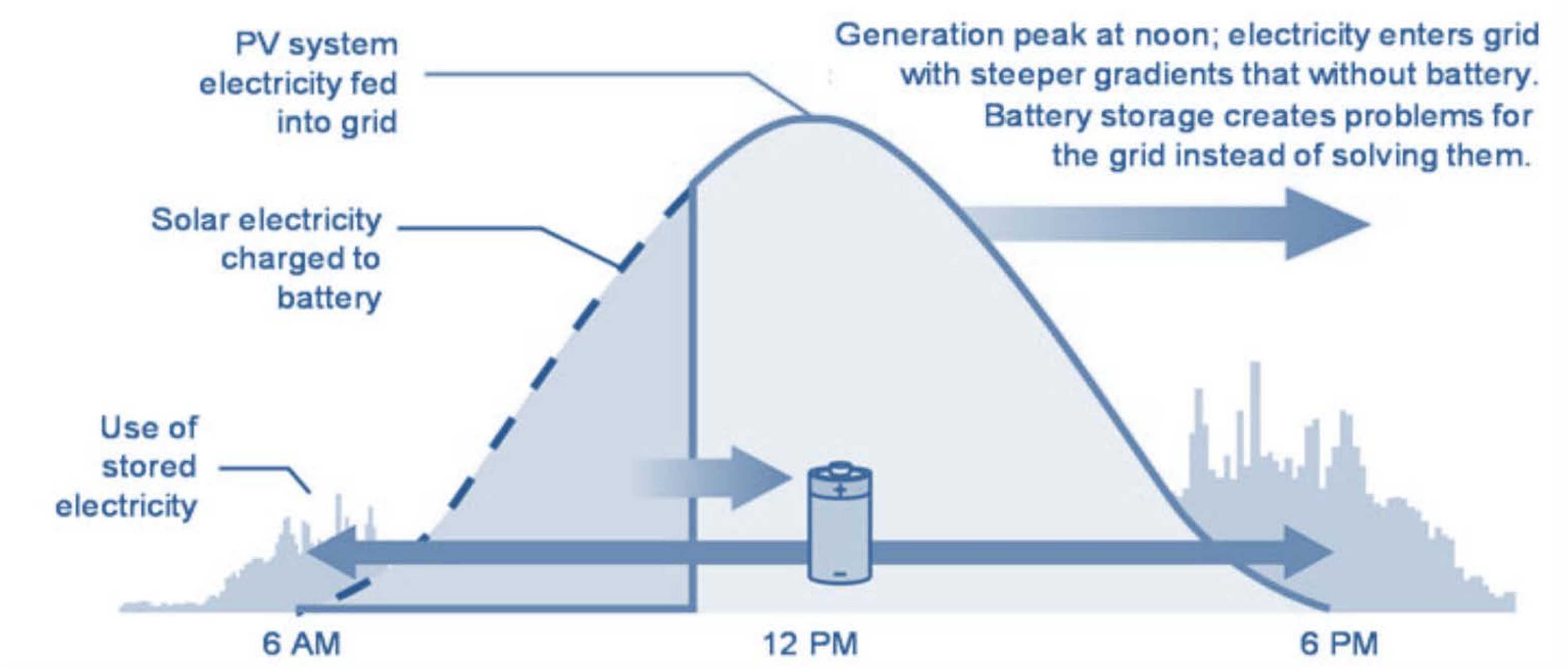
- Shift PV generation to peak demand in evening hours?



Source: (https://earthbound.report/2018/10/10/why-it-pays-to-reduce-energy-demand-at-peak-times/)

Storage can smoothen the profile of PV influx

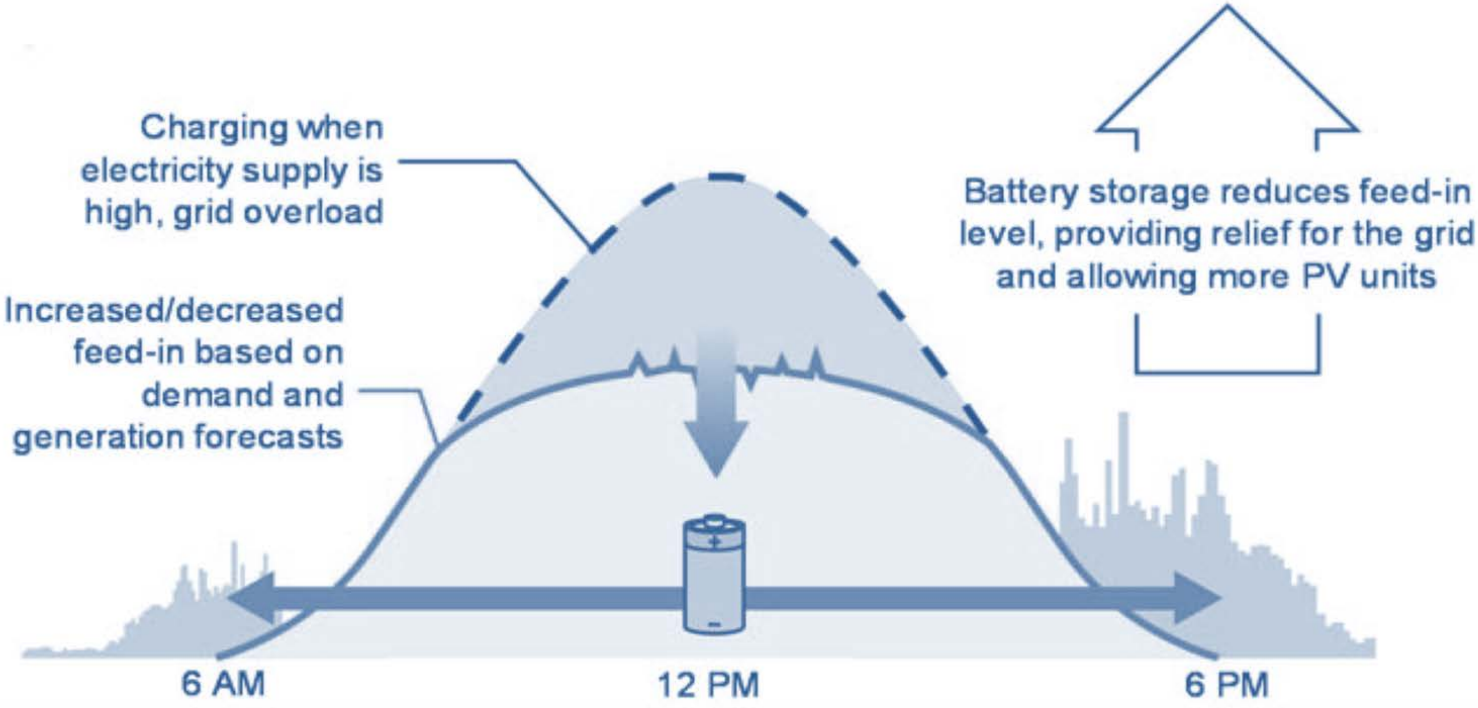
- Example of system unfriendly charging and discharging of batteries



Source: (Weniger, Bergner et al. 2015) (Deutsch and Graichen 2015, Sterner, Eckert et al. 2015)

Storage can smoothen the profile of PV influx

- Forecast-based charge and discharge of distributed battery storage to increase system stability and reduce grid expansion



Source: (Weniger, Bergner et al. 2015) (Deutsch and Graichen 2015, Sterner, Eckert et al. 2015)

