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: Session 29

Dealing with the Duck Curve

In partnership with the Clean Energy Solutions Center (CESC)

Toby D. Couture

August 2019

Supporters of this Expert Training Series

INTERNATIONAL
SOLAR
ALLIANCE

CLEAN ENERGY
SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Overview of Training Course Modules

This Training is part of Module 5, and focuses on the issue of How to Deal with the Duck Curve

Eight Modules

Expert Content and Analysis

Up-to-date Market Insights

1. Policies for Distributed PV
2. Policies for Large-Scale PV
3. The Future of Solar Policy
4. Technical Integration of Solar
5. Market Integration
6. Socio-Economic Aspects
7. Off-grid Solar
8. Solar Heating & Cooling

Overview of the Presentation

1. Introduction: Learning Objective
2. What is the Duck Curve?
3. Strategies for Dealing with the Duck Curve
4. Concluding Remarks
5. Further Reading
6. Knowledge Check: Multiple-Choice Questions

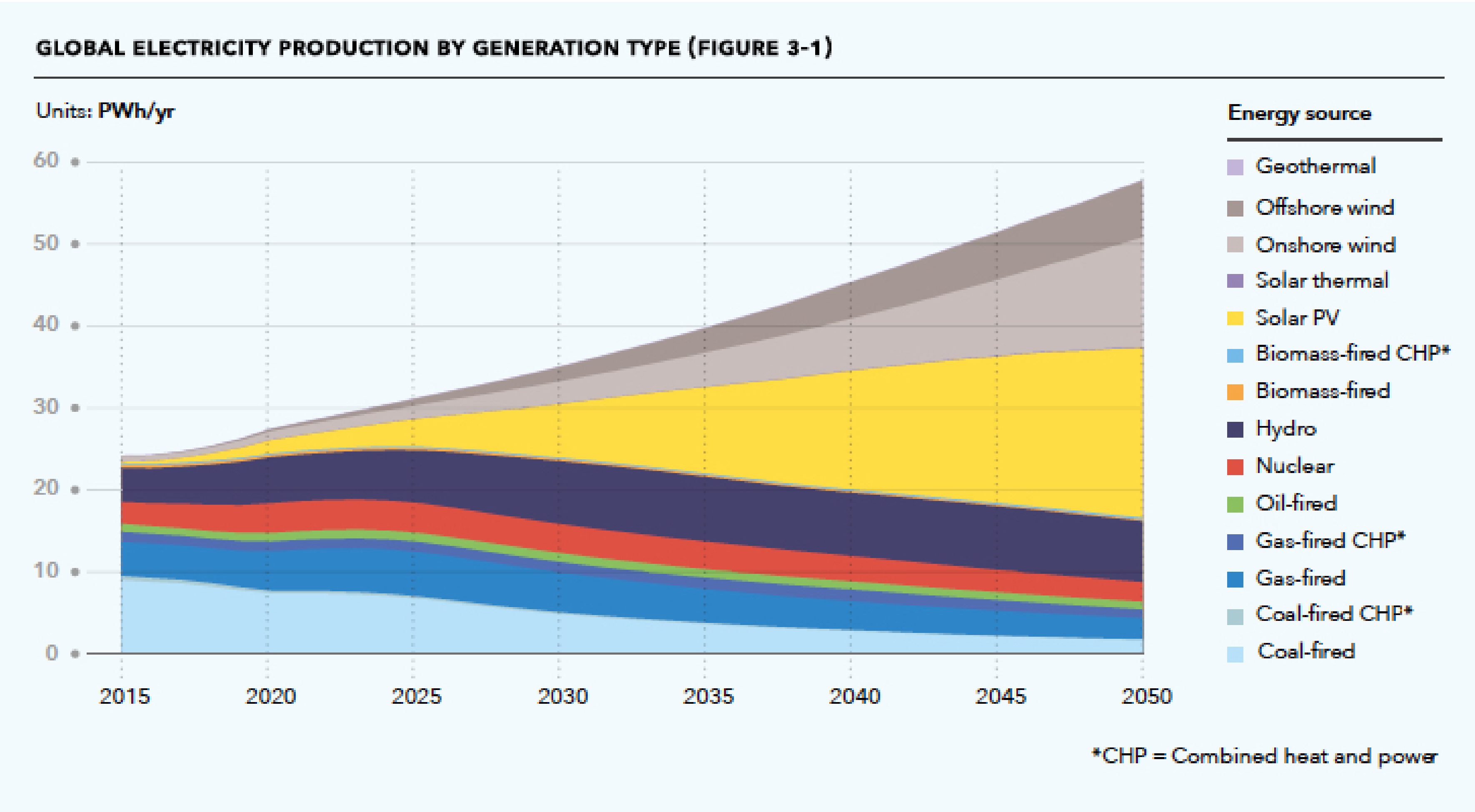
1. Introduction: Learning Objective

Learning Objectives

- Understand what the duck curve is, and what it means for utilities and for renewable electricity markets
- Understand how utilities and stakeholders are trying to deal with the duck curve
- Understand how the duck curve fits into the broader discussion around reaching high shares of variable renewable energy sources
- Understand the relevance of the duck curve for both developed and developing countries

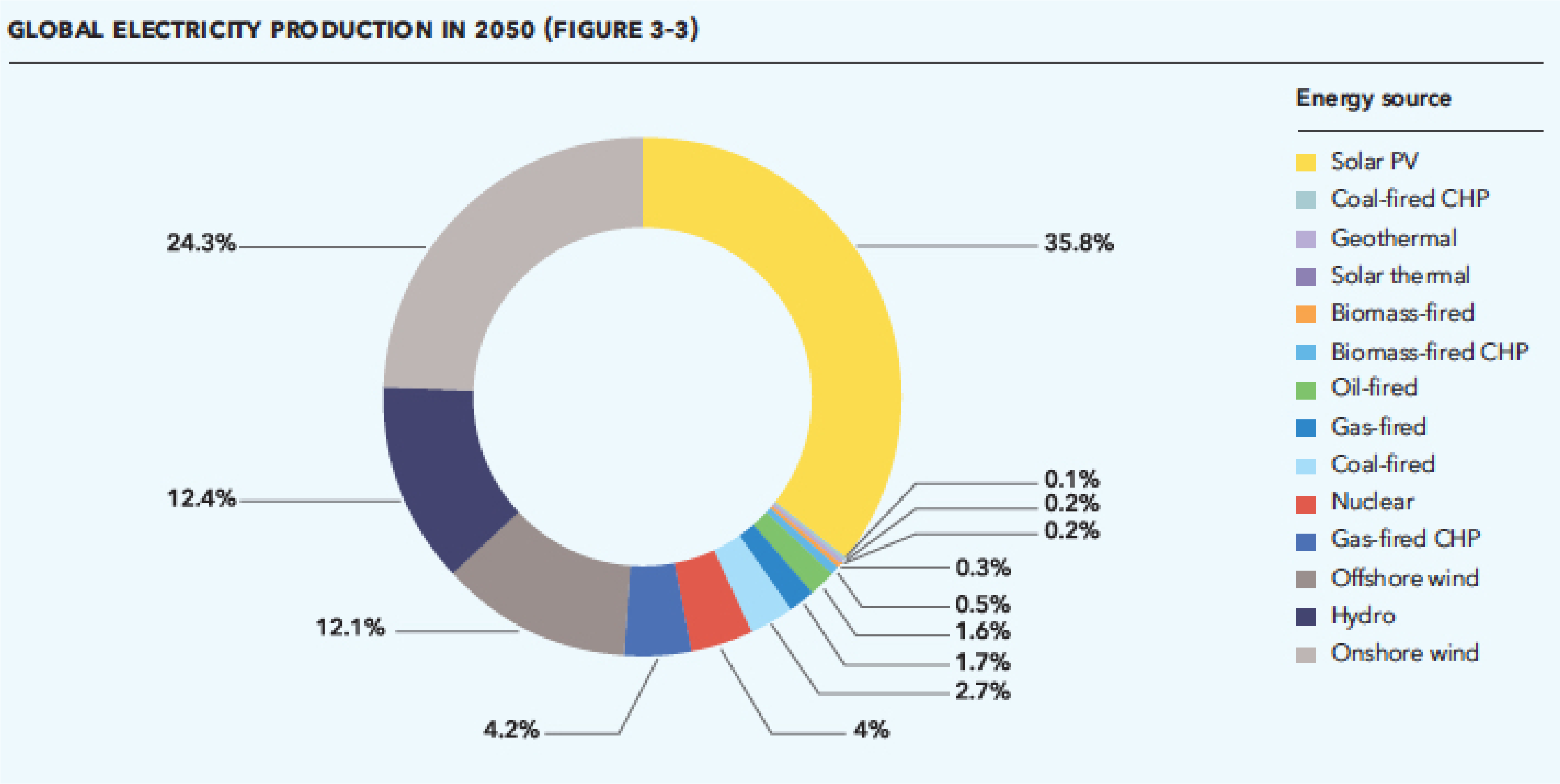
2. Understanding the Rise of VRE

Analyses of the Global Energy Transition put a growing emphasis on Variable Renewable Energy (VRE)



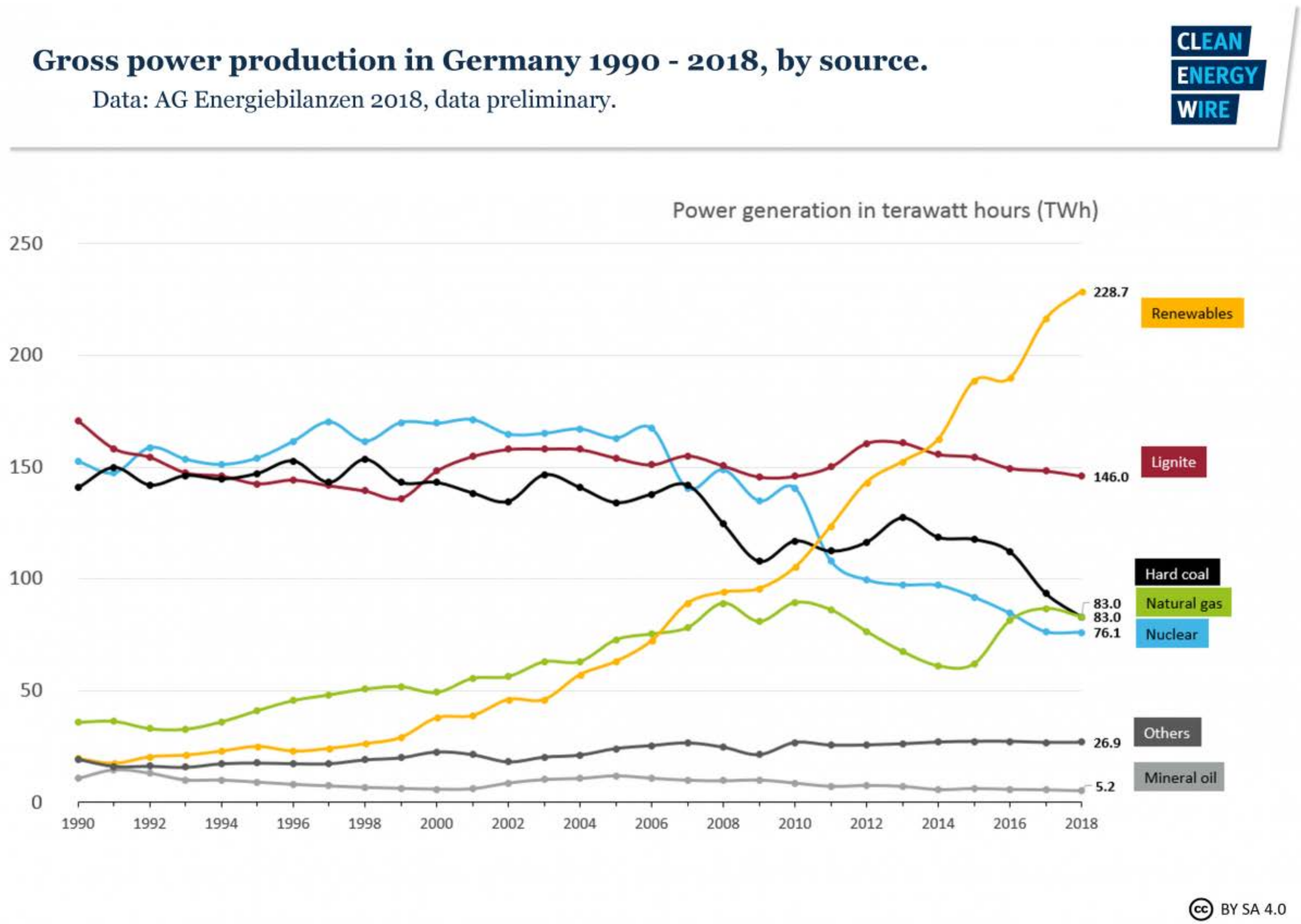
Sources: https://eto.dnvgl.com/2017/#Energy-Transition-Outlook

VRE = mainly solar PV and wind



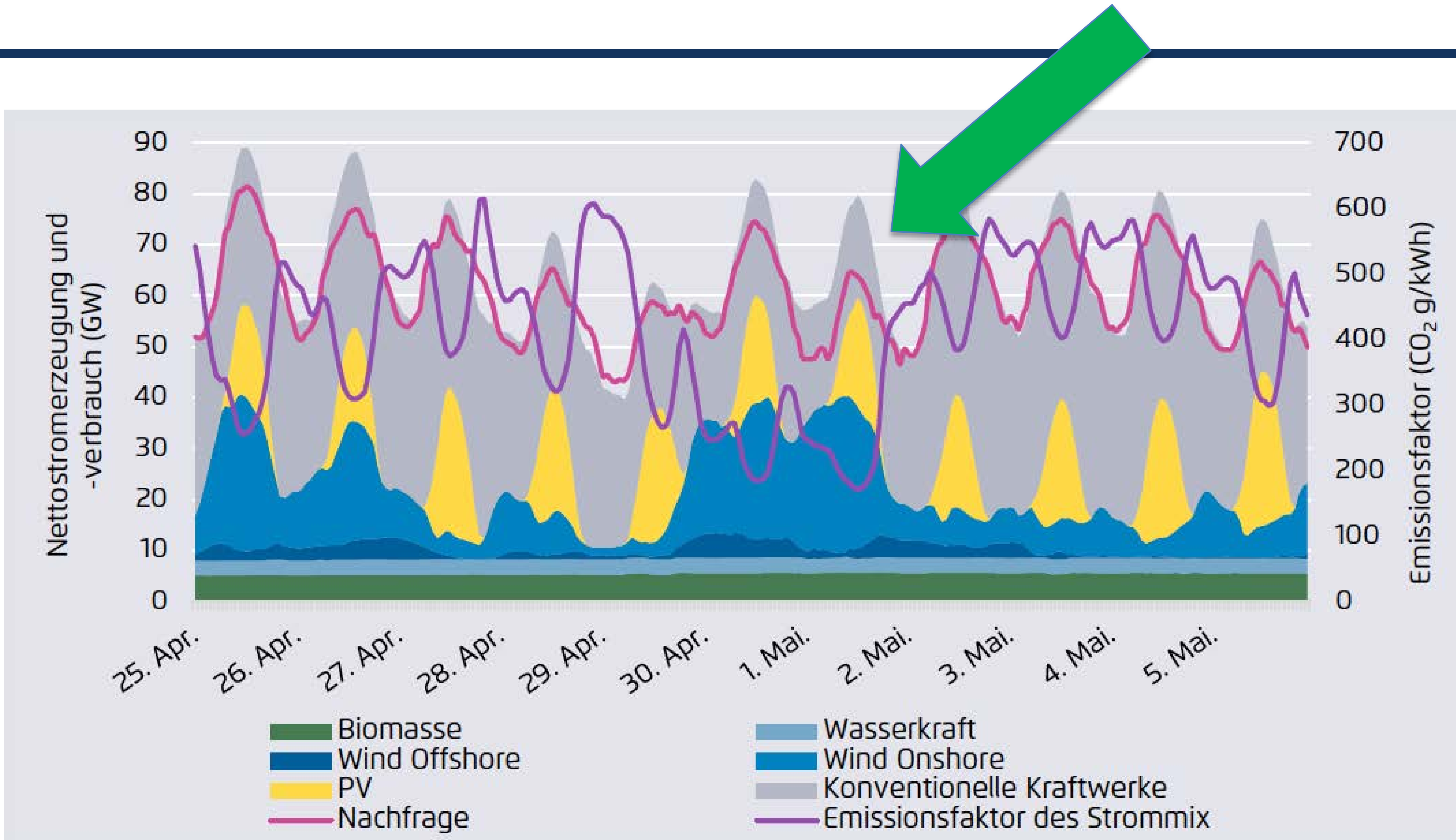
Sources: https://eto.dnvgl.com/2017/#Energy-Transition-Outlook

German power generation: 1990-2018



Sources: https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts

German RE share recently hit 94%



Sources: https://www.agora-energiewende.de/veroeffentlichungen/die-energiewende-im-stromsektor-stand-der-dinge-2018/

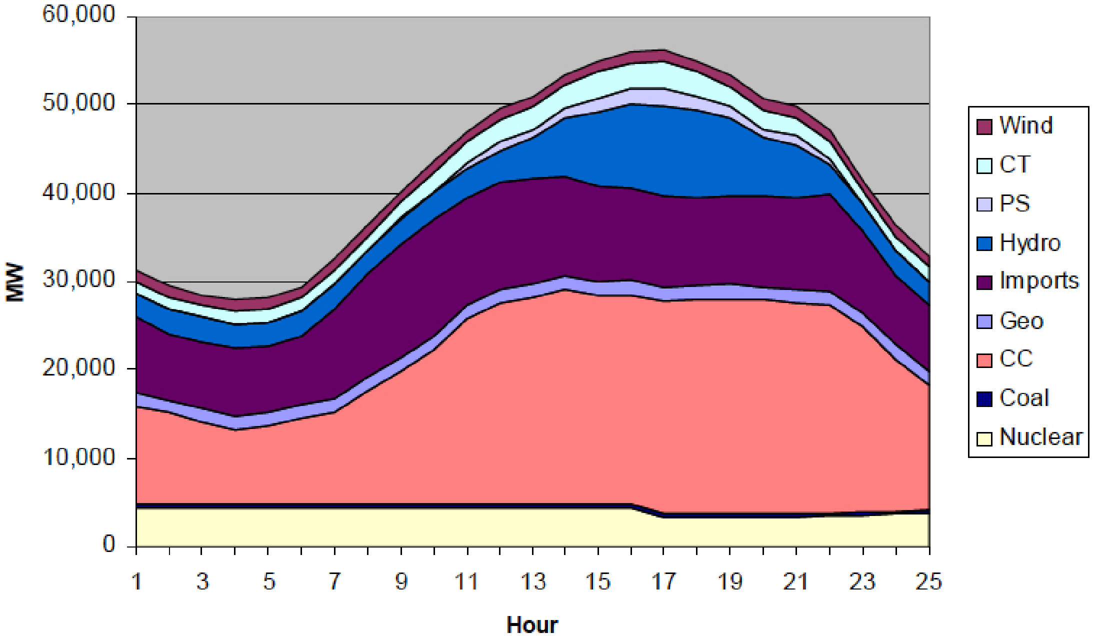
3. What is the Duck Curve?

What causes the Duck Curve?

Electricity demand profiles follow a fairly typical pattern:

- Low overnight
- Ramping in the early morning hours (6AM – 9AM)
- Late Afternoon - Evening Spike (4PM – 9PM)
- Low in the late evening and early morning hours

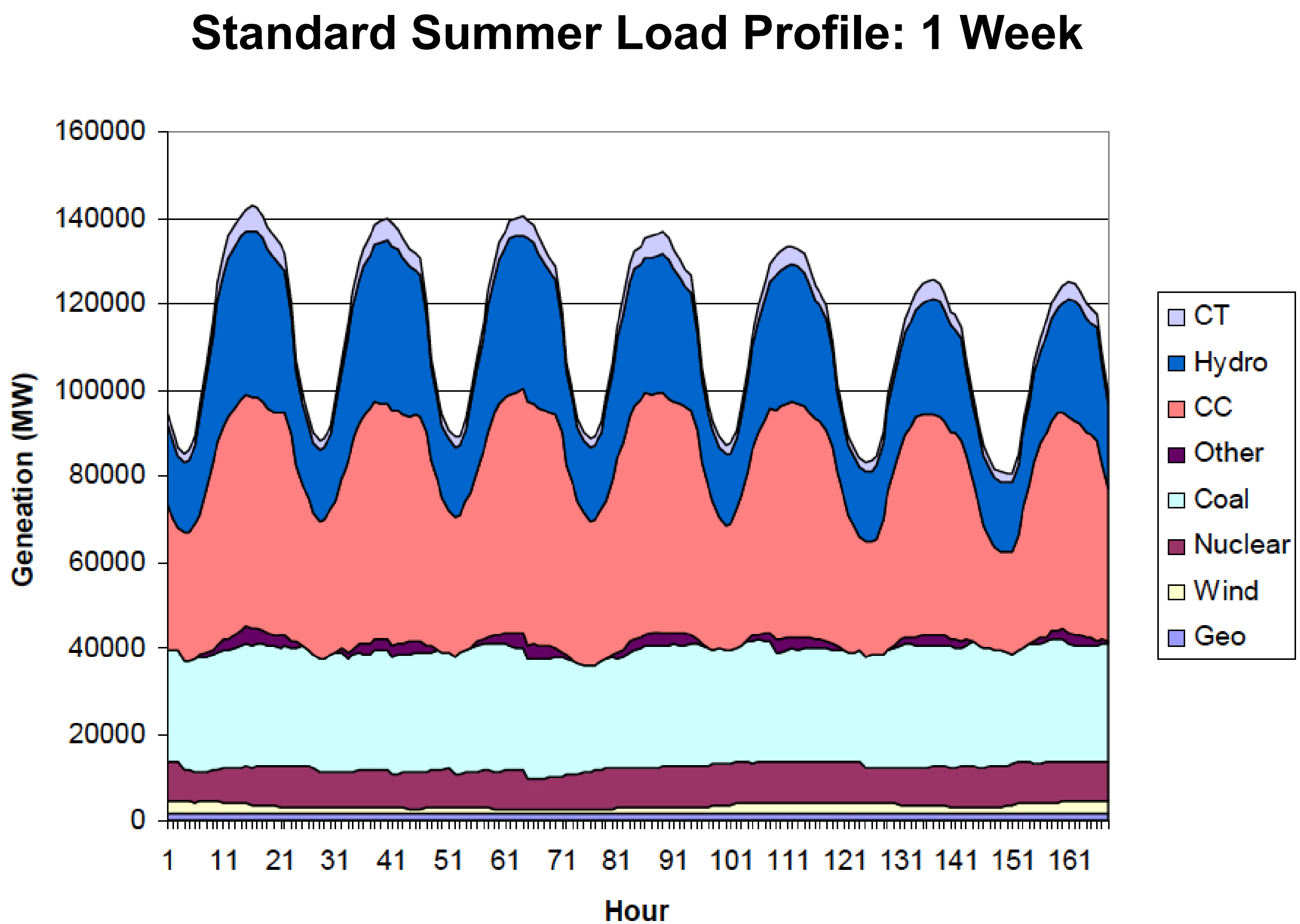
Simulated Load Profile: 1 Day in California



Sources: https://www.nrel.gov/docs/fy08osti/42305.pdf

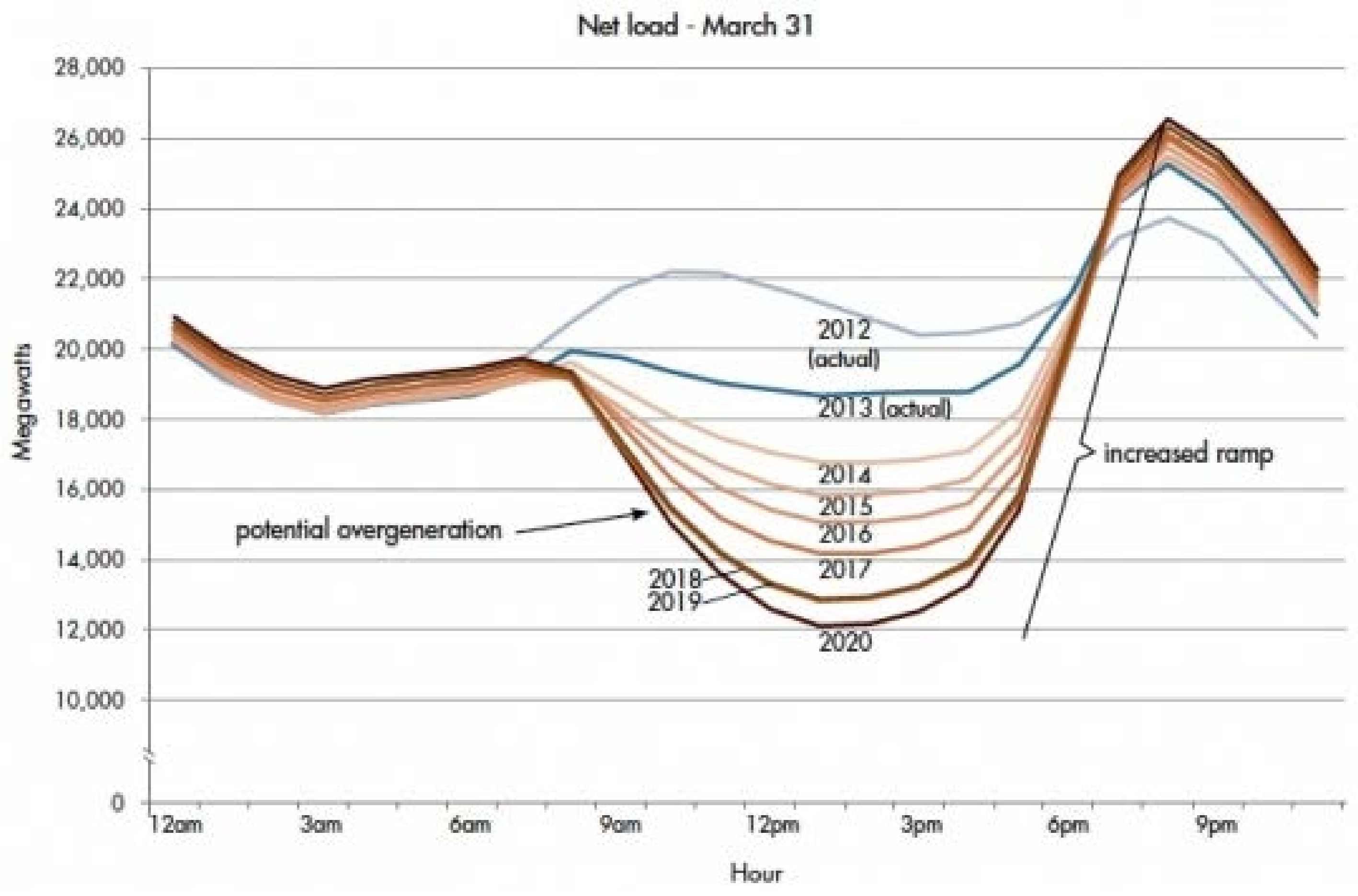
What causes the Duck Curve?

Original NREL paper by Denholm(link) first to identify the problem, caused by rising solar PV penetration



Sources: https://www.nrel.gov/docs/fy08osti/42

If it walks like a duck…



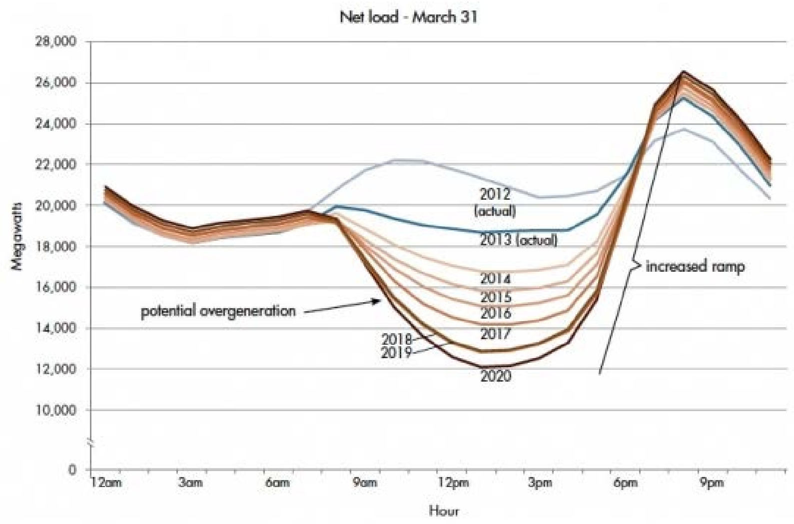
Sources: https://www.utilitydive.com/news/on-the-ducks-10th-birthday-heres-how-to-keep-it-from-eating-the-power-sy/519367/

And quacks like a duck…

Solar PV generates electricity during the day (6AM – 6PM or 8AM – ±9PM in the summer months)

The more solar PV enters the grid during this time, the more it displaces other sources of generation

This disrupts the historical dispatch order of power plants in the electricity system, creating a ”trough” in the midday hours

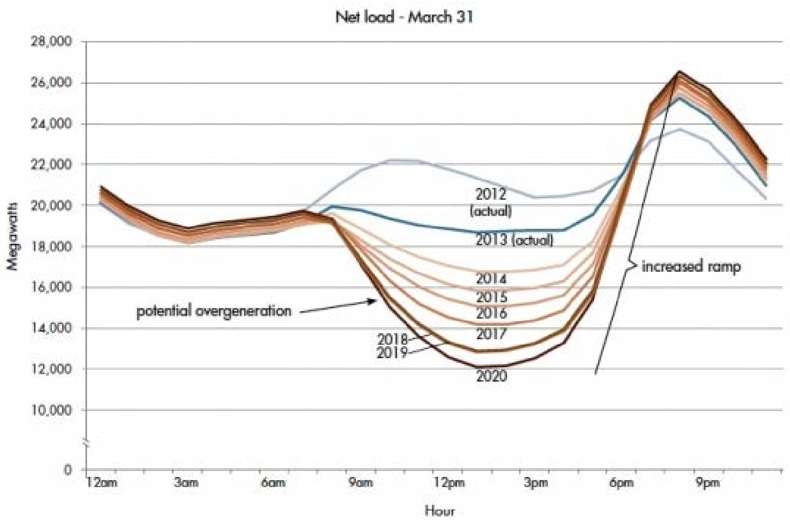


Sources: https://www.utilitydive.com/news/on-the-ducks-10th-birthday-heres-how-to-keep-it-from-eating-the-power-sy/519367/

What is the Duck Curve?

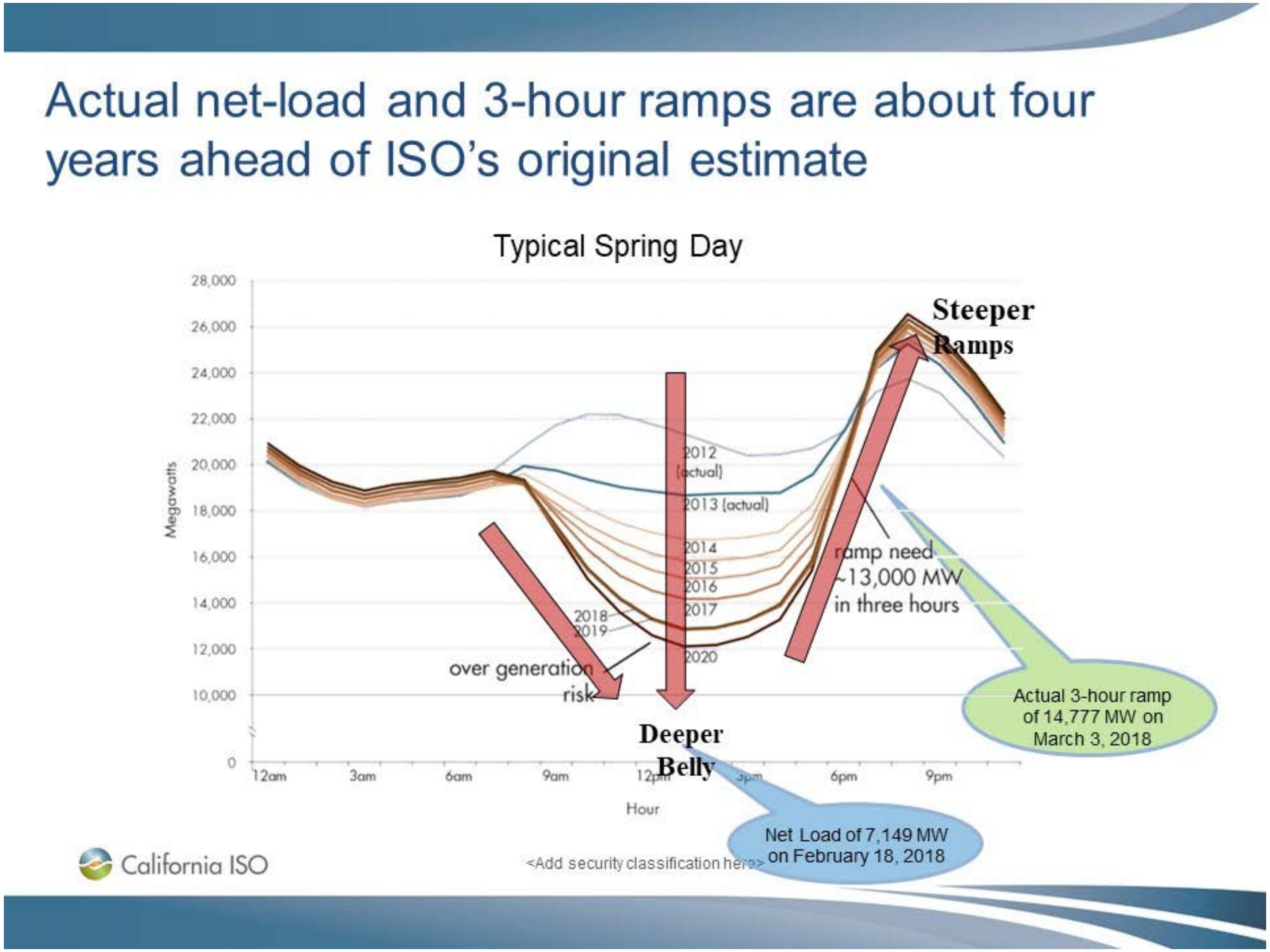
Put differently, rising solar output during the daytime progressively erodes the “residual” (i.e. post solar) daytime load that was previously met by other sources on the network (coal, nuclear, gas)

The Duck Curve can get even steeper, generating further challenges in keeping the lights on



Sources: https://www.utilitydive.com/news/on-the-ducks-10th-birthday-heres-how-to-keep-it-from-eating-the-power-sy/519367/

Duck Curve trends in California are already beyond estimates

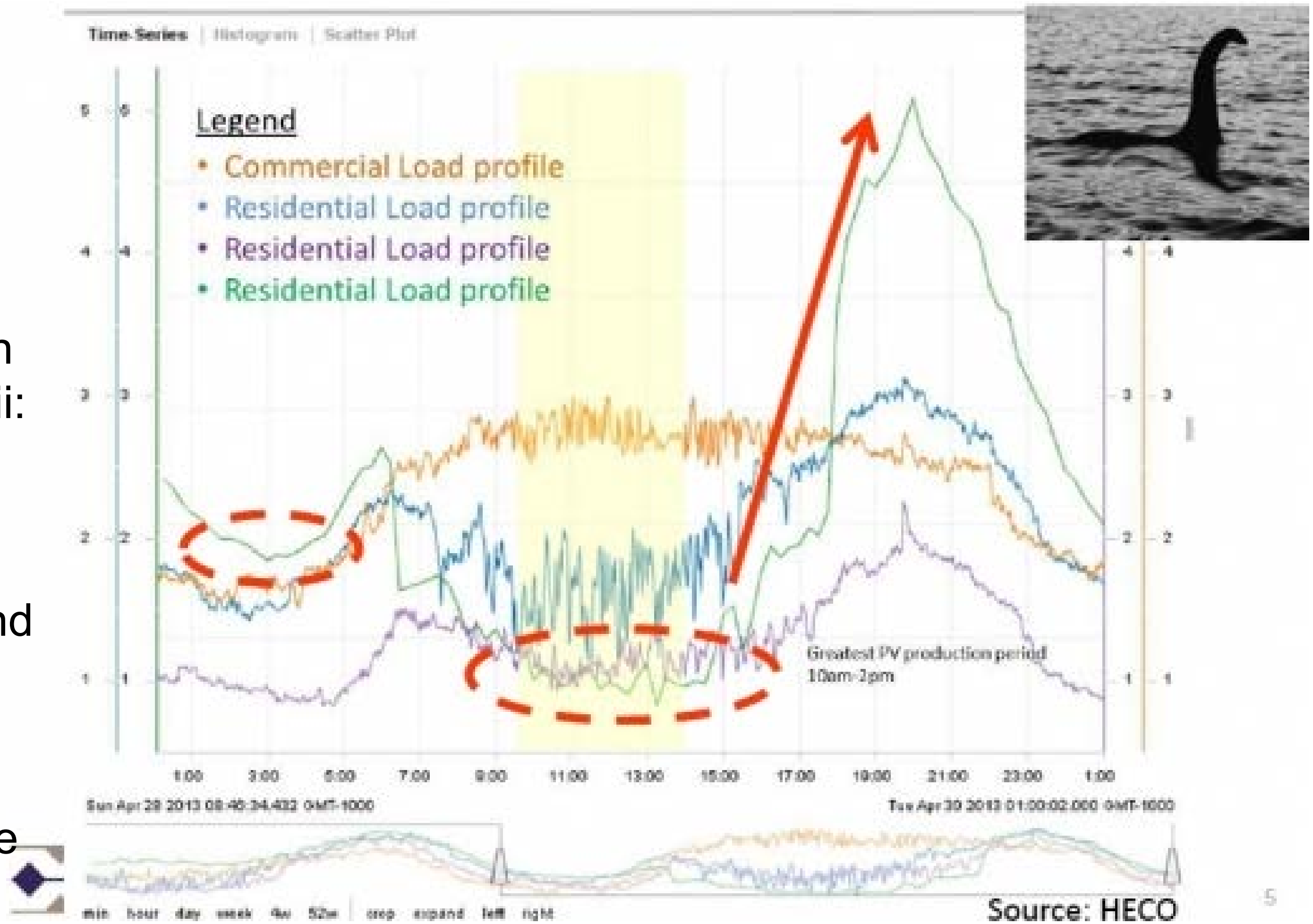


Sources: https://www.utilitydive.com/news/on-the-ducks-10th-birthday-heres-how-to-keep-it-from-eating-the-power-sy/519367/

Introducing v.2.0: The Nessy Curve

Officials in Hawaii coined the term the ”Nessy Curve” to describe what has started to happen on some days in Hawaii:

Very little residual demand during the day time (i.e. demand not met by solar), leading to a rapid spike in the early evening hours as the sun sets

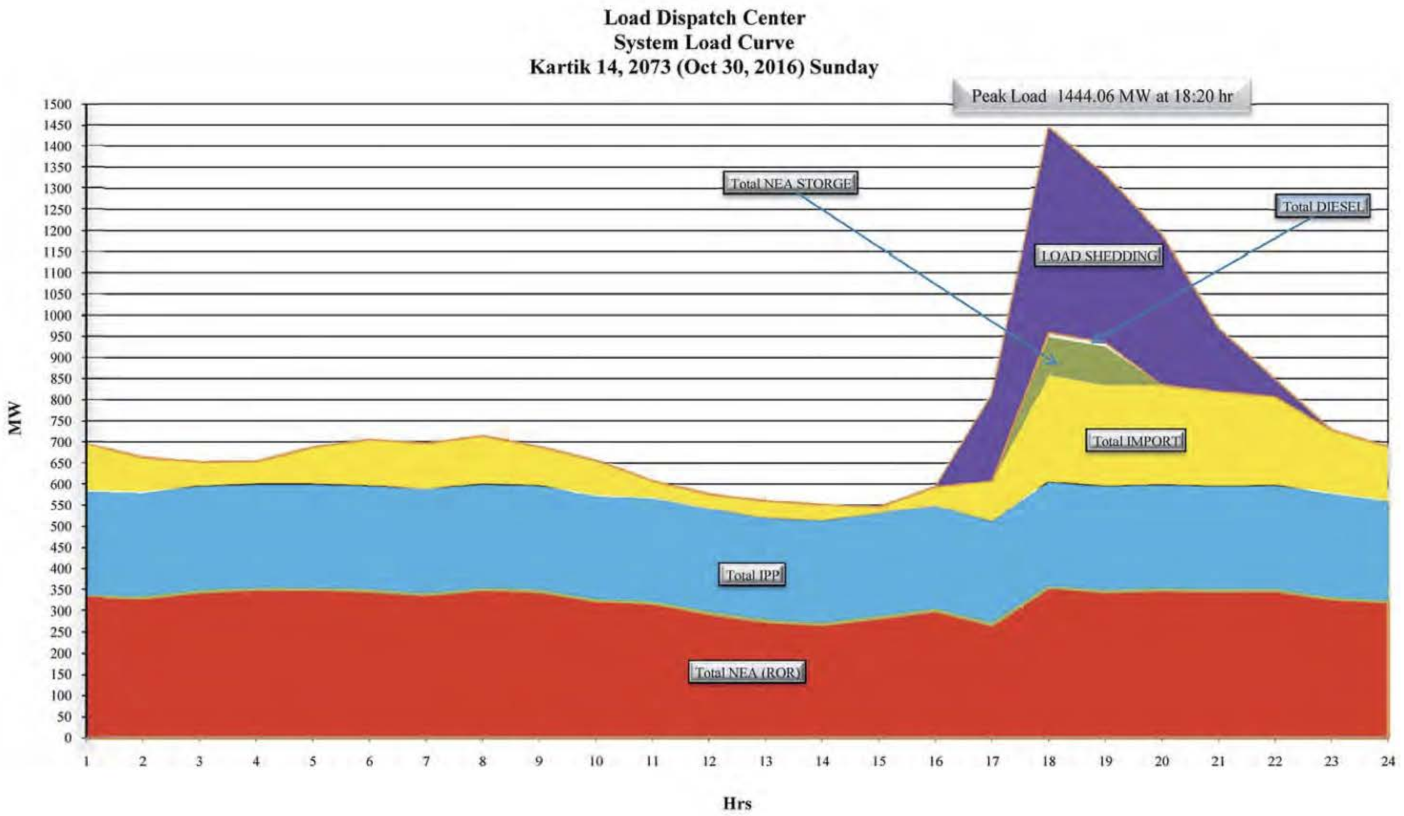


Sources: http://www.greentechmedia.com/articles/read/hawaiis-solar-grid-landscape-and-the-nessie-curve

Introducing v.0.0: The Shark Curve

However, in many developing countries, the daily load curve looks different in important respects

e.g. Nepal (see right)



Sources: http://www.e3analytics.eu/wp-content/uploads/2018/05/Analytical-Brief_May-2018_FINAL.pdf

Introducing v.0.0: The Shark Curve

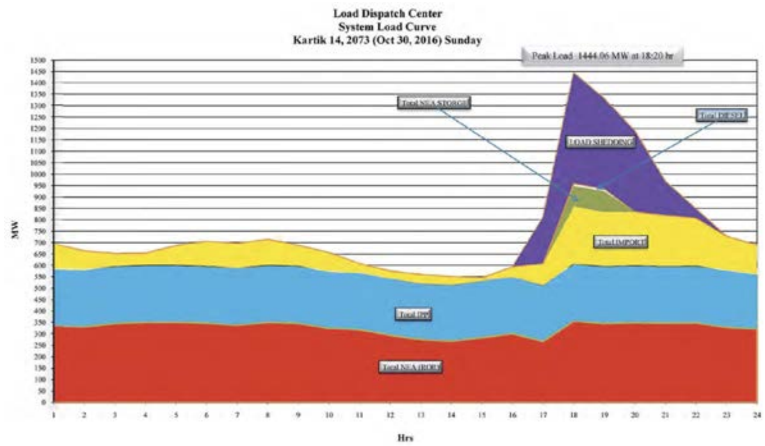
- This leads to more acute challenges, as the evening spike is even sharper, and beyond most existing power systems' ability to reliably supply

- The fact that evening load is frequently unmet also erodes utility revenues, which could otherwise be used to invest in solutions

- Lower energy efficiency and the frequent absence of price signals makes the spike worse

E.g. Nepal:

- A slight morning bump followed by relatively flat daytime demand
- A trough in the mid-afternoon
- A rapid and largely unmet evening peak: unmet = load shedding/power outages



Sources: http://www.e3analytics.eu/wp-content/uploads/2018/05/Analytical-Brief_May-2018_FINAL.pdf

3. Strategies for Dealing with the Duck Curve

How to Deal with the Duck Curve

In a follow-up paper by the original authors of the Duck Curve paper, the authors suggest two basic approaches:

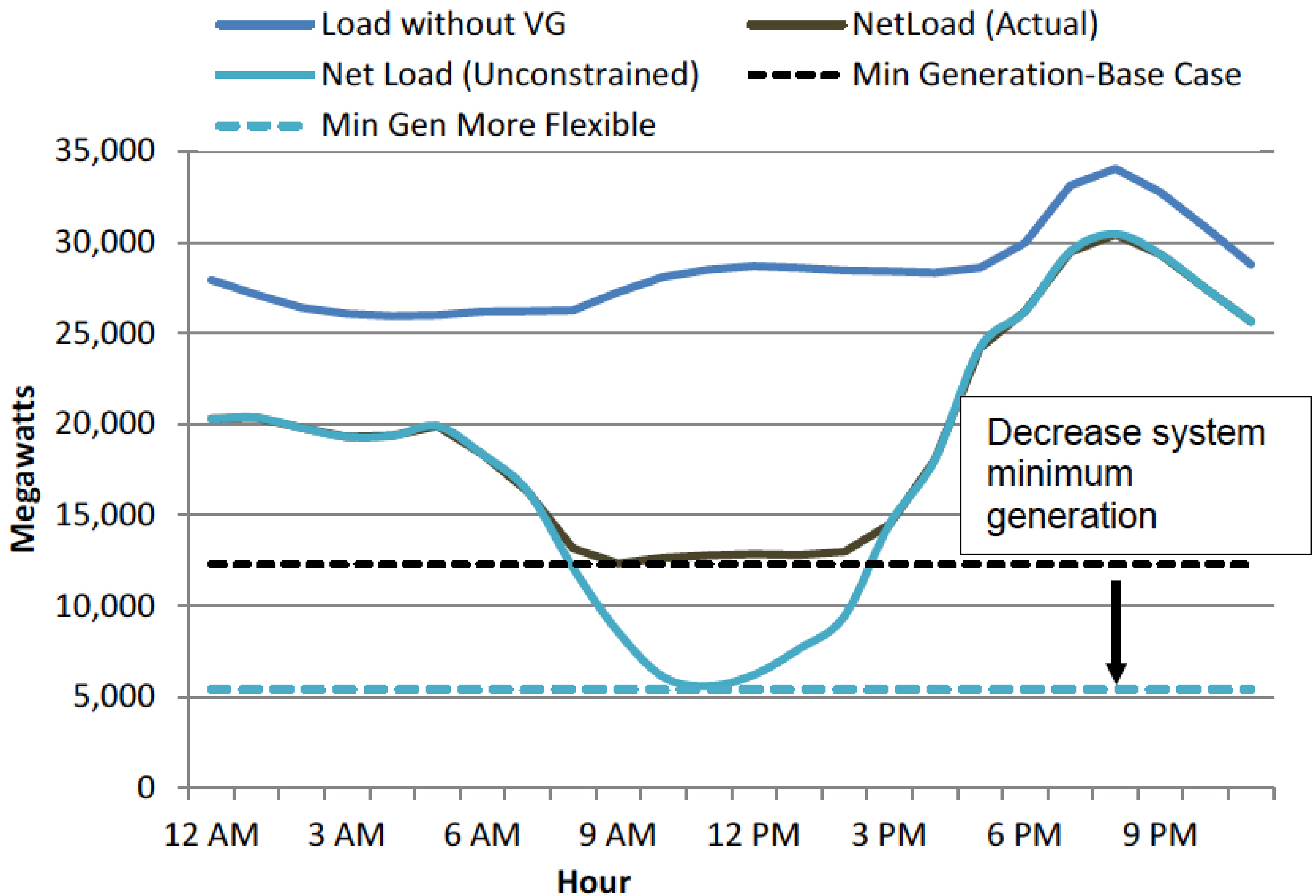
1. **Fatten the Duck**: introduce measures to increase the flexibility of existing power plants and make it easier for the power system to sustain lower minimum (i.e. residual, post-solar PV) loads
   - e.g. reducing must-run capacities, removing inflexible assets, etc.

2. **Flatten the Duck**: Shrink the belly of the duck by shifting supply and demand to other times of the day.
   - e.g. boosting daytime demand via demand response, storage, power-to-x, etc.

Sources: https://www.nrel.gov/docs/fy16osti/65023.pdf

Strategies to Deal with the Duck Curve

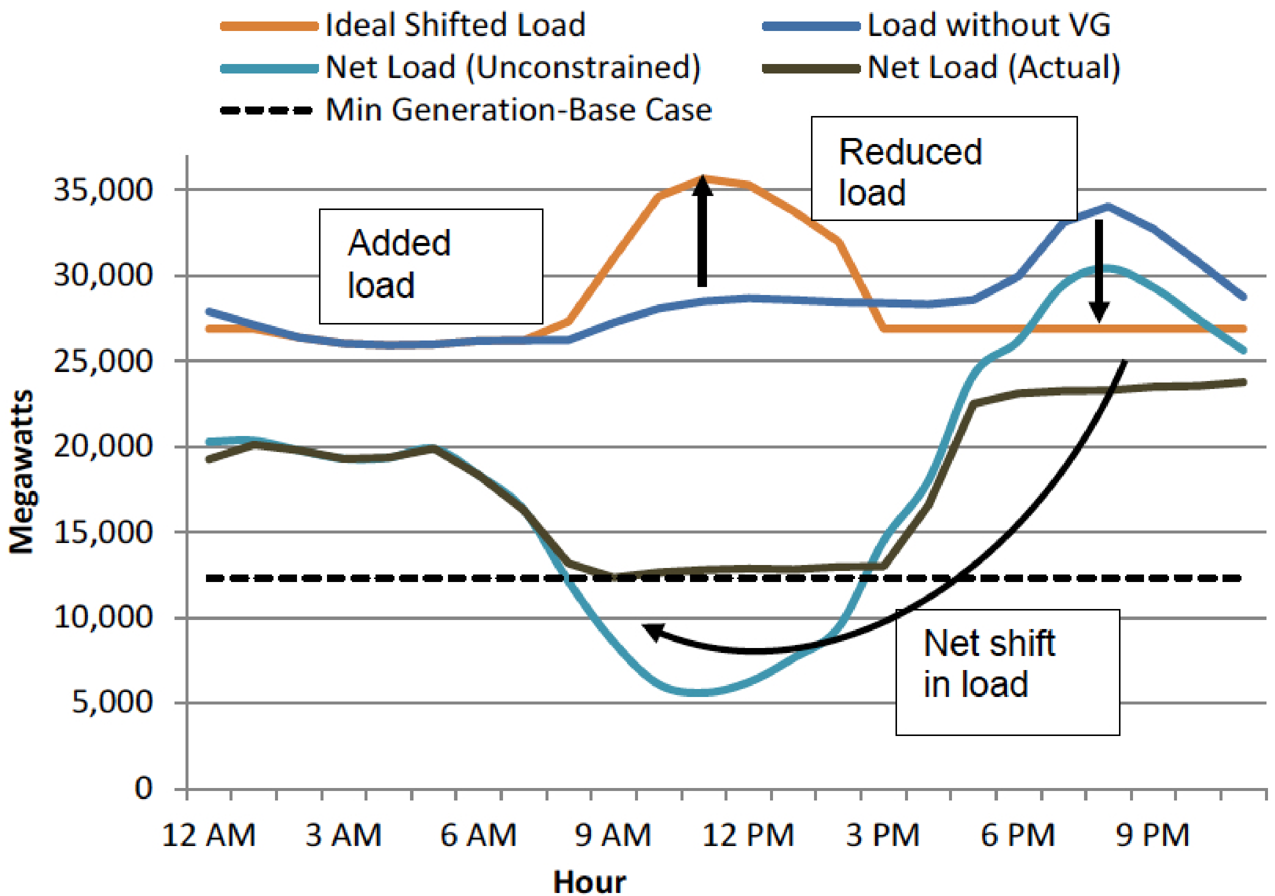
Fatten the Duck:



Sources: https://www.nrel.gov/docs/fy16osti/65023.pdf

Strategies to Deal with the Duck Curve

Flatten the Duck:



Sources: https://www.nrel.gov/docs/fy16osti/65023.pdf

Strategies to Deal with the Duck Curve

The other obvious strategy, and the one that many utilities would be inclined to use if allowed is simply to curtail solar PV output: i.e. stop accepting solar PV during those daytime hours

However, not only would this risk undermining the economics of many solar PV projects (which rely on their power output to repay their loans), it would also be **counter-productive**, as the power system would effectively be rejecting clean, locally produced power in favor of inflexible, non-renewable power

Photo credits: RENAC

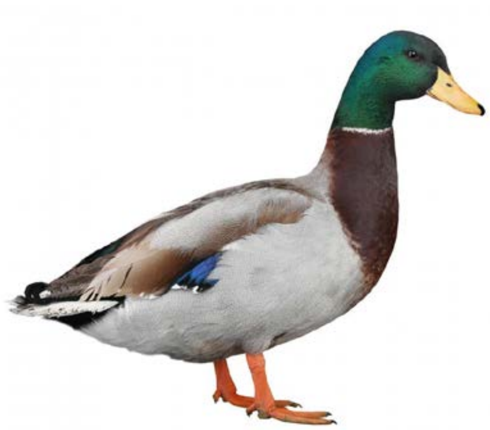
Sources: https://www.nrel.gov/docs/fy16osti/65023.pdf

Strategies to Deal with the Duck Curve

The aim is ultimately to use fewer non-renewable resources during the daytime by making optimal use of the existing solar PV generation on the network: also, to avoid over-generation (where supply exceeds load)

This can involve either creating more load during the daytime, when the sun is shining, or shifting other loads that currently occur in the evening (e.g. air conditioning) to earlier in the day

There is a wide range of ways in which these and other related objectives can be met.



Sources: https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingtheduck2-2016-feb-2.pdf

1. Scale-up energy efficiency

Energy efficiency can help reduce both the evening peak, as well as the steepness of the evening ramp

Increases in the efficiency of lighting (i.e. LEDs) have already contributed to mitigating the evening peak in most jurisdictions around the world

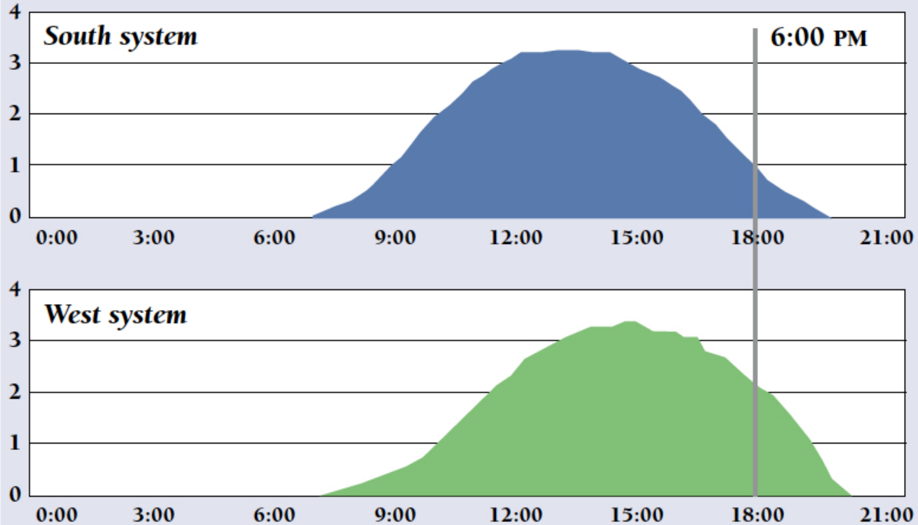
Efforts to boost efficiency of air conditioners, TVs, etc. can help further

2. Orient solar PV panels to the west

Orienting solar PV panels to face west shifts the traditional "bell curve" output of a solar PV project

More output in the late afternoon hours (e.g. from 4PM to 8PM), as the sun is setting, is beneficial for the system, as it corresponds better with the overall system's electricity demand profile

Put differently, the value of solar generation at those hours is higher



Source: Pecan Street Research Institute. (2013). South-facing solar cut peak demand from grid 54% - west-facing systems 65%.

Sources: https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingtheduck2-2016-feb-2.pdf

3. Scale-up demand response

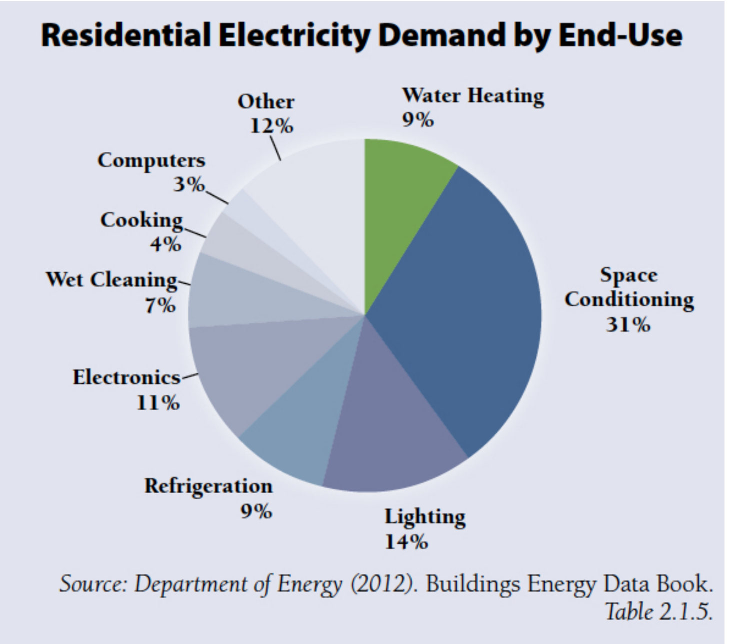
Demand response involves shifting around electricity demand to different times of the day in a smart and coordinated way

Price signals can support demand response, as can other regulatory approaches

Demand response can be led by the market (e.g. by companies, households, and the greater use of smarter home devices) or by the utility

However, in many jurisdictions, there are limits in place on the extent to which utilities can access behind-the-meter resources like appliances

US Household Electricity Demand



Sources: https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingtheduck2-2016-feb-2.pdf

4. Enable utilities to link up dispatchable loads

Dispatchable loads like water heaters, electric vehicle charging, etc. can help "use up" the abundant solar PV generation during the day,

Furthermore, they can help reduce the occurrence of such loads during the critical evening ramp hours

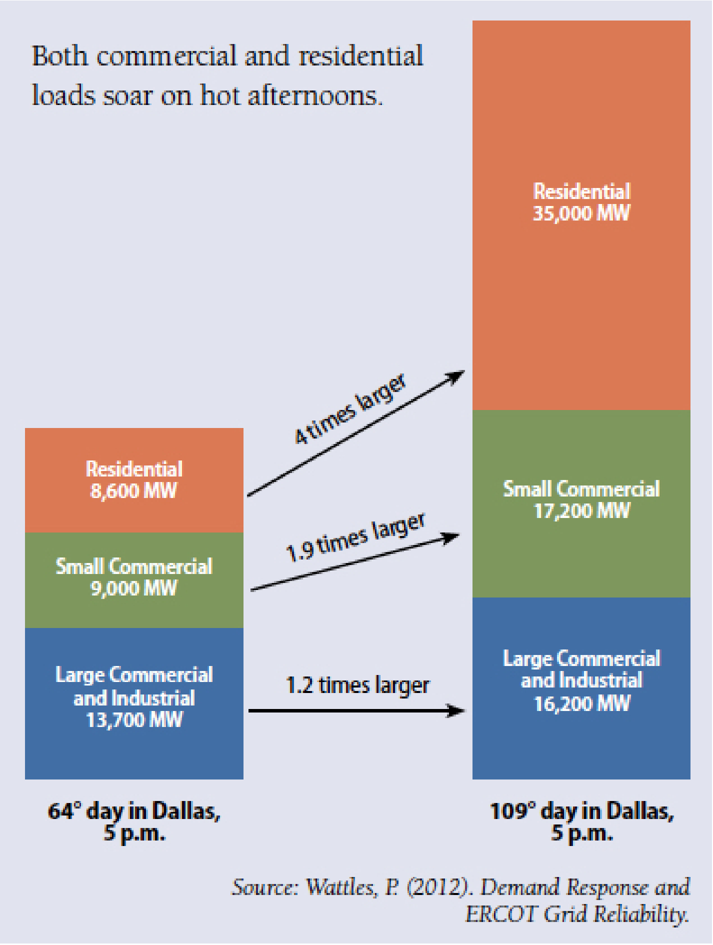
Allowing utilities to own certain behind-the-meter appliances (e.g. water heaters) and lease them to households and businesses, for instance, can enable utilities to use these appliances directly as part of their demand response programs

This can ease the aggregation of customer-sited loads and facilitate load shifting

5. Require air conditioners to integrate thermal storage

Air conditioners represent a major component of the evening ramp in many countries around the world

Requiring air conditioners to be equipped with thermal storage, or to rely on ice storage, can enable them to ”charge up” with cooling energy during the day and release it in the early evening hours, thereby alleviating this additional stress on the grid



Sources: https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingtheduck2-2016-feb-2.pdf

6. Apply demand charges (or time-of-use rates) for the ramping hours

Using higher demand charges specifically during the critical ramping hours can help to trigger price-driven changes in electricity demand

Similarly, time-of-use rates can help discourage consumption during those hours of the day

Behavioral change, driven by price signals, can therefore help alleviate stresses on the grid

7. Increase the use of Power-to-X

Electricity can be converted into a wide range of end-use applications, including fuel cells, storage, hydrogen, among others

By scaling-up the use of power-to-x, electricity markets can increase their ability to use up the large volumes of daytime generation from solar PV, thereby reducing the depth of the residual (post-PV) load

Power-to-x can ultimately help create new sources of daytime demand that can be more easily modulated in relation to solar PV output (or daytime spot market prices)

8. Expand regional power trading

By expanding balancing areas, and facilitating the flow of electricity across wide geographic areas, both constraints and over-generation within the system can be minimized

Excess power can be exported to where there is more demand, and shortages can be addressed by bringing in imports

In addition, different geographic regions often have different solar PV generation profiles, due to different cloud cover, weather patterns, etc., making it advantageous to link regions together

9. Remove inflexible generation plants from the system

One of the major causes of over-generation during the daytime, which contributes to curtailment of solar PV, is the inflexibility of the existing generation fleet

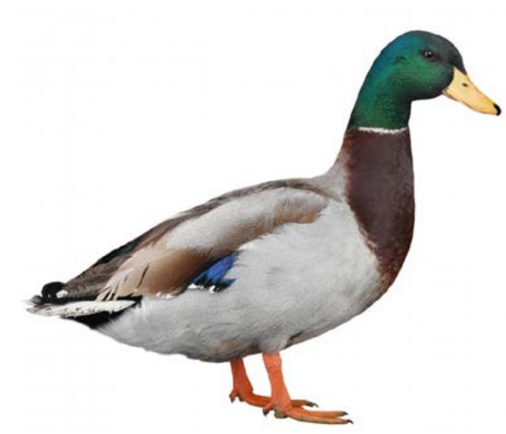
Old coal and nuclear plants, for instance, are typically less flexible, and have a harder time ramping up and down in response to changes in demand; they also often have minimum-run requirements (minimum full-load hours of operation)

This can act as a barrier in the evolution toward more flexible electricity systems

10. Expose solar PV projects to real-time market prices

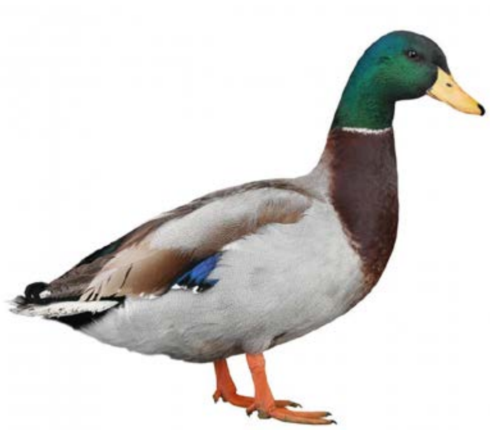
By exposing solar PV to market prices, developers and project owners may have to explore alternative ways of using up their daytime power output and mitigate the risk of being curtailed

Plants could then respond by investing in their own power-to-x facilities, or seek out other ways of adjusting their solar PV output to market prices (e.g. orienting panels westward, to take advantage of higher real-time spot market prices)



11. Deploy storage

Storage can help mitigate the need for curtailment in the system, and help create demand during the daytime hours, effectively storing daytime power output for later



12. Acquire other renewables with complementary production profiles

Acquiring or procuring other renewable energy sources such as hydro, or wind power, that have complementary production profiles can help alleviate some of the challenges associated with grid integration of high shares of daytime PV supply

Hydro with storage capacity can be helpful, as the reservoir helps build up more flexibility in the system, and some wind parks naturally produce more in the evening hours, thereby helping meet the evening peak

Synthesis: Strategies to Deal with the Duck Curve

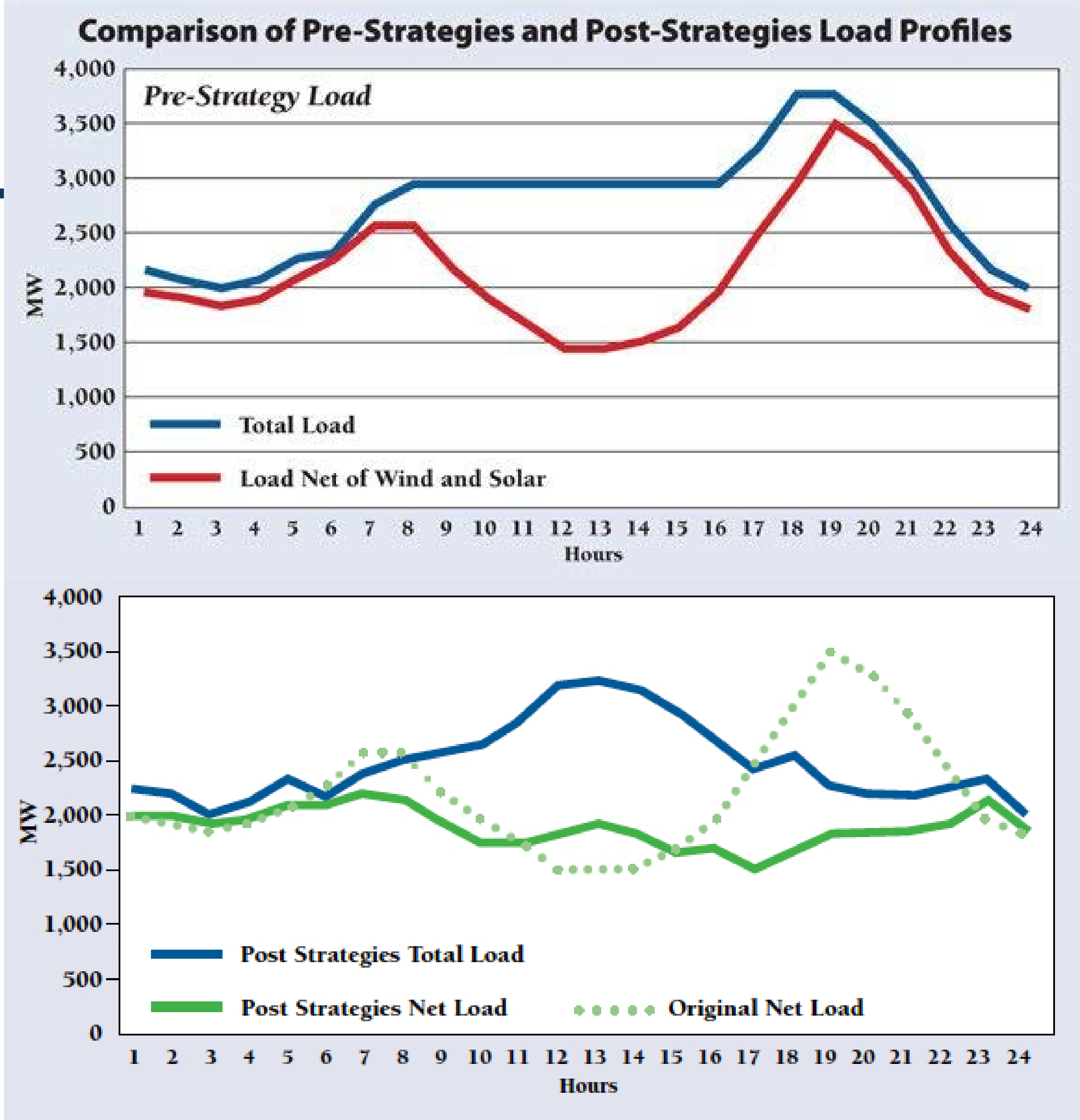
1. Scale-up EE for the hours of the rapid ramp (early evening)
2. Orient solar PV panels to the west
3. Scale-up demand response
4. Enable utilities to link up to dispatchable loads
5. Require air conditioners to integrate thermal storage
6. Apply demand charges (or time-of-use rates) for the ramping hours
7. Increase the use of Power-to-X
8. Expand regional power trading capacity
9. Remove inflexible generation plants from the system
10. Expose solar PV projects to real-time market prices
11. Deploy storage
12. Acquire other renewables with complementary production profiles

Sources: https://www.nrel.gov/docs/fy16osti/65023.pdf

Impacts?

In California, modeling a number of these measures together yielded the following results:

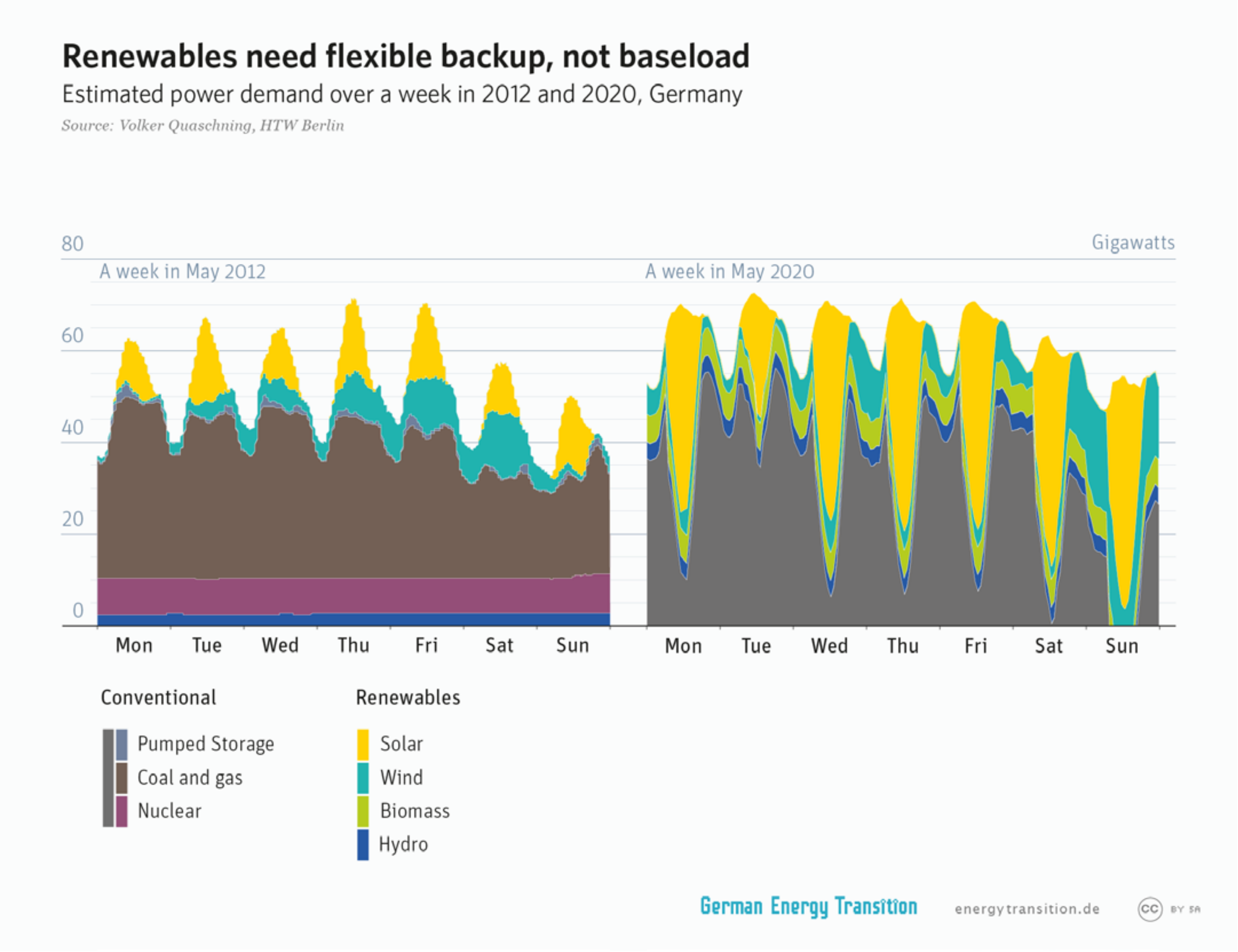
- A smoother demand curve, softer evening ramp, and more manageable power system



Sources: https://www.greentechmedia.com/articles/read/10-ways-to-solve-the-renewable-duck-curve#gs.tzijo8

4. Concluding Remarks

Concluding Remarks



Sources:

Concluding Remarks

Four Main Factors Define the Challenge of integrating VRE:

1. **Geographic spread** of RE development

2. Extent of **existing flexibility** in the system (e.g. hydro, OCGT)

3. **Level of interconnection** with neighboring jurisdictions

4. Overall **size and mix of RE** portfolio

Sources:

Concluding Remarks

The Duck curve entails a fundamentally different approach to operating the power system

A portfolio of approaches will be required to integrate high and growing shares of solar PV

5. Further Reading

Further Reading

Original Denholm Paper (2008): https://www.nrel.gov/docs/fy08osti/42305.pdf

Follow-up Paper (2016): https://www.nrel.gov/docs/fy16osti/65023.pdf

RAP 2016: Teaching the Duck to Fly: https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingtheduck2-2016-feb-2.pdf

E3 Analytics 2018. Introducing the Shark Curve: http://www.e3analytics.eu/wp-content/uploads/2018/05/Analytical-Brief_May-2018_FINAL.pdf

Thank you for your time!

INTERNATIONAL SOLAR ALLIANCE

E3 ANALYTICS

IET International Energy Transition

Factor
Ideas for change

CLEAN ENERGY SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

6. Knowledge Checkpoint: Multiple Choice Questions