CFNT
Climate Finance Network Thailand

Integration of Higher Solar and Wind Energy into the Power Grid

CFNT Webinar Series
November 21, 2024

Dr. Tharinya Supasa
Project Lead Southeast Asia Energy Policy
Agora Energiewende

Integration of higher solar and wind energy into the power grid

How to keep the lights on

November 2024

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By the end of this session, you will be able to:

1. Describe the role of the grid in the power system
2. Discuss the challenges posed by the integration of VRE
3. Describe several solutions to facilitate the integration of VRE

The role of grids

Traditional power system operations

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Power system goals

24/7 availability
Resilient to big loss
Can recover when fails
…

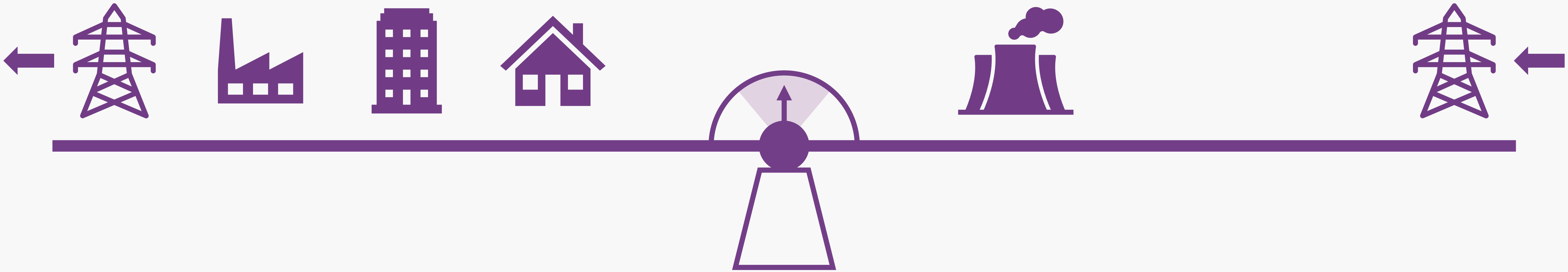
Reliable
High Quality
Affordable
…

Voltage, frequency, etc.
within tight constraints
…

Protect low-income users
Competitive for industry
…

Supply and demand must be balanced instantaneously. Always.

If the balance is too far off, the system crashes, leading to damaged equipment, cascading effects, and ultimately blackouts. Traditionally, our main tool to manage this balance have been conventional, fossil fuel-fired power plants.



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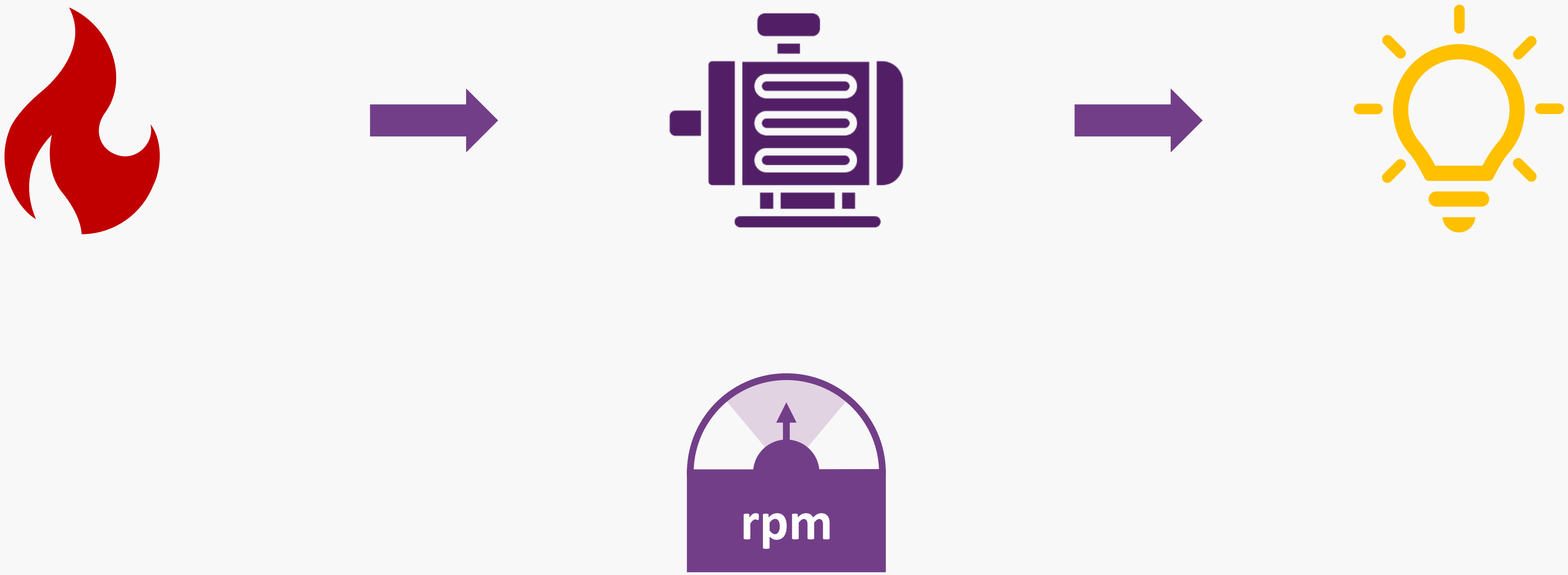
Running a power plant is very much like riding a bike

You put your energy into spinning the pedals so that you can ride off into the horizon

A power plant is just a big bike

Power plants burn fuel to turn water into steam, which spins a steam turbine, which spins a generator that generates electricity



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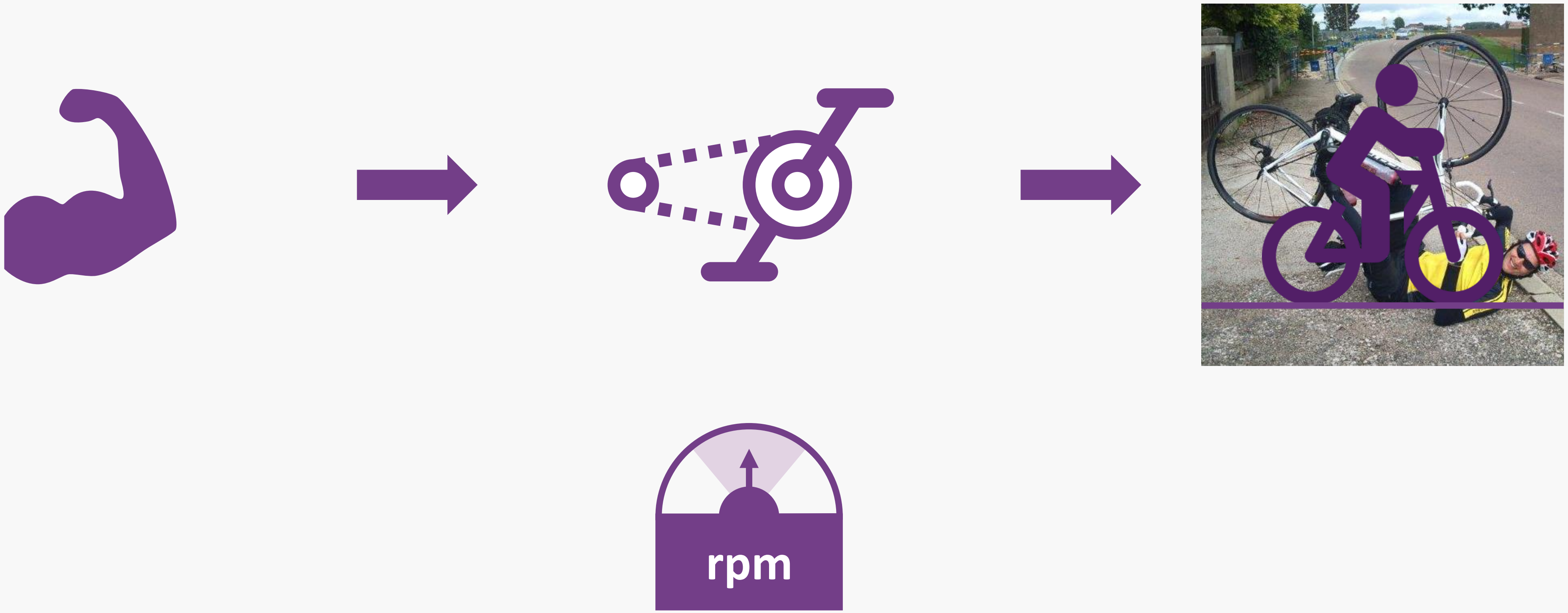
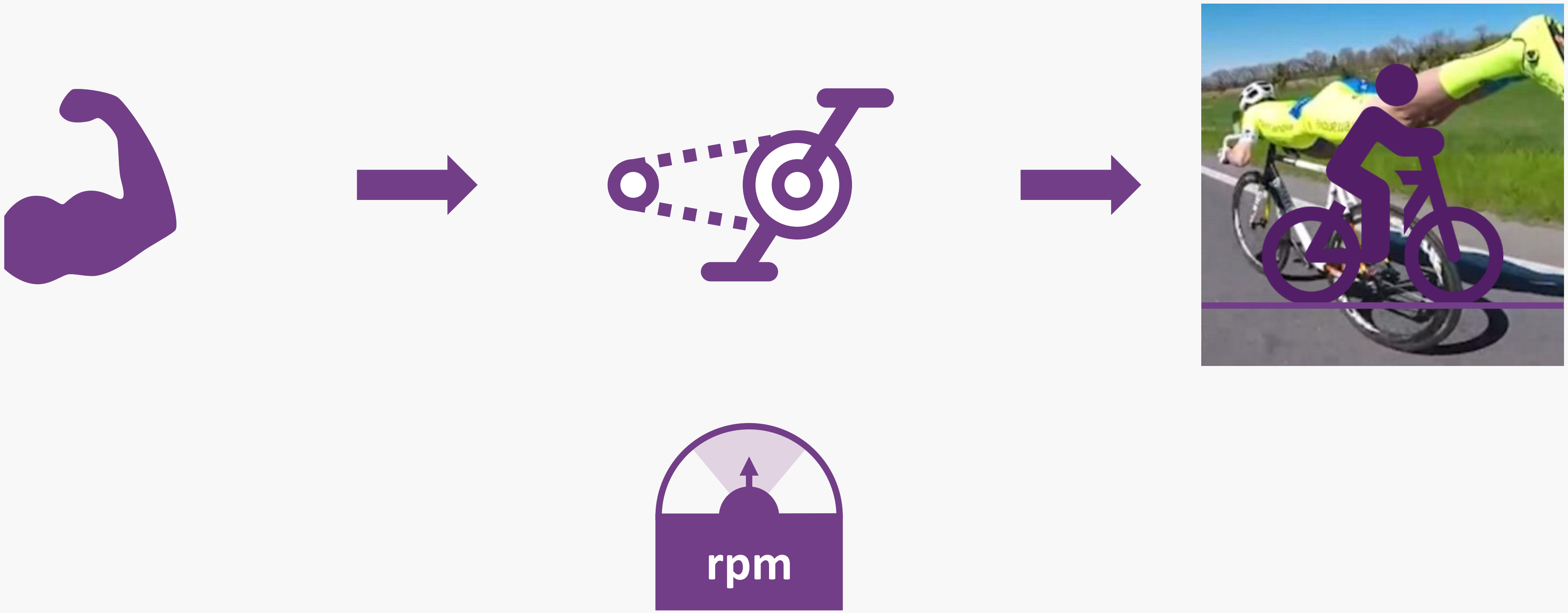
Sadly, the world is not flat: sometimes the road goes uphill…

If you don’t put more power into your pedals as the road goes uphill, at some point you fall over!



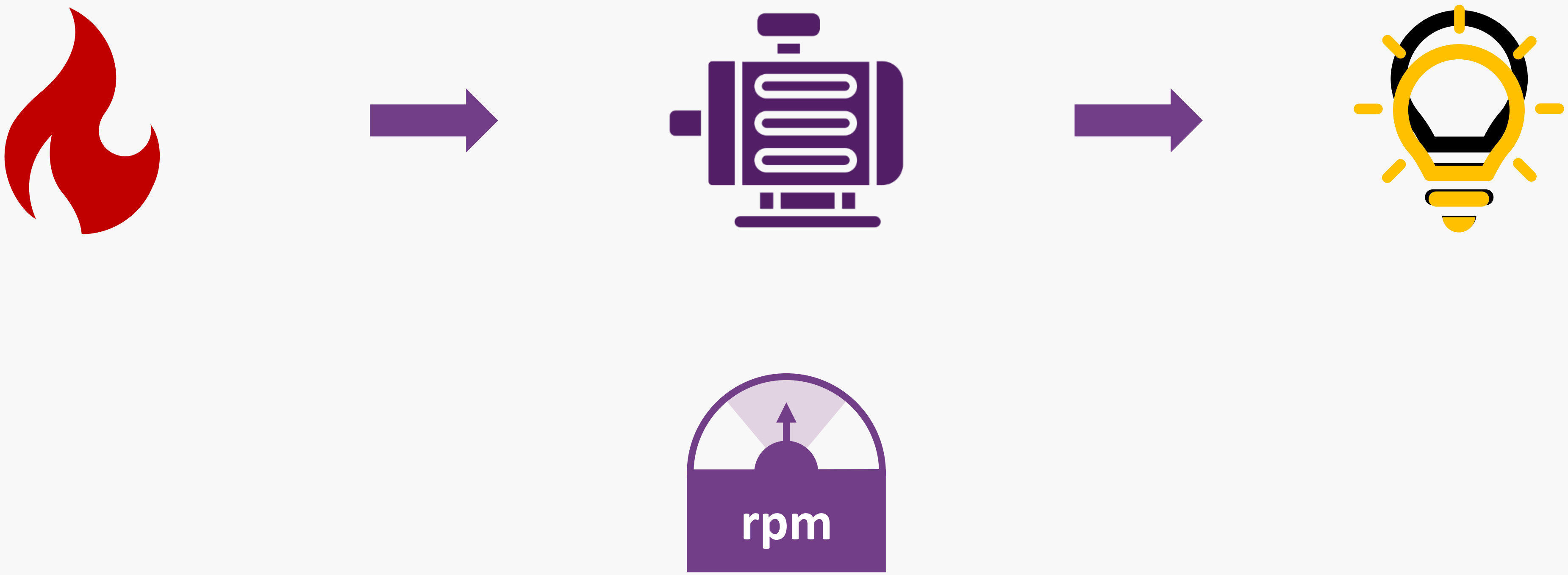
… Sometimes the road goes downhill

If you go downhill and keep putting power into your pedals, your pedals turn so quickly that you lose control



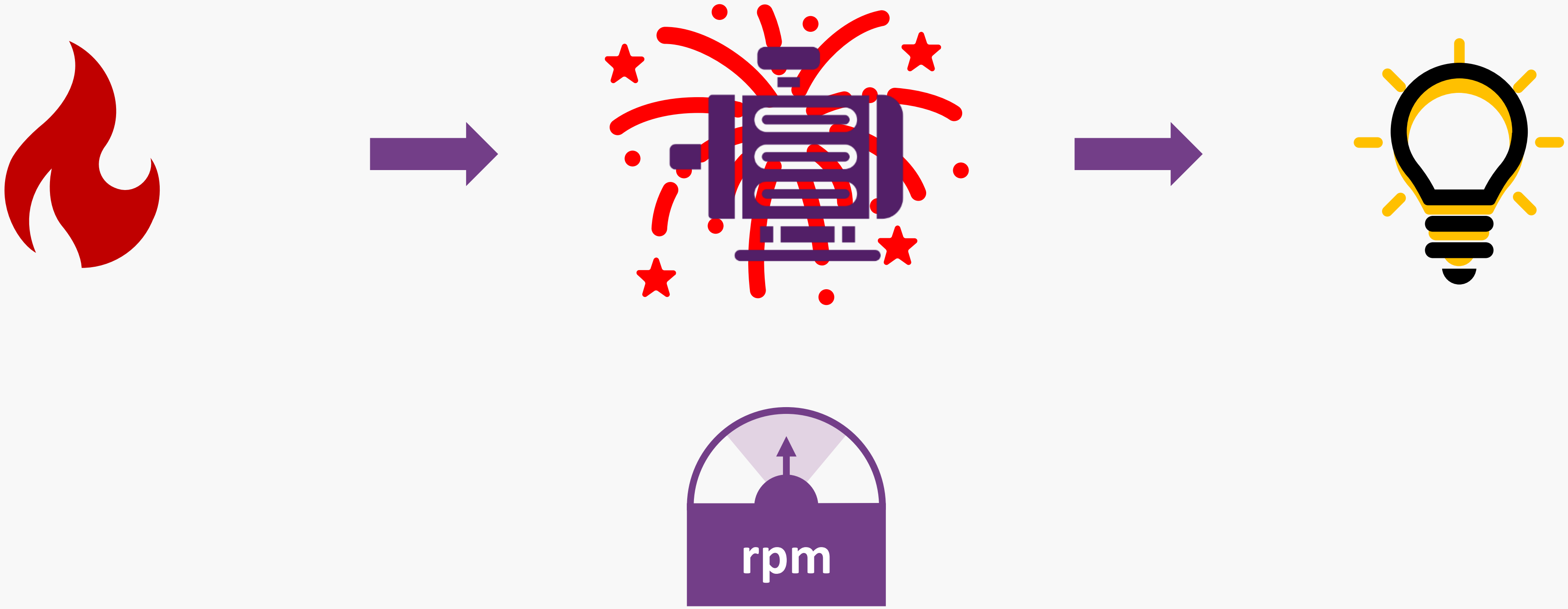
Demand for electricity isn’t constant either: sometimes it increases…

If you don’t burn more fuel to generate more power, at some point the lights go out



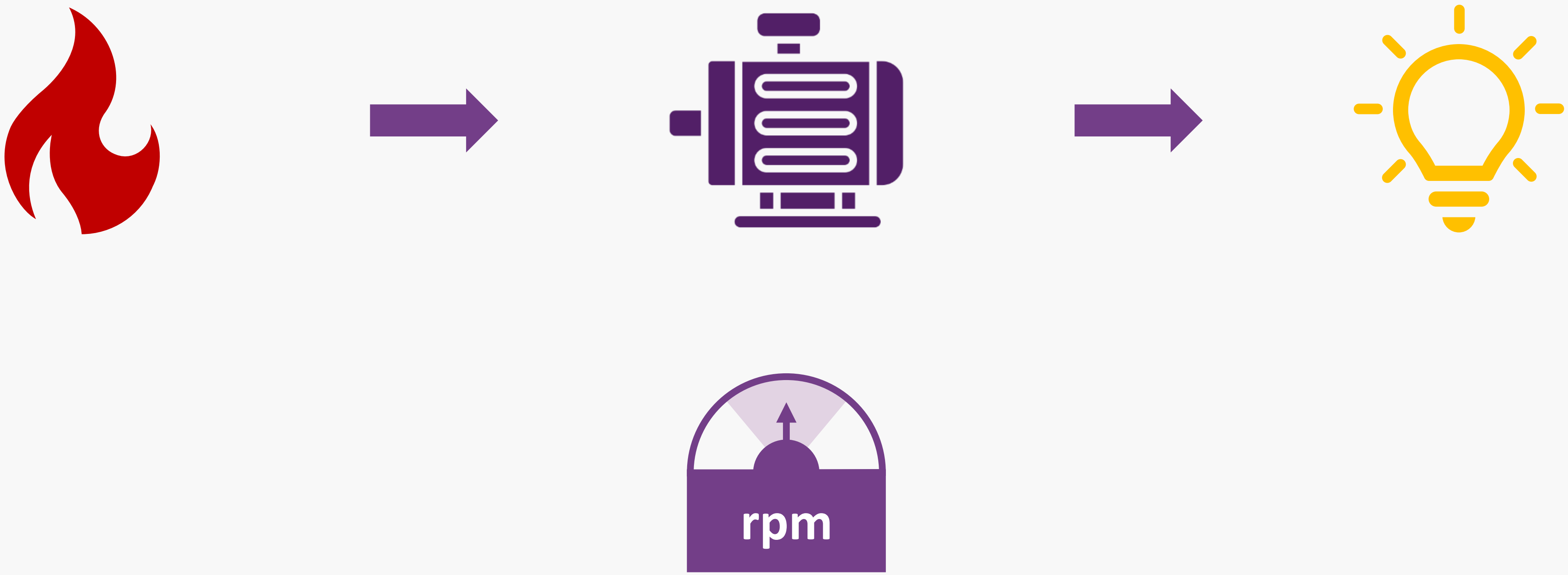
Demand isn't constant either (continued)

If you keeping burning fuel as the demand decreases, the generator spins out of control (and that's an expensive thing to replace)

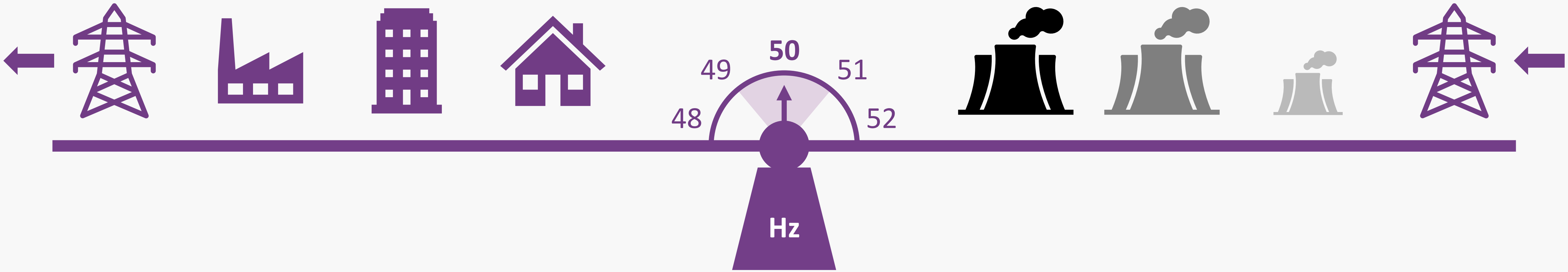


That’s why we like to keep it spinning nice and steady

We all agree on the default speed of a generator, which in most places in the world is 3,000 rpm = 50 rps = 50 Hz



Of course, there is more than 1 power plant in a power system



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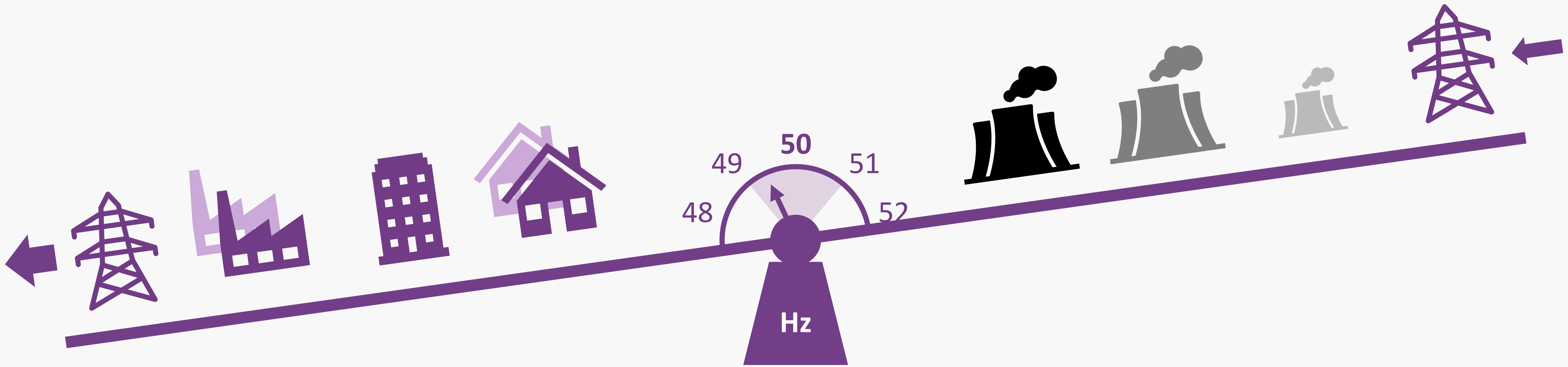
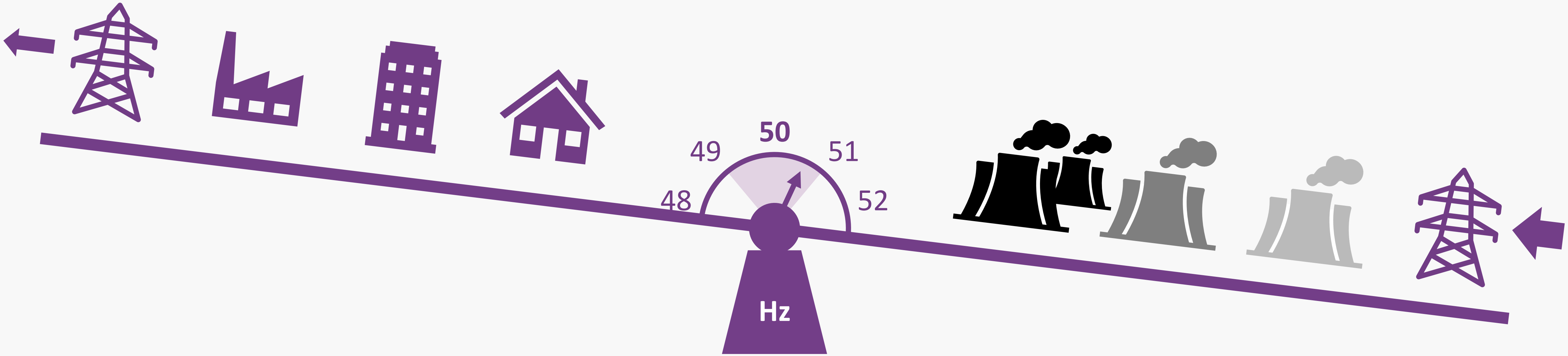
They have to work together to keep the balance (1/2)

A *surplus of demand* will result in a *decrease* of frequency



They have to work together to keep the balance (2/2)

A *surplus of supply* will result in an *increase* of frequency



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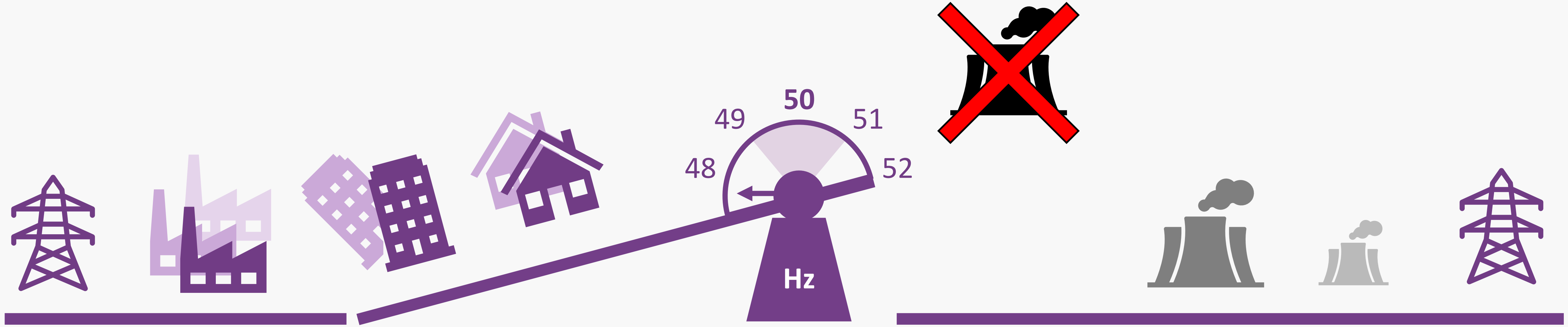
If the imbalance is too big, the system can crash

The frequency being too far outside the safe interval is both a sign and a cause of problems



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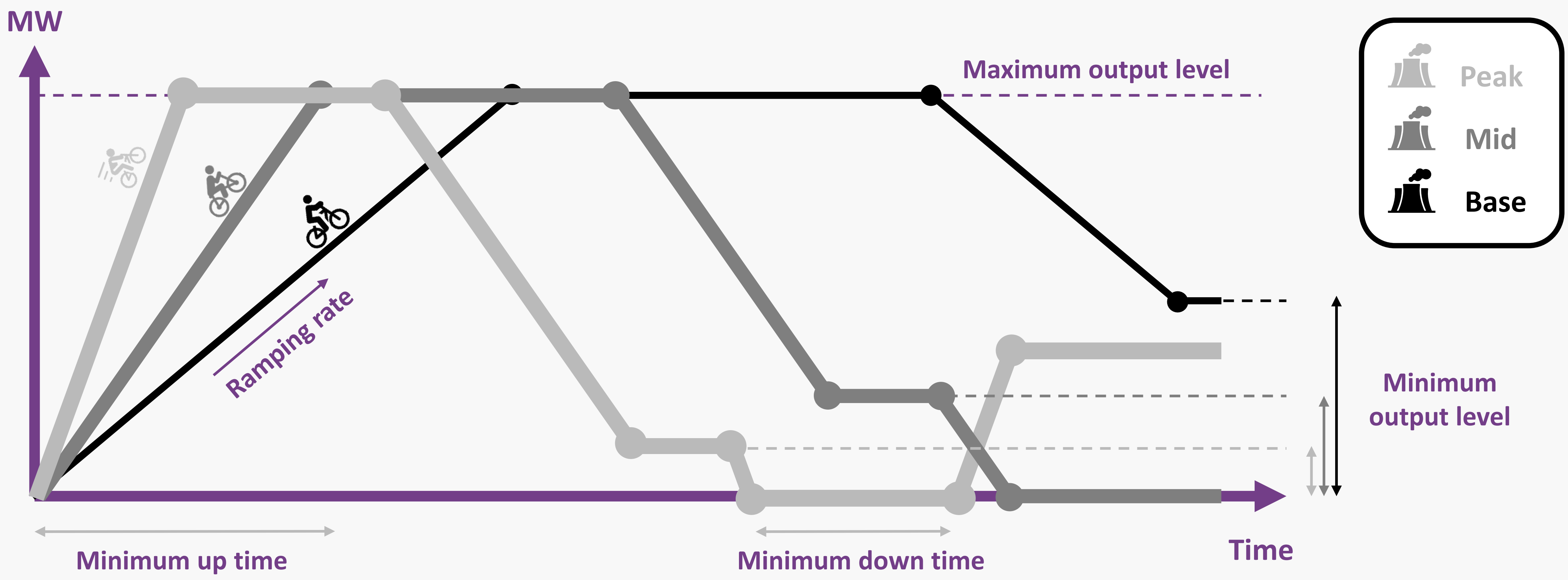
Sadly, there are limits to how quickly plants can adjust



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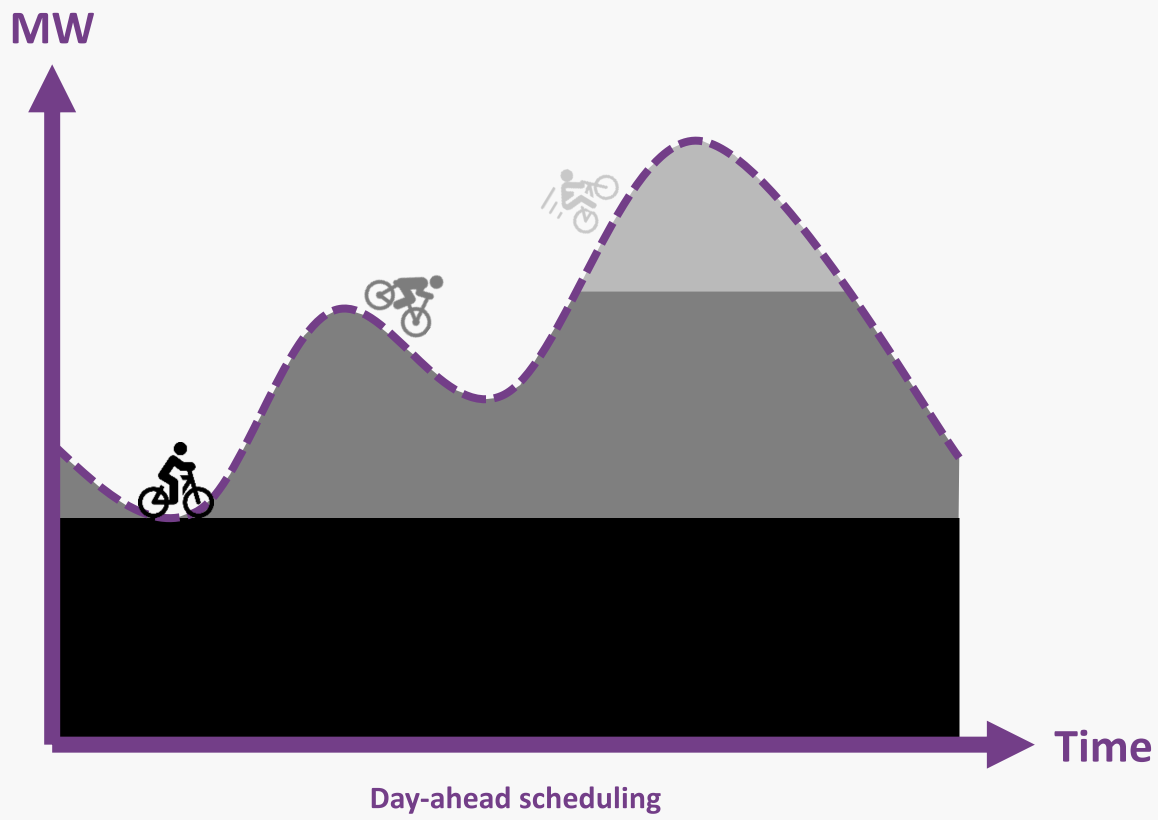
That’s why system operators forecast demand and then schedule generation

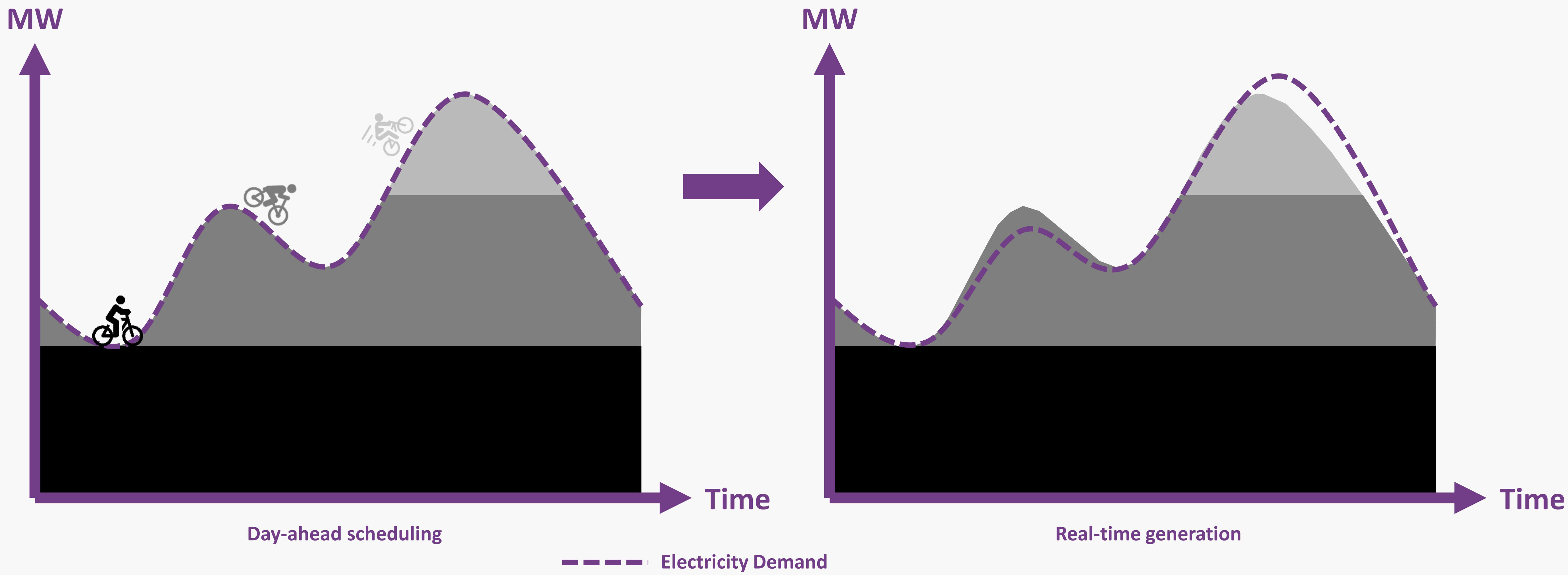
For example, in Europe, scheduling decisions are made at noon for the next day (24h period starting at midnight)



Time

But we can't predict the future…

Which is why we need to keep some fast-acting reserves ready to close the gaps (e.g., fast gas plants or jet engines)



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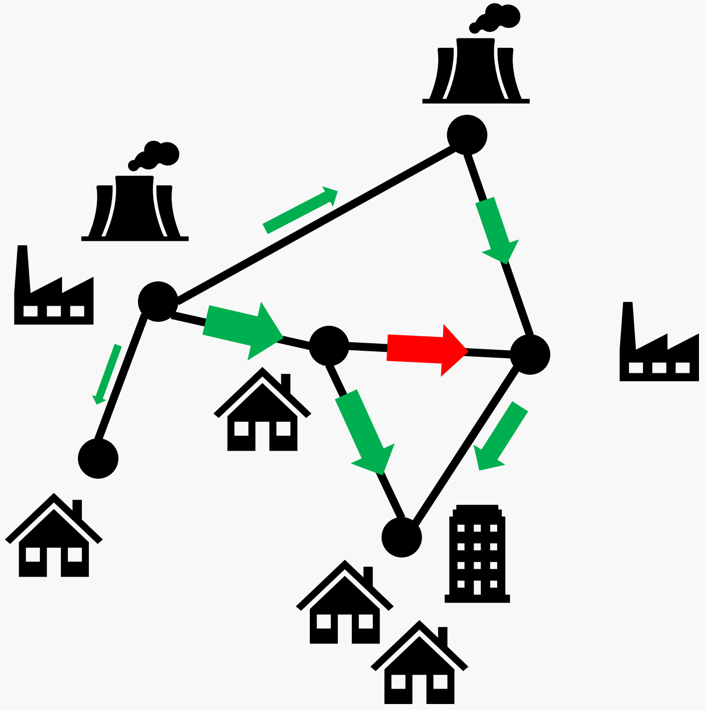
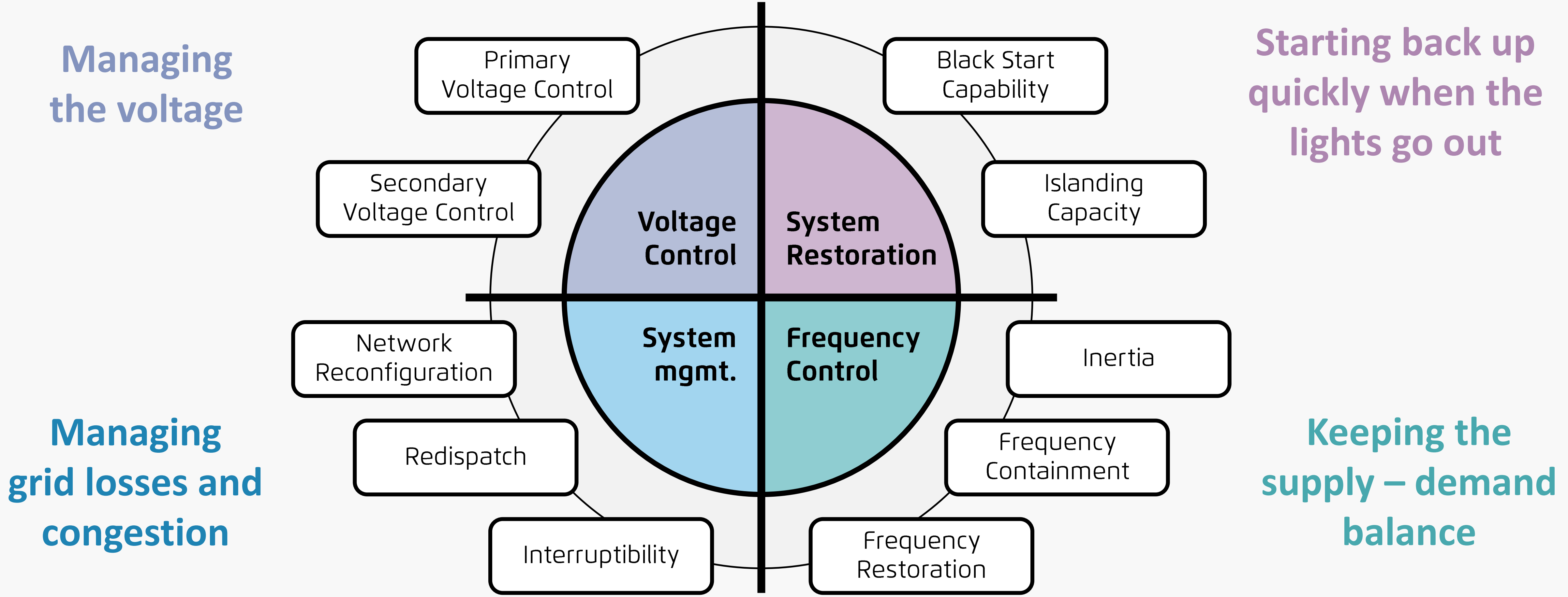
To make it even harder, we can't just send electricity wherever we want it



- Grid lines connecting different locations with supply (e.g., power plants) and/or demand (e.g., factory, apartment buildings) have a **limited capacity** for how much power they can safely and efficiently carry
- Moreover, we **cannot fully control** where electricity goes: the flow of electricity is determined by the laws of physics, not the laws of the market or the wishes of the system operator
- In complex networks this can lead to unexpected results and overloading of specific lines (a.k.a., **congestion**), requiring system operators to intervene to keep lines in safe limits, for example:
  - Redispatch: change how much electricity certain power plants are generating (includes curtailment)
  - Interruptibility: change how much electricity certain users are consuming (typically big factories)

To manage all of this (and other things like the voltage level), system operators have to perform several "system services"



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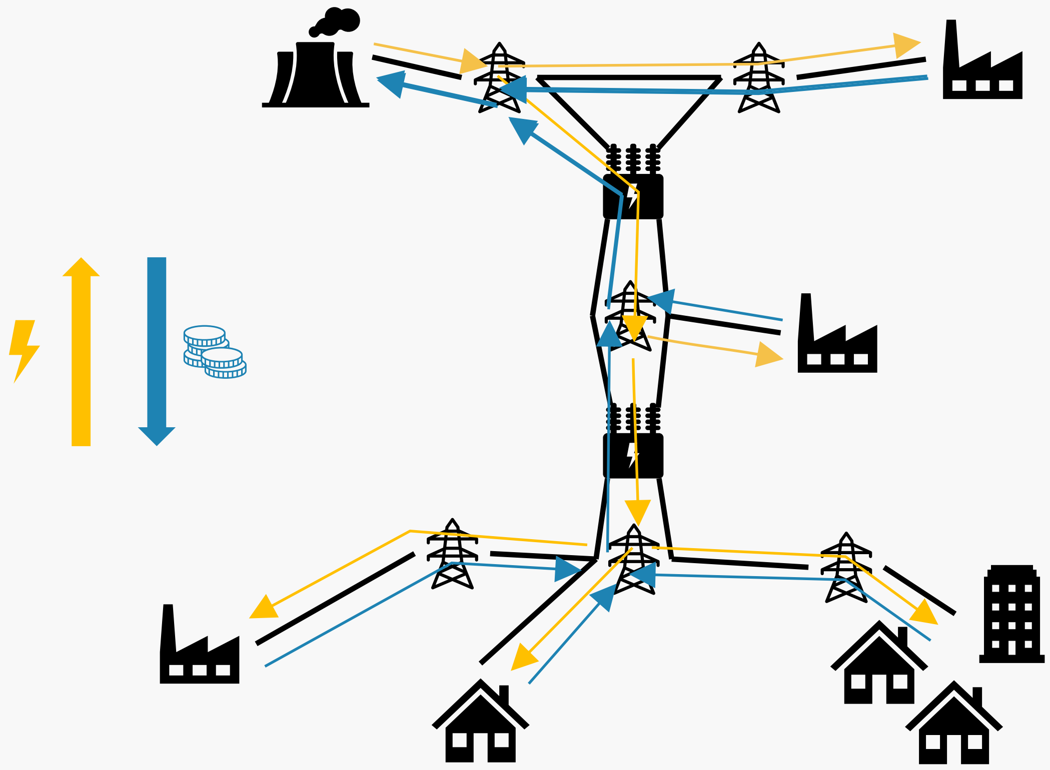
This involves the coordination of a lot of stuff



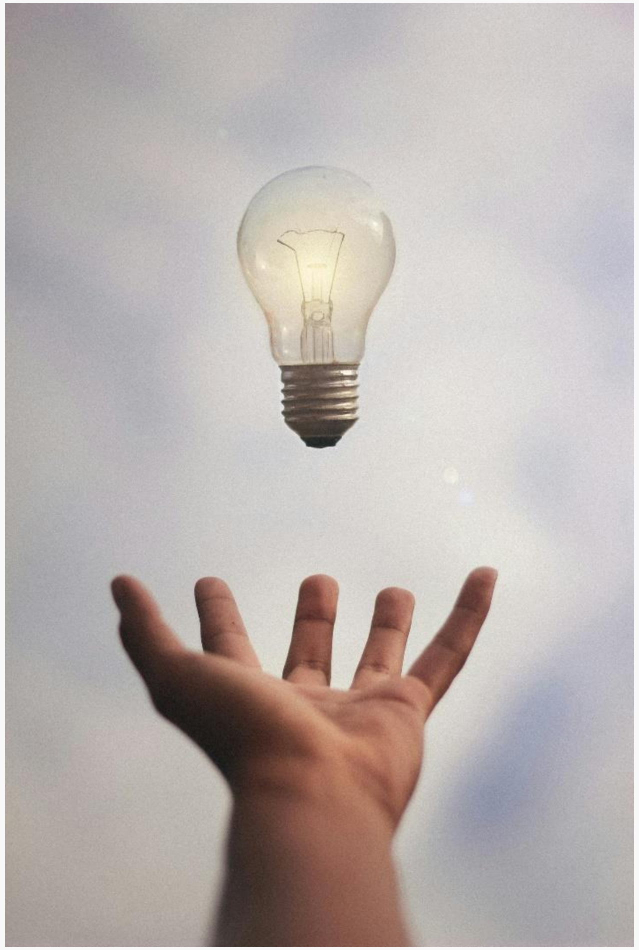
→ **Typical grid stuff**

- **Lines**: cables, pylons, isolators, …
- **Substations**: transformers, bus bars, capacitors, …
- **Protection**: breakers, protection relays, …
- **Dispatch**: supervisory control software, facilities, …
- **Monitoring**: current, voltage, frequency, … sensors
- **Metering**: active/reactive power, “smart” meters

→ **Not-so-typical grid stuff**

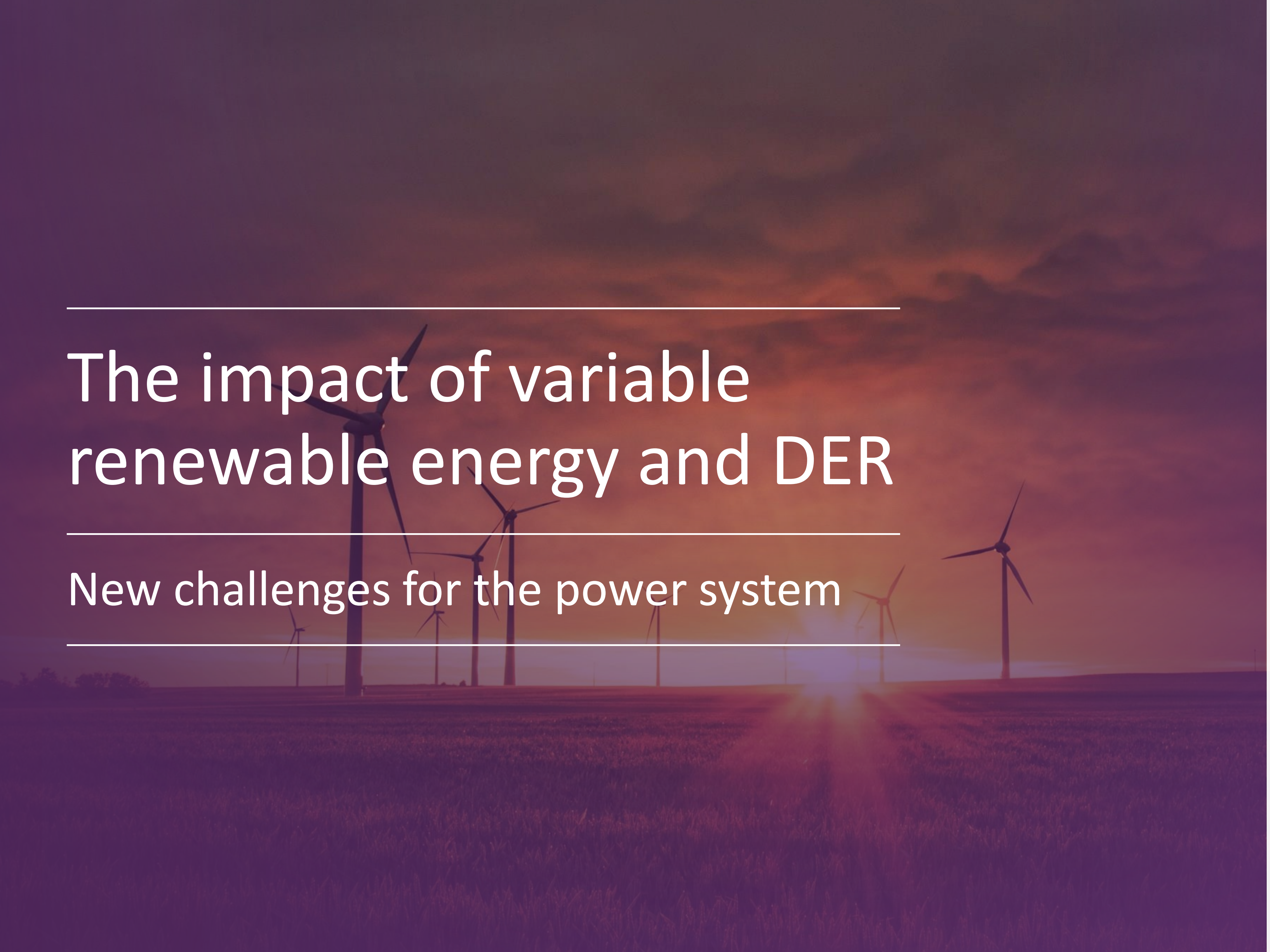
- Power plants
- Large consumers (factories, industry)
- Appliances?

This requires deliberate actions across a variety timescales



That’s all great, but why do I have to think about this now? Isn’t this just the system operator’s job?

Write down in 1-2 sentences, why we are talking so much about grids now.



The impact of variable renewable energy and DER

New challenges for the power system

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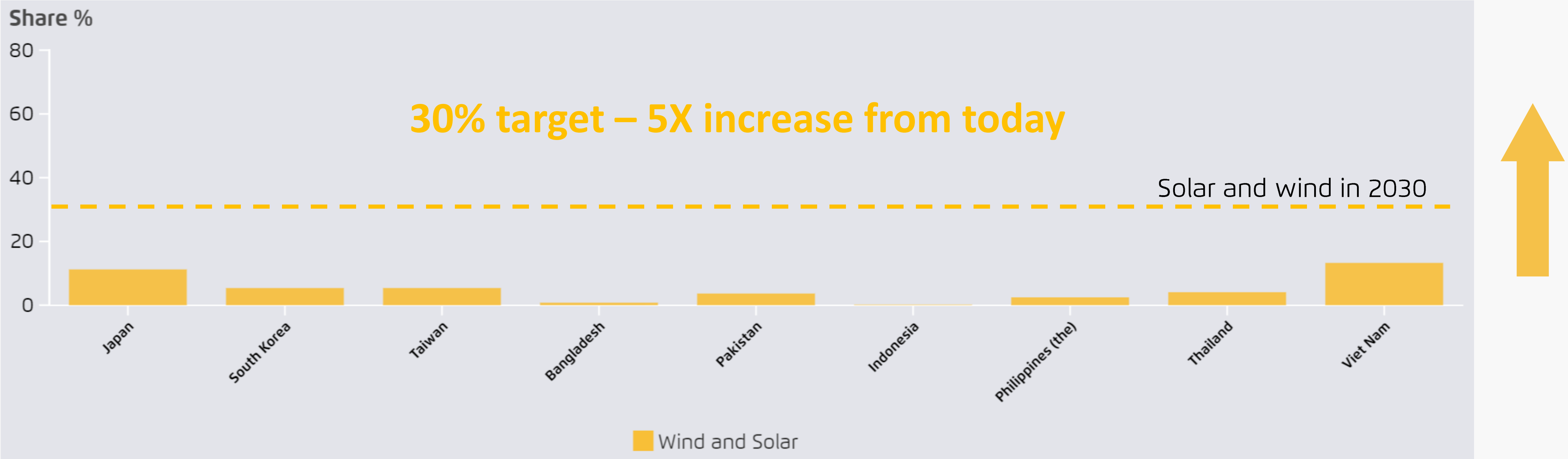
Photo by Karsten Wuerth on Unsplash

Power system goals 2.0

To meet these goals, we need a lot of renewables…

The magic formula:
Electrify as much as possible, and meet demand with clean electricity

In particular, we need a lot of variable renewable energy (i.e., solar and wind):
Share of wind and solar (%) in 2022 and avg share required in 2030 to be aligned with net-zero



What are Variable Renewable Energy Sources (VRE)?

Some, but not all, are also "DER"

Dispatchable Renewable Energy sources
(e.g., hydropower, biomass, geothermal, CSP)

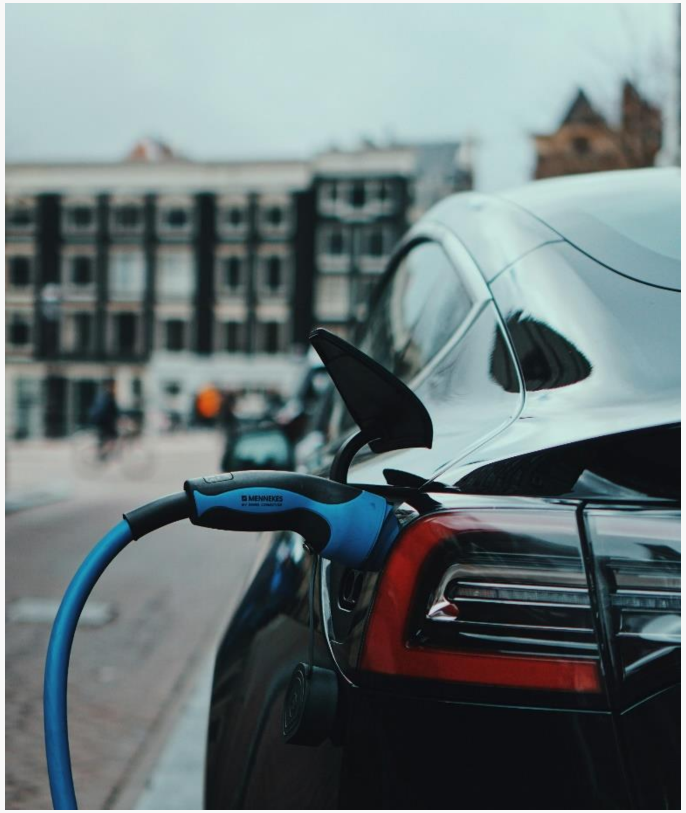
Variable Renewable Energy sources
(e.g., solar PV, on- and offshore wind, tidal)

What are Distributed Energy Resources (DER)?

Distributed **generation**
(e.g., rooftop PV, small-scale wind)

Distributed **storage**
(e.g., Battery Energy Storage)

Distributed controllable **demand**
(e.g., EVs, HVAC, wet appliances)



 | Photos by Benjamin Jopen, Bebat and Precious Madubuike

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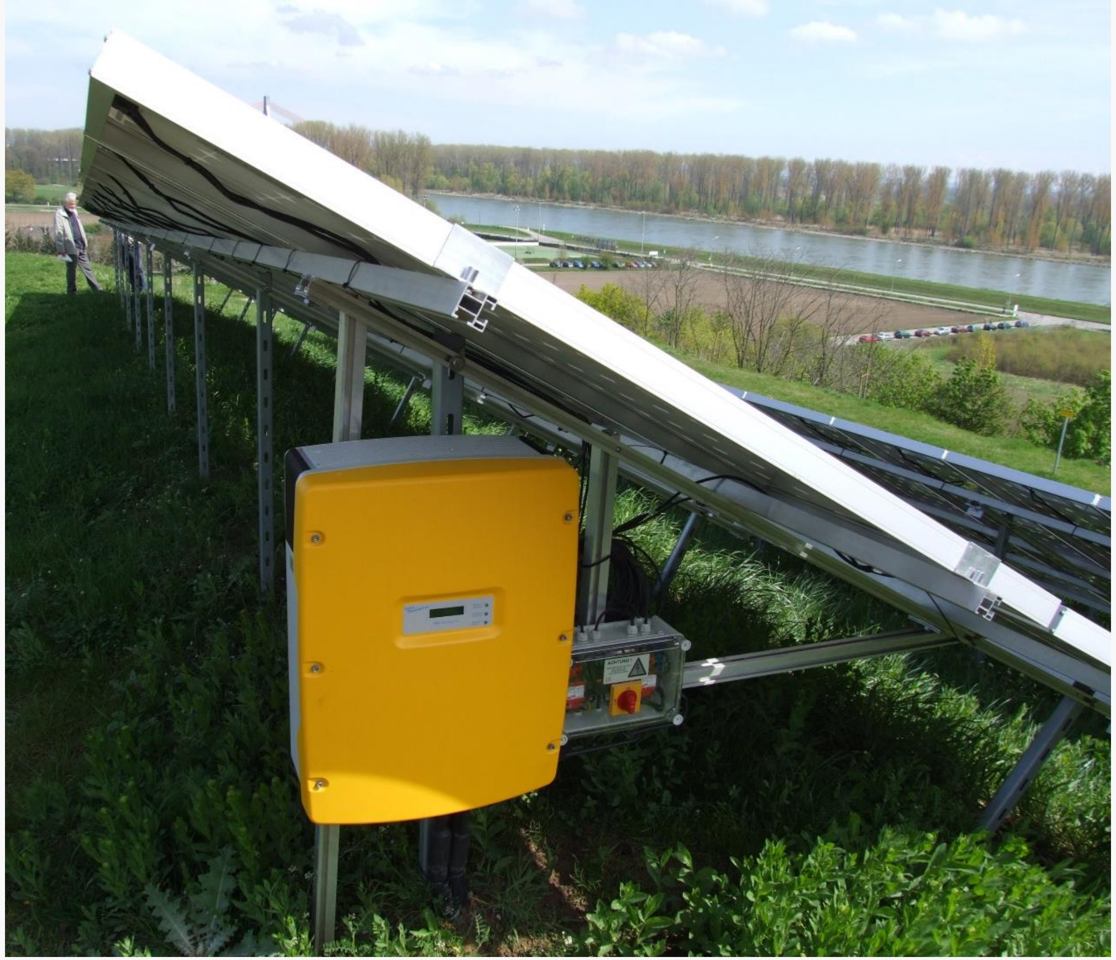
VRES, and certain DERs, are Inverter-Based Resources



Inverter-Based Resources (IBR)

- → Electricity supply or demand resources that use **power electronics** to convert direct current (DC) electricity into alternating current (AC) electricity (or vice versa) to supply (or demand) power to the grid
- → These resources have some particular technical characteristics that differ from conventional power plants (e.g., they don't spin like a bike)

Some common examples include:

- → Solar PV
- → Wind turbines
- → Battery energy storage systems
- → Air conditioning

 | Photo by Claus Ableiter on Wikipedia

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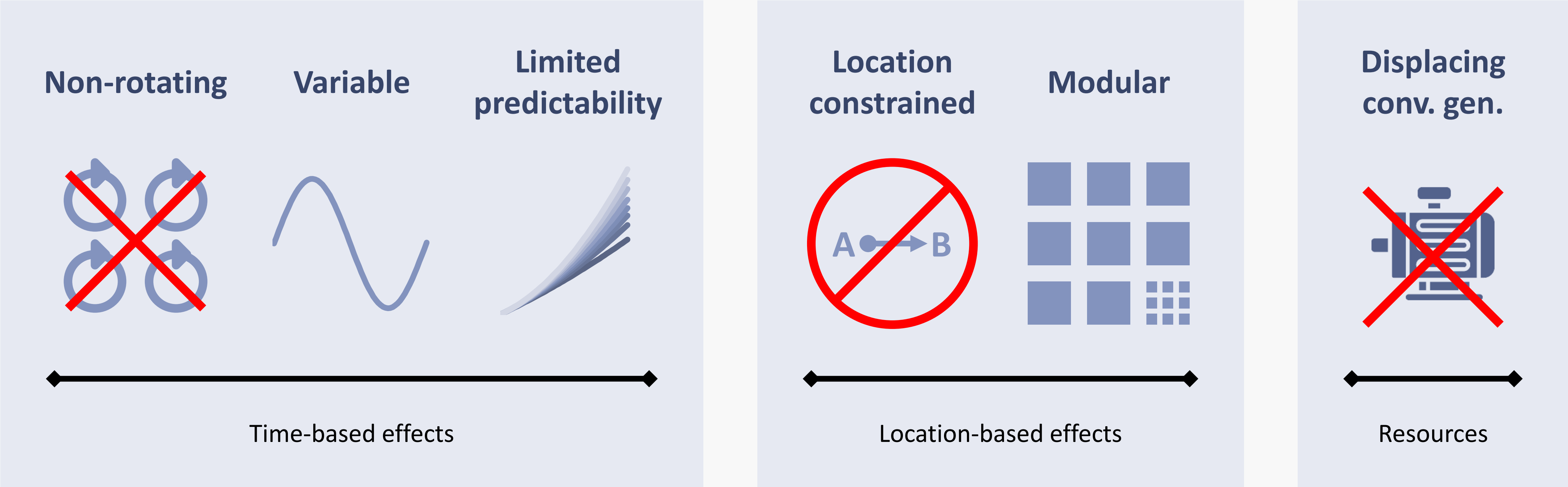
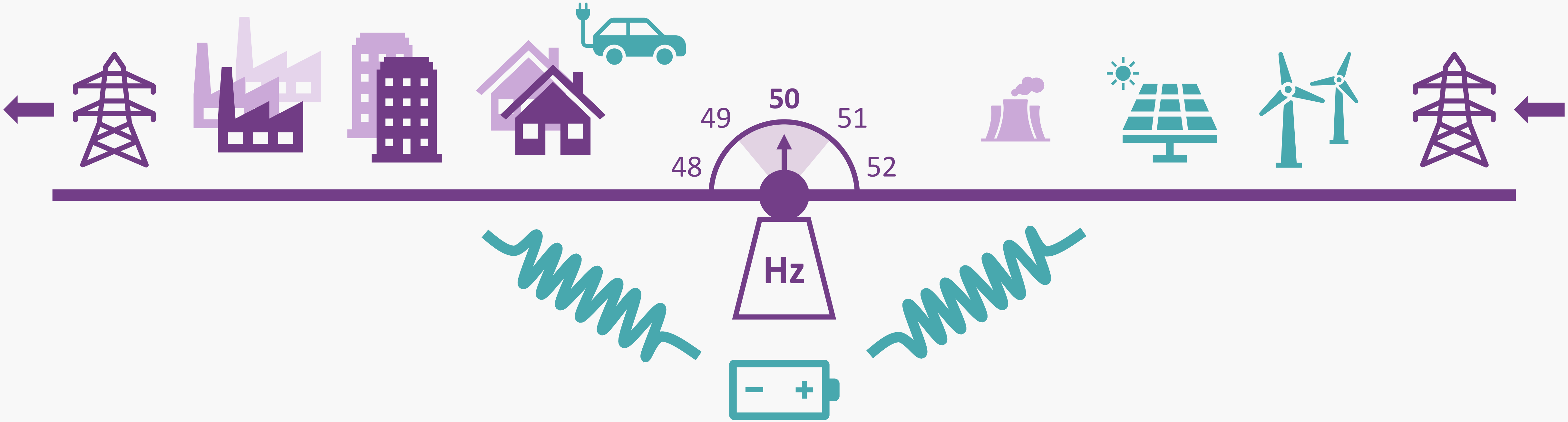
Integrating VRE (i.e., solar and wind) poses some (new) challenges

Variable renewables, like solar and wind, have characteristics that challenge traditional operations & planning practices



VRE and (uncontrolled) DER make it harder to keep the balance

More variable generation, growing demand, and new technologies are changing the operational reality



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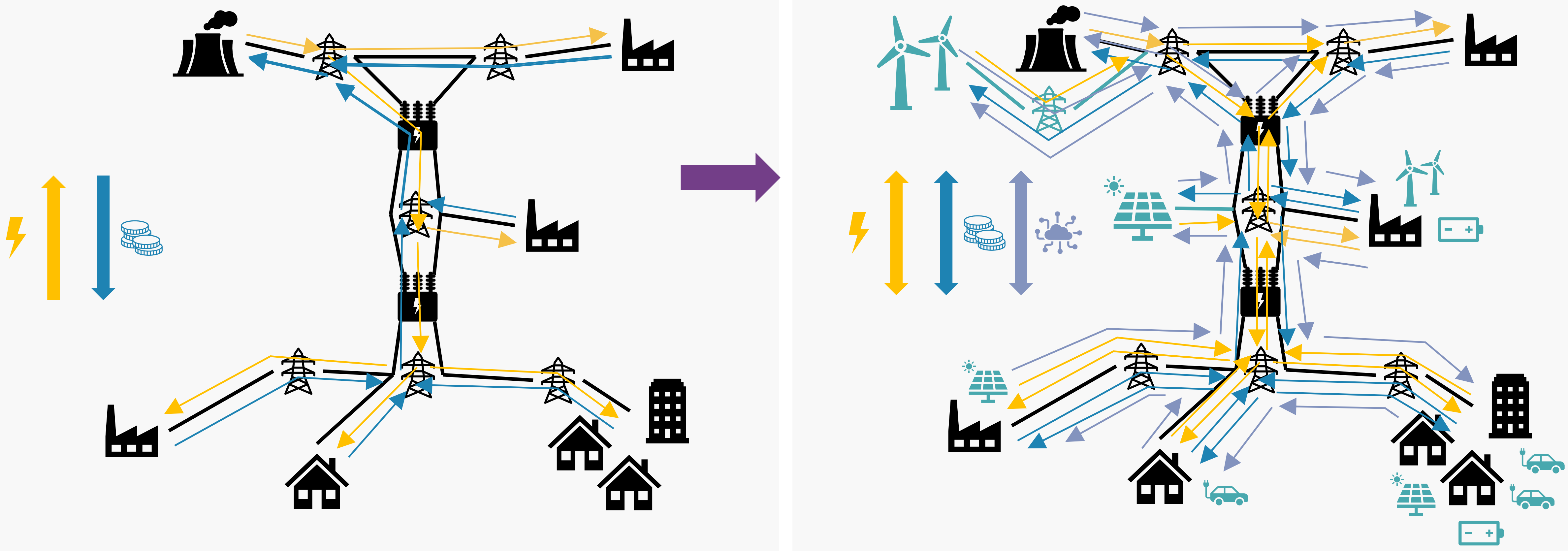