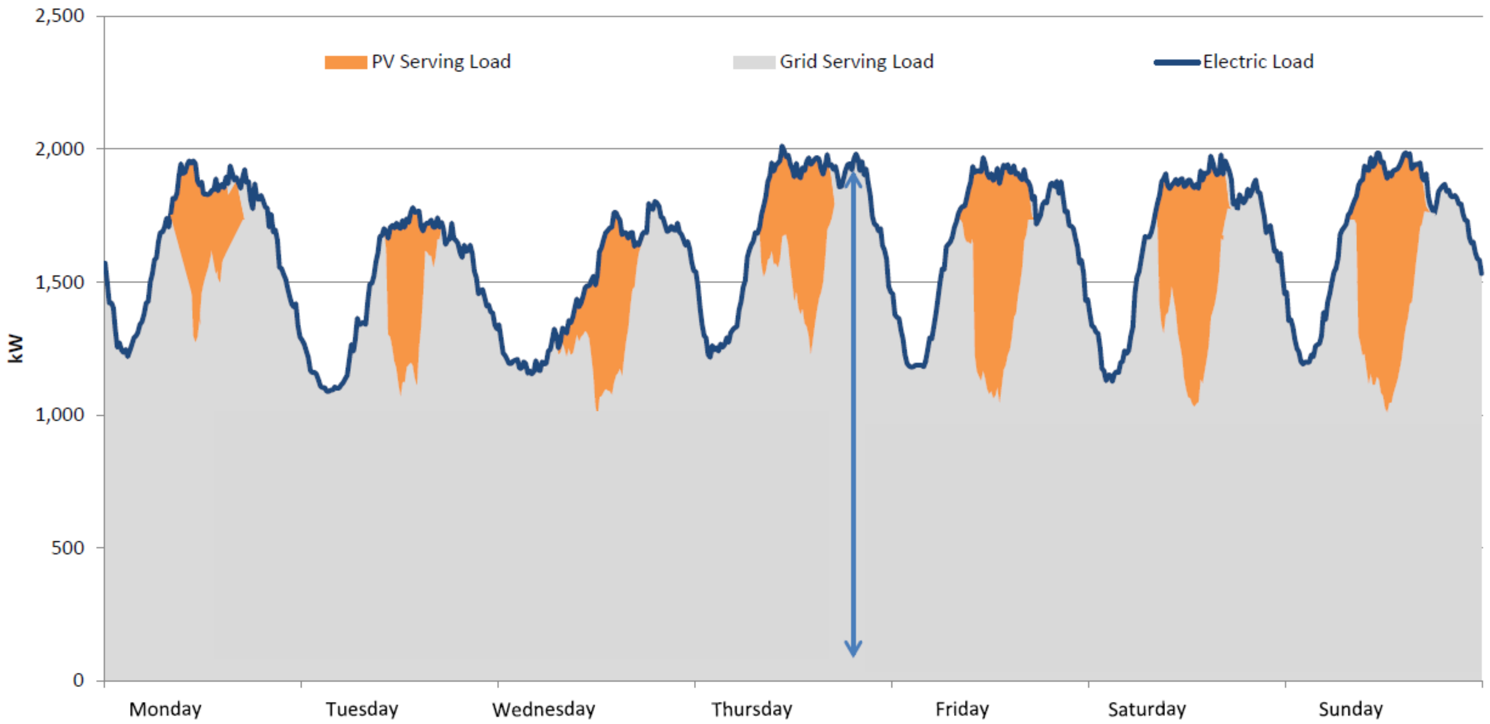
Reduced Demand Charges – Recap of rate design options

Traditional rates	Smart rates
• Volumetric Charges	• Time-of-Use
• Fixed Charges	• Critical Peak Pricing
• Minimum bills	• Real-Time Pricing
• Demand Charges	• Locational Pricing
Can be implemented based on **existing meter technologies**	Require **advanced metering infrastructure (AMI)**

Source: IET based on Cross-Call, D., et al. (2018), Linvill 2014

Reduced Demand Charges

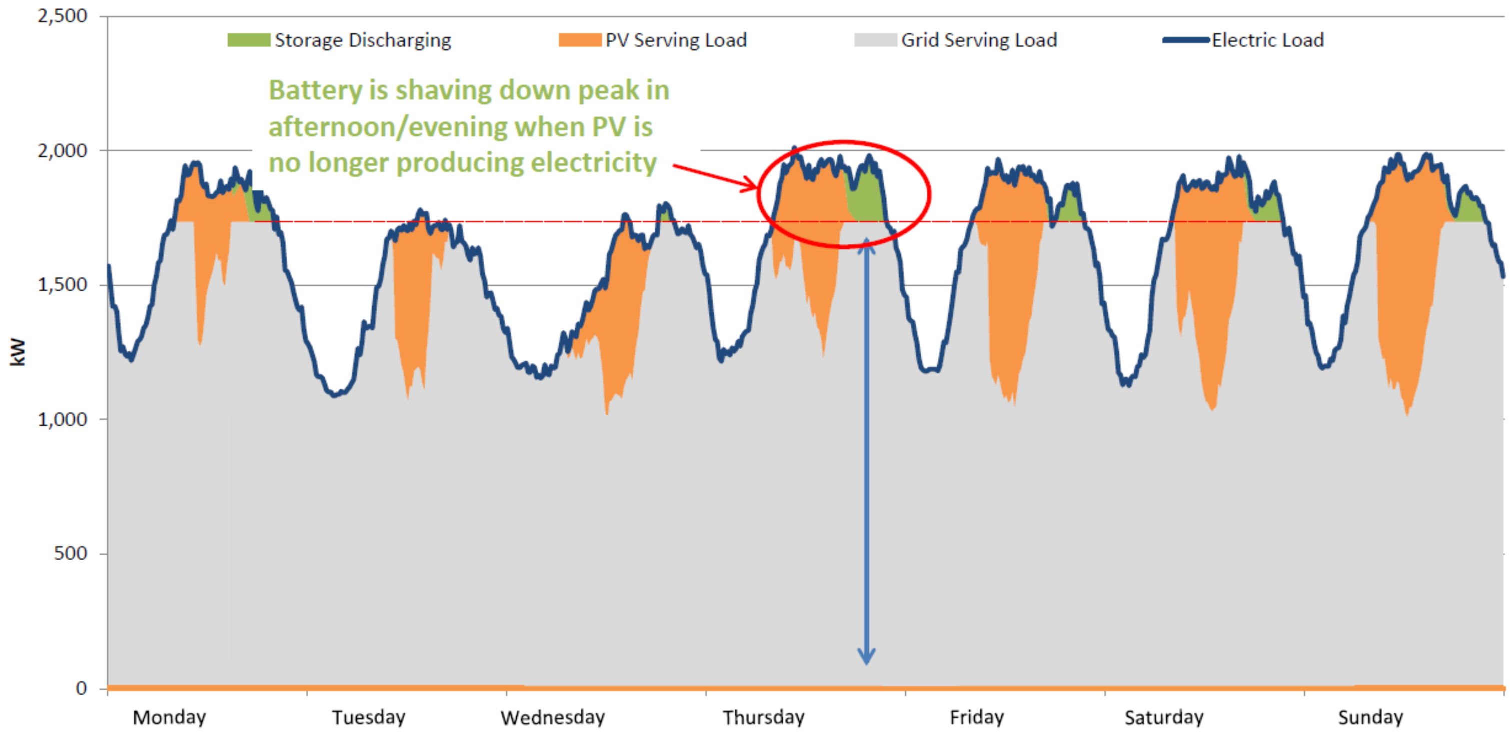
- PV alone sometime cannot help to reduce demand and thus demand charges



Source: Elgqvist (2017)

Reduced Demand Charges

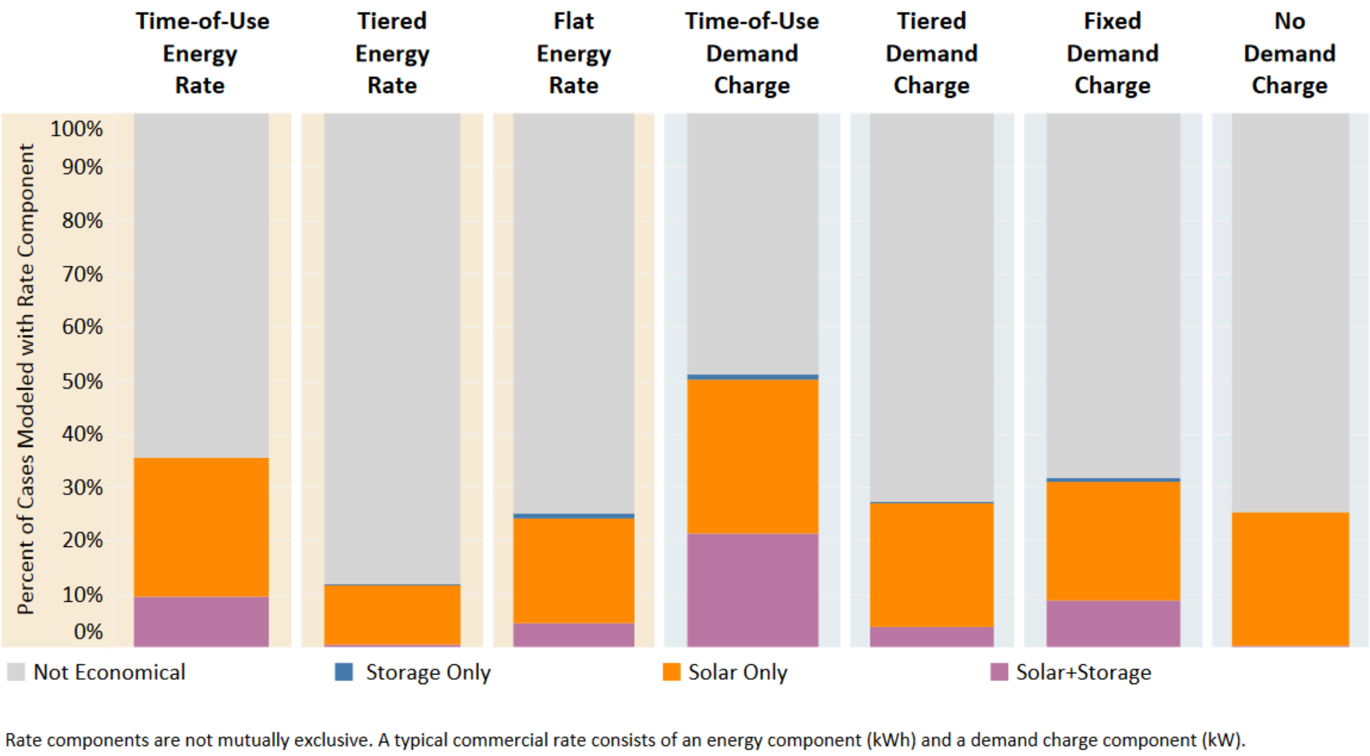
- PV+Battery combinations can more easily help to reduce demand charges



Source: Elgqvist (2017)

Rate Design and the Economics of Battery Storage

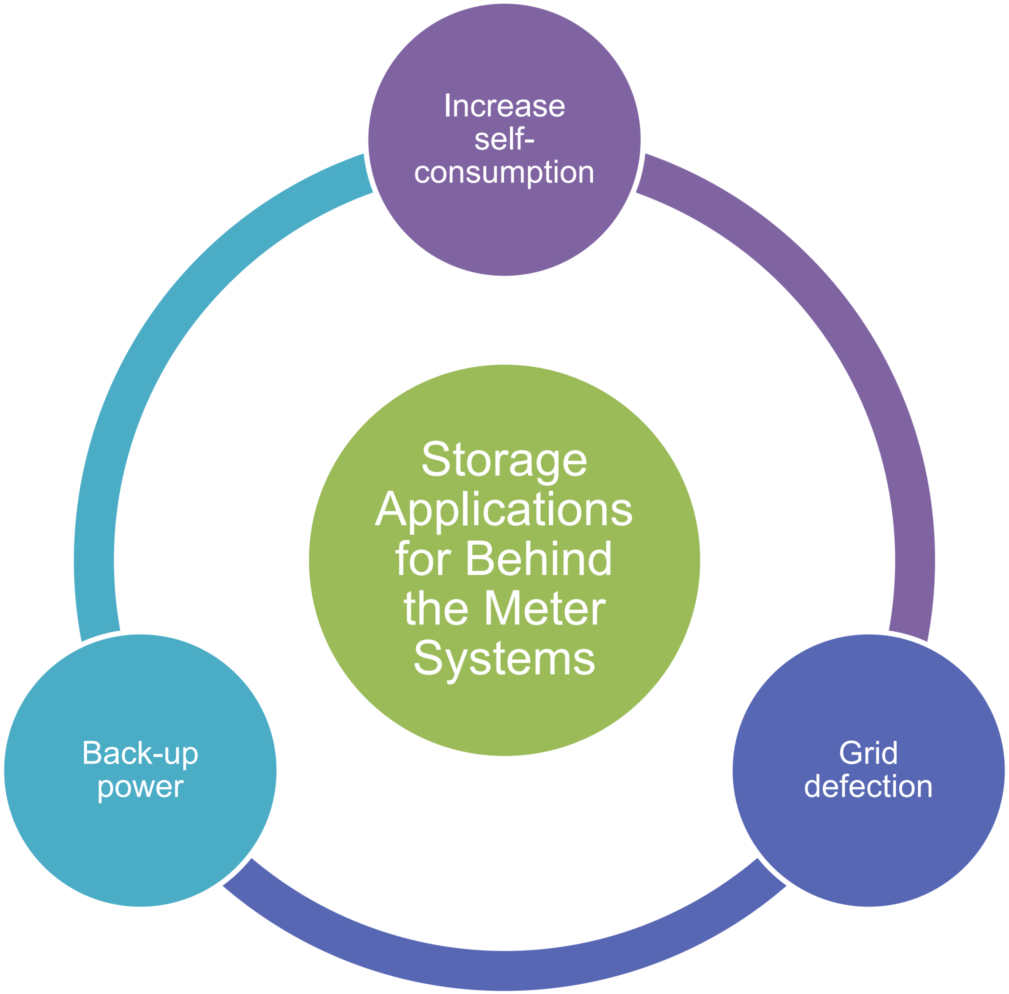
- Solar PV combined with storage is more likely to be economical under demandcharges and under rates with Gme-of-use componentsTemplate



Source: McLaren et al. (2018)

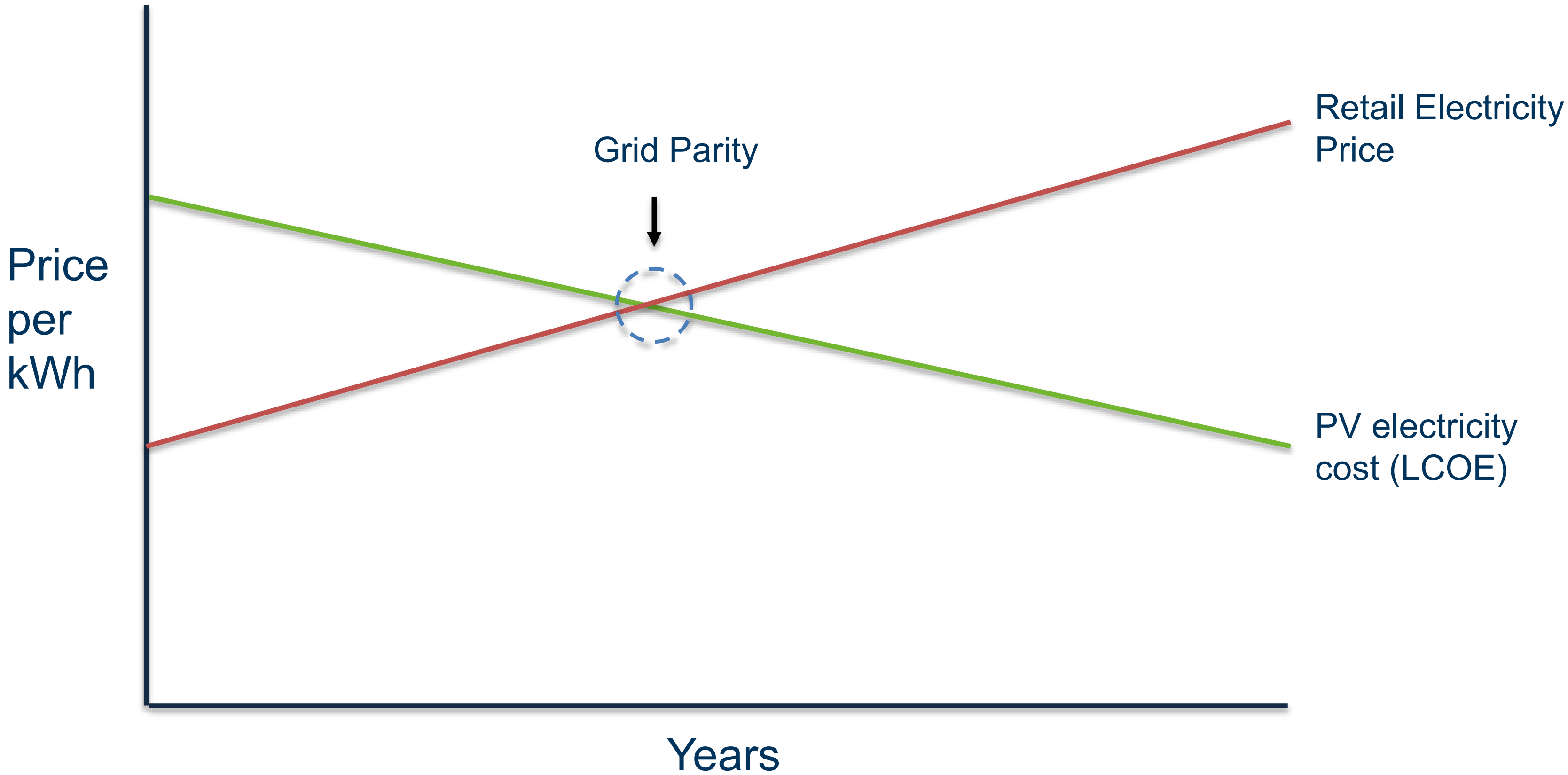
PV+Battery Systems and Self-Consumption

Storage Applications



Source: IET

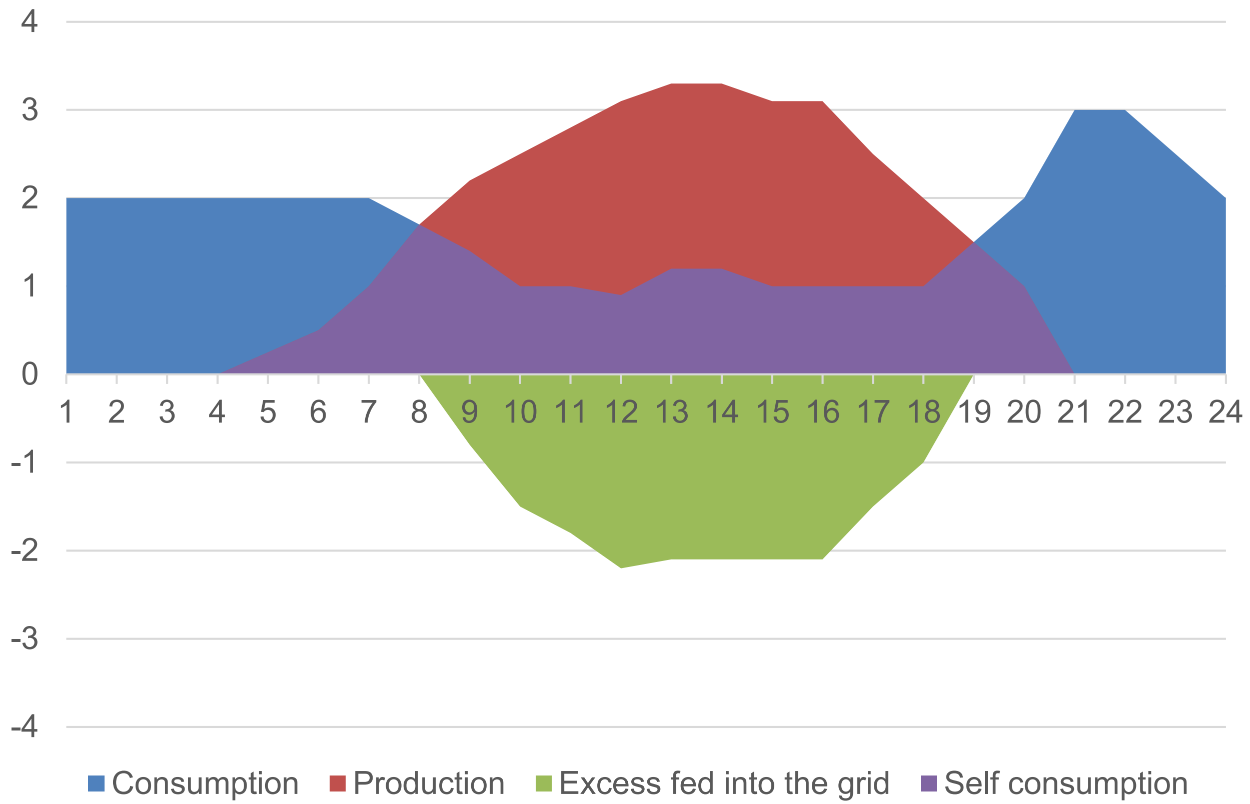
Self-consumption and grid parity



Source: IET

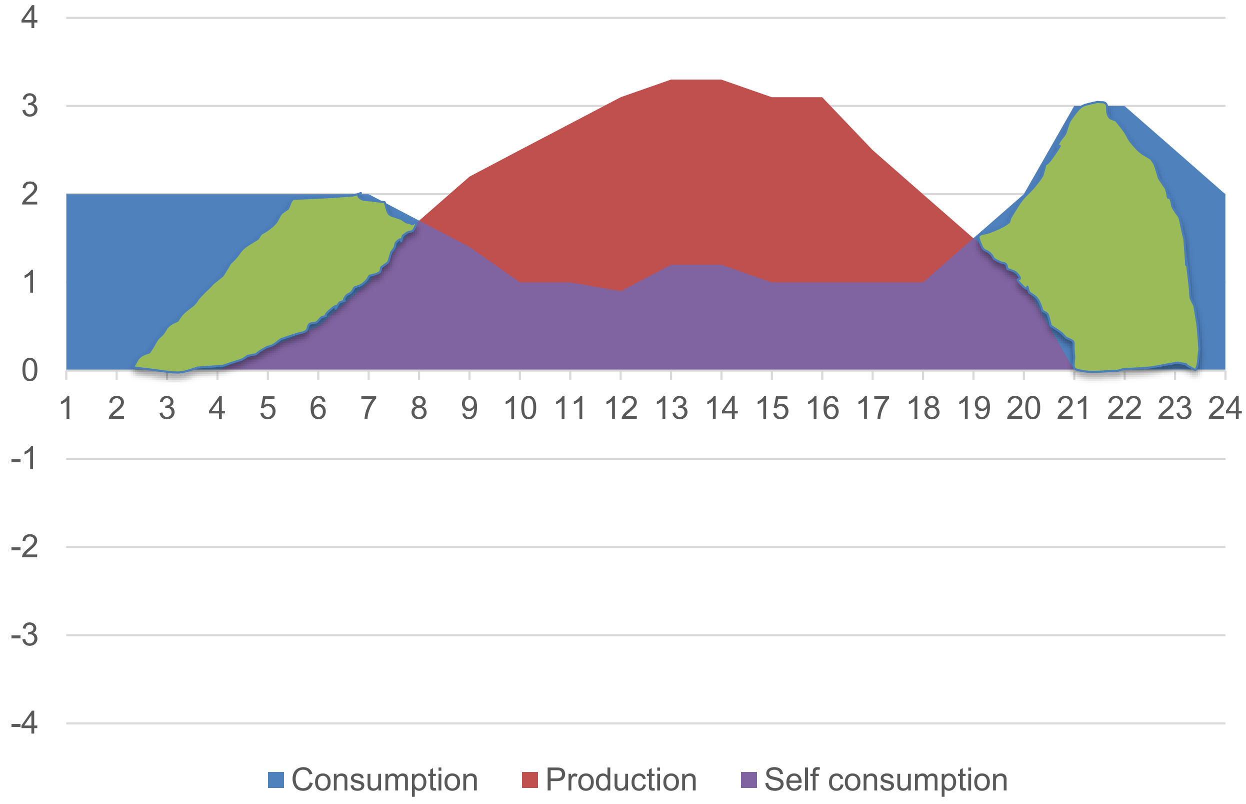
PV Self-Consumption

- PV self-consumption without storage (excess electricity is fed into the main grid)



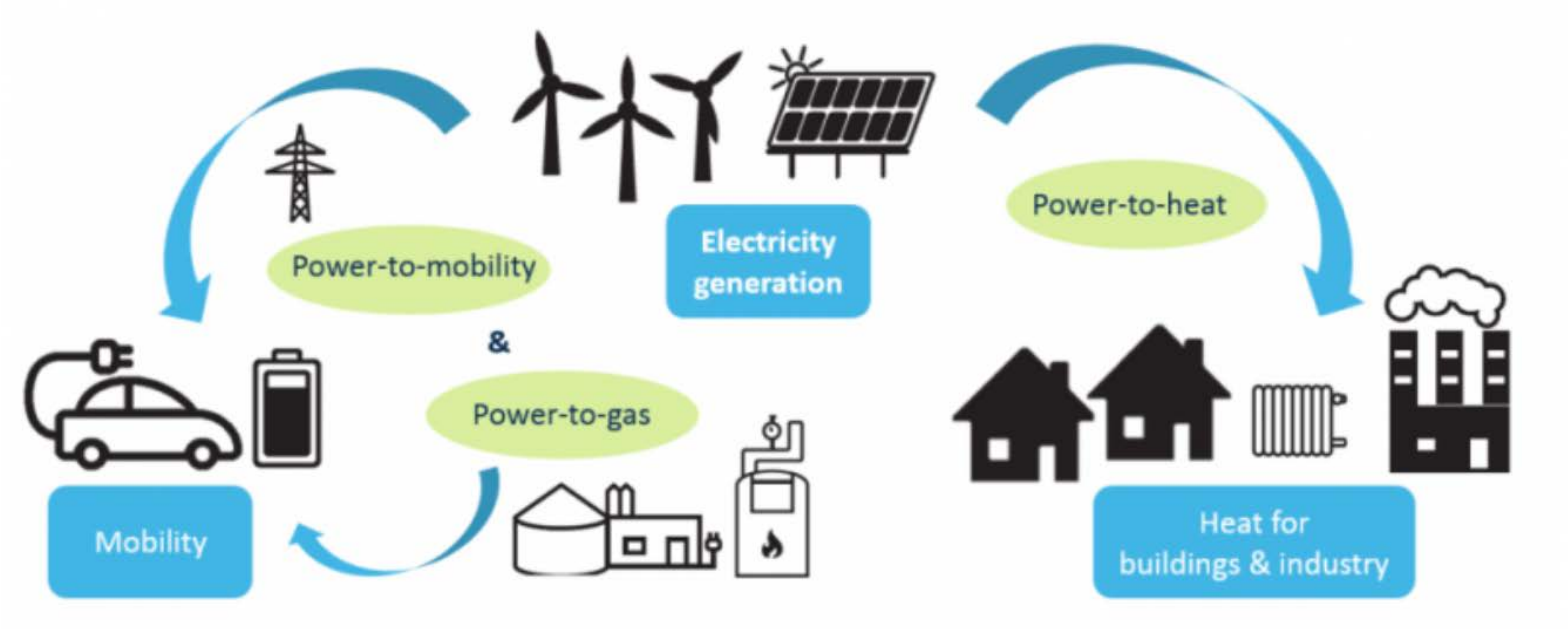
PV Self-Consumption

- Increasing self-consumption with electricity storage (reducing influx of excess electricity into the grid.



PV Self-Consumption

- Self-consumption optimization can be further enhanced via sector-coupling

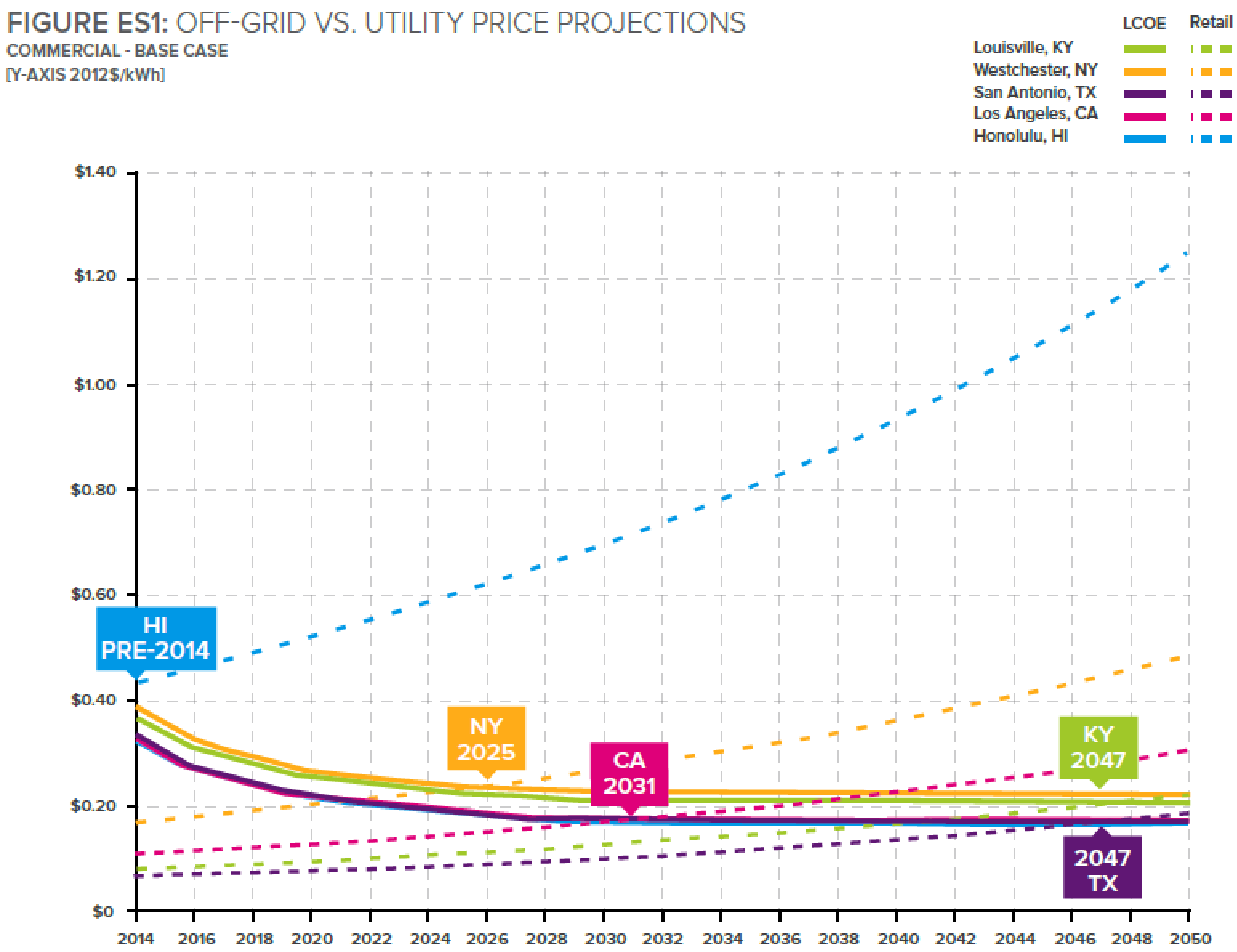


PV Self-Consumption

- Self-consumption optimization can be further enhanced via sector-coupling

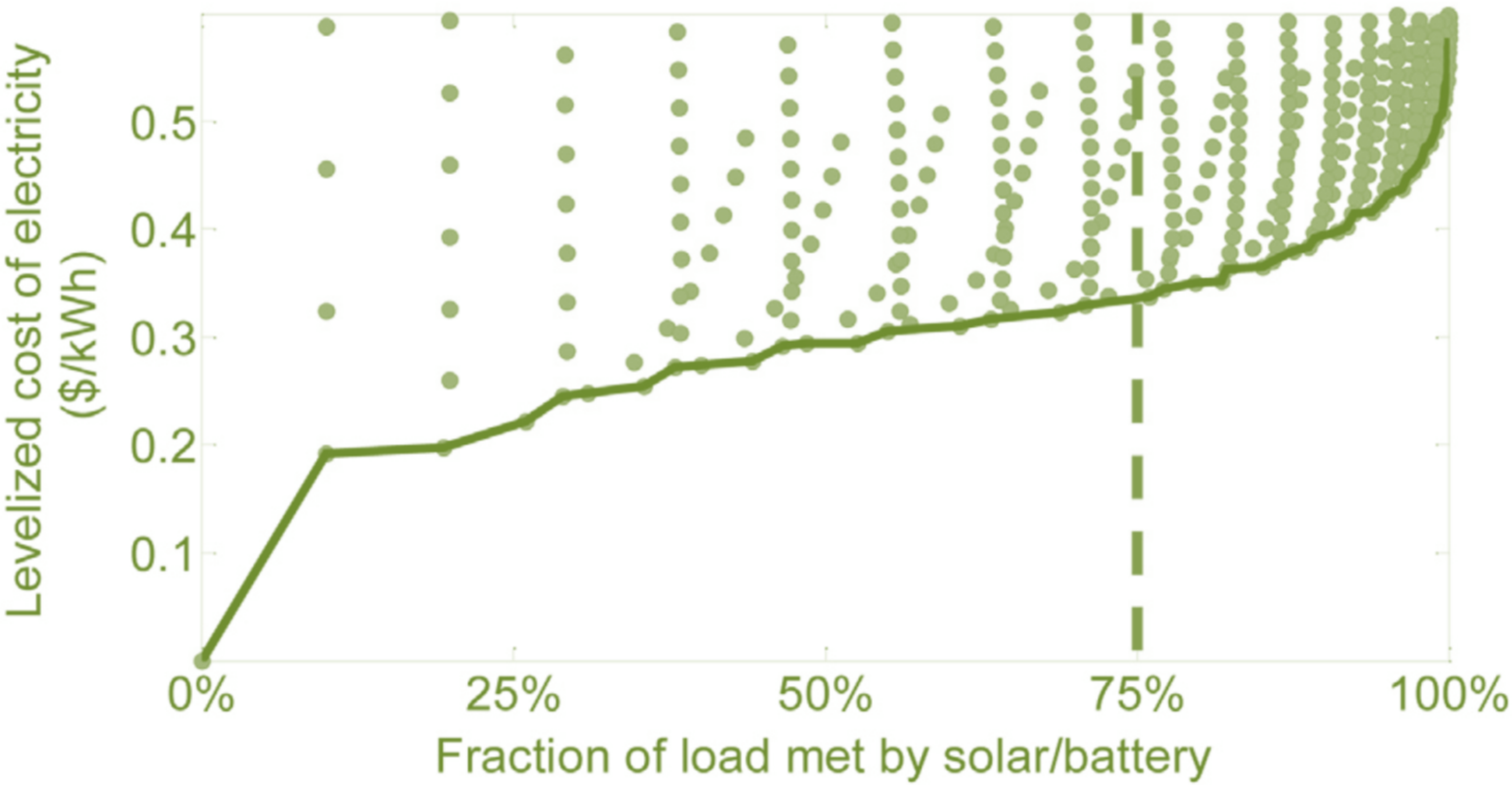
Check out Session 31 (Sector Coupling)

Grid defection: Timelines for the US



Source: RMI 2013

Cost of Grid Defection



Source: Hittinger et al. 2017

Barriers to Grid Defection

- In order to defect from the grid, a considerable amount of electricity storage capacity is required.
- Even customers that could theoretically „cut the cords“ might opt for staying connected to the grid as an (inexpensive?) back-up solution
- Grid defection is currently a theoretical threat in most jurisdictions (cost for electricity storage)
- Grid defection depends on climatic conditions:
  - Unrealistic in regions with large seasonal differences in solar radiation (regions with four seasons).

Battery Storage Technologies and Market Trends

Market trends in battery storage

- Global investment in battery technologies has increased significantly over the past decade.

- In the past years, investment was primarily triggered by:
  - the IT sector (USD 4.5 billion),
  - electrical equipment (USD 3.6 billion),
  - the renewable energy sector (USD 1.9 billion); and
  - the automotive industry (USD 1.8 billion).

Sources: Dansie 2015, IFC 2018

Market trends in battery storage

- World-wide, lead-acid batteries are most commonly used, with an annual world market (2015) of $33 billion.
- Li-ion batteries come second with a world market of $16.6 billion
- This trend is also reflected solar PV and renewable energy systems, where the most frequently used battery technologies are lead-acid batteries and li-ion batteries.

Source: Battery University (2018)

Lead-acid Batteries

- Historically, lead-acid batteries have been in use for more than 150 years which explains their wide application around the world.
- 85% of lead world-wide is used for battery production.
- Lead recovered by the recycling of lead-acid batteries is primarily re-used for new batteries.

Advantages and disadvantages of lead-acid batteries

Advantages	Disadvantages
Low initial cost compared to other rechargeable battery technologies	Total lifetime costs are higher than for Li-ion
High reliability and round-trip efficiency (70-90%)	Low cycling times
Low Maintenance requirements	Low energy density (50 to 100 Wh/L)
Established recycling infrastructure and natural incentives for re-use	Poor performance at low or high ambient temperatures (need for thermal management system)
Can be implemented in large-scale storage applications	Cannot be stored in a discharged condition
Low self-discharge rate	Hazardous substances; high environmental and safety risks

Source: IET based on (Graulich and Manhart 2017, IRENA 2017)

Lithium-ion Batteries

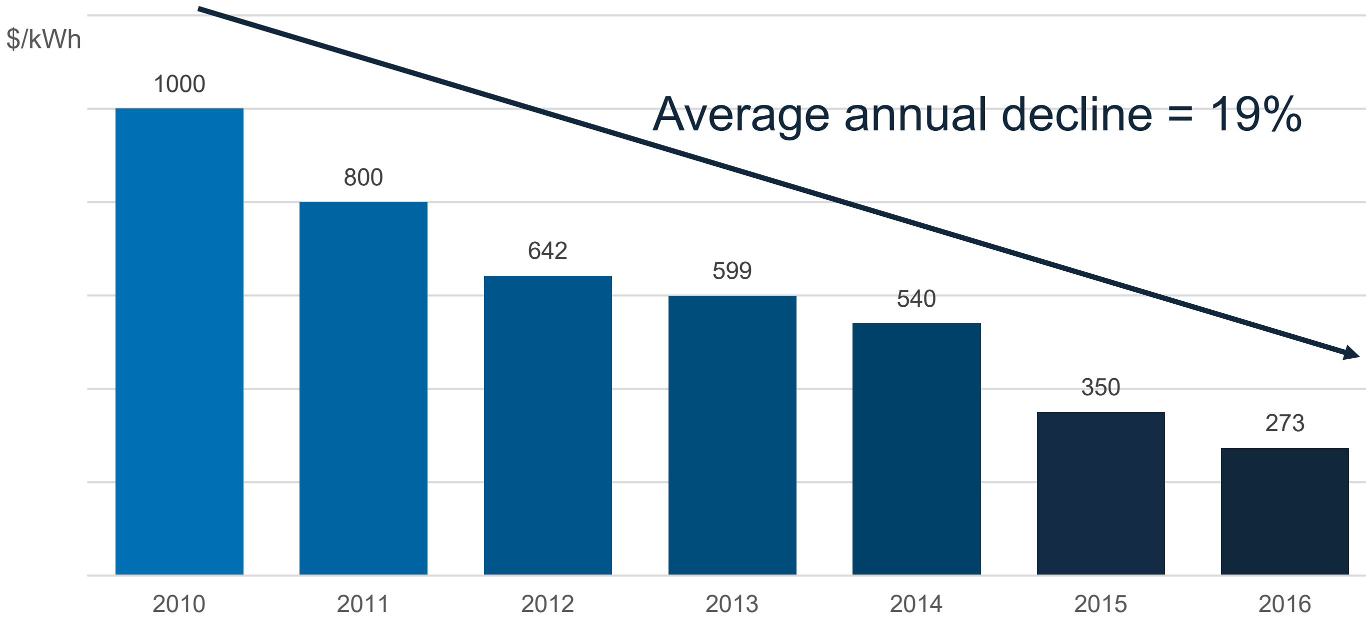
- Lithium-ion batteries are relatively young.
- They emerged on the market at the beginning of the 1990s and were first introduced by Sony Corporation for electronic equipment.
- Today, the global battery storage market is dominated by lithium-ion batteries.

Lithium-ion Batteries

- The cost of lithium-ion batteries has declined sharply in the past decades and years – by approximately 20% annually between 2010 and 2017.
- The costs might even decrease more rapidly in the future.
  - From 2018 to 2022, an annual cost decrease of up to 32% has been predicted due to increasing global manufacturing capacity and economies of scale (IFC 2018).
  - Cost reductions will be primarily triggered by economies of scale (increasing production capacity), improved materials and more competitive supply chains (IRENA 2017).

Evolution of the cost of Lithium-ion Batteries

Declining costs of lithium-ion batteries ($/kWh, 2010-2016)

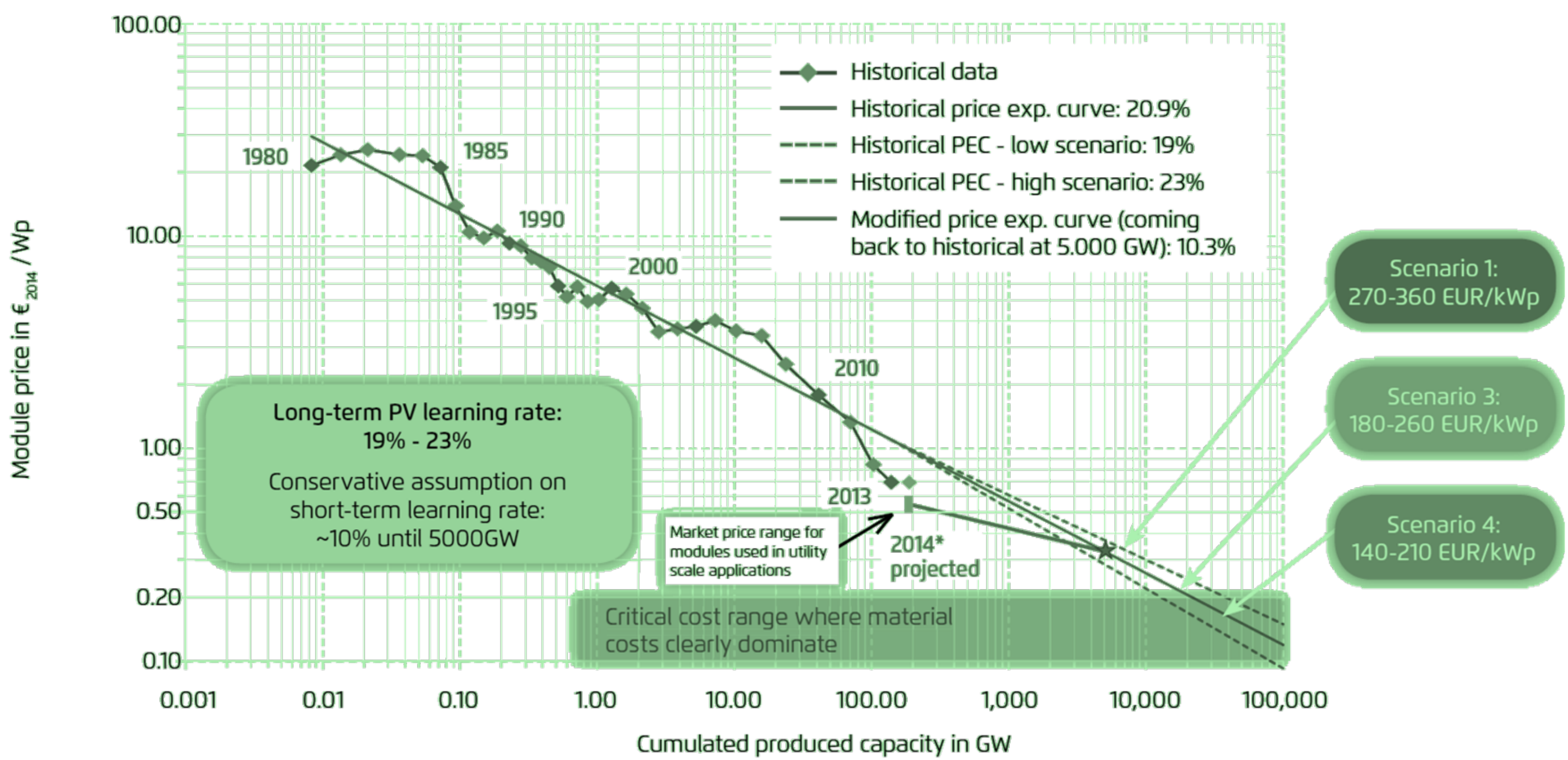


Source: BNEF lithium-ion battery price survey
Source: CleanTechnica (2017), based on BNEF

Decreasing Costs of Solar PV

- Ranging from 1.4 -2,1 €cent/kWh in 2050 (for utility scale systems)

Future module prices in different scenarios based on the historical "learning rate" Figure E2



Source: Agora 2015

Lithium-ion Batteries: Outlook

- Lithium-ion batteries are expected to become the default option for energy storage in the future, making up a $20 billion per year market by 2040, a tenfold increase compared to today (BNEF 2017).
- Already today, lithium-ion batteries are the preferred choice households solar+battery applications and for off-grid for pico and small-scale installations.
  - As of 2017, 95% of certified pico devices used lithium-ion batteries, compared to 5% in 2010 (IFC 2018).

Advantages and disadvantages of li-ion batteries

Advantages	Disadvantages
Sharply decreasing costs	Limited recycling capacity world-wide; no recycling facility in Ghana or Africa
Relatively long lifespan (number of full cycles)	No intrinsic value for recycling (except for cobalt based technologies). Incentive scheme required for collection and recycling.
Very high round-trip efficiency and low self-discharge rate	Danger of thermal runaway and complex transportation to recycling facilities in Europe or North America.
High-power discharge capability	Some Lithium-ion battery types include highly toxic materials (LNMC is classified as hazardous for environment and health)
Toxicity of applied materials is lower than in the case of lead-based batteries.	Risk of supply shortage since cobalt is a “critical raw material“. Extraction takes primarily place in the Congo under insufficient working conditions.

Source: IET based on (Graulich and Manhart 2017, IRENA 2017, Manhart, Hilbert et al. 2018)

Recycling Challenges

Lead-acid Battery Recycling

- Due to the high material value of the contained lead, most waste lead-acid batteries are directed towards recycling facilities
- Stringent regulation and sound management practices are necessary to prevent any damage to human health and the environment:
  - Without clear regulation, “there is systematically a clear motivation for sub-standard recycling by private actors” (Manhart, Hilbert et al. 2018).
  - This include proper drainage of batteries, battery breaking and smelting of raw lead ingots for export purposes (Manhart and Schleicher 2015)

Lead-acid Battery Recycling Challenges

- A frequent problem in developing counties is unofficial backyard smelting of lead-acid batteries.
  - Since the temperature required for smelting lead is not very high (melting point for lead = 327°C), it can be carried out without major investments by simply using melting pots over open fires.
- Backyard smelting can cause substantial health impacts due to emission of lead in form of dust and lead fumes during the smelting process.
- Contaminants can also leach into ground water and waterways used by local communities.

Lead-acid Battery Recycling: Options for Developing Countries

- Due to a current lack of appropriate recycling factories in many developing countries, it is often recommended to export lead-acid batteries to countries with state-of-the-art recycling infrastructure.
- There are primarily four export options:
  - Export of wet lead-acid batteries (original state after recollection)
  - Export of drained lead-acid batteries (after local drainage of acid)
  - Export of lead scraps (after local battery breaking and extraction of lead scraps)
  - Export of lead ingots (after local smelting of raw led ingots).

Source: Manhart and Schleicher (2015)

Lithium-ion Battery Recycling

- Most lithium-ion batteries are currently not recycled properly.
- There are only very few recycling factories world-wide that have specialized in the treatment of end-of-life li-ion batteries.
  - All of them are based either in the EU or North America.
  - The existing recycling plants are primarily focusing on the recovery of nickel, copper, cobalt and rare earth elements.
  - Other materials such as iron, graphite and phosphor are lost during the recycling process
- Other countries with a similar lack of recycling infrastructure, e.g. Kenya, are storing the batteries until a sufficient volumes are reached and a more efficient recycling technology is available

Sources: Manhart, A., et al. (2018); Magalini, Sinha-Khetriwal et al. (2016).

Lithium-ion Battery Recycling

- The recycling of lithium-ion batteries can cost up to 5000 USD per ton but can also have a positive value if the batteries contain cobalt.
  - For cobalt-containing lithium-ion batteries, it is very likely that (informal or formal) collection will improve in the large urban centres.
- However, there is no intrinsic value for collecting and recycling other lithium-ion battery types (namely LMO and LFP).
  - For these battery types, financial incentives for collection and recycling need to be established.

Source: Magalini, Sinha Khetriwal et al. (2017).

Lithium-ion Battery Recycling: Costs and Risks

- Shipping end-of-life lithium-ion batteries can result in additional challenges and costs triggered by the risk of thermal runaways.
  - Lithium-ion batteries with a residual charge of more than 30 percent can be subject to these thermal runaways.
  - Because batteries are usually stored and transported in large volumes, larger battery fires constitute a real risk.

Dealing with Li-on battery recycling-related risks

Strategies to prevent the risks of battery fires during the collection and shipment of Lithium-ion batteries include:

- Manually discharge all batteries in preparation for transport
- Prolonged the storage of batteries (several weeks) to maximize the self-discharge effects
- Storage and transport of lithium-ion batteries in sand

Source: Manhart, Hilbert et al. (2018)

Summary

Summary

- Storage technologies can be used for a wide variety of services in the electricity system.
- In the case of (residential) solar PV, battery storage can help to optimize self-consumption and provide back-up power.
- Grid defection is comparatively expensive and keeping connections with the main grid will be beneficial for most electricity customers.
- Lithium-ion batteries are emerging as the default option, even replacing lead-acid batteries for larger-scale (off-grid) applications.
- There is a severe recycling challenge and specialist recycling facilities need to be established in all corners of the world.

Further Reading/List of References

Further Reading on Storage

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- Manhart, A. and T. Schleicher (2015). The recycling chain for used lead-acid batteries in Ghana. Freiburg, Öko-Institute

Thank you for your time!

E3 ANALYTICS

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Factor
Ideas for change

CLEAN ENERGY SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

6. Knowledge Checkpoint: Multiple Choice Questions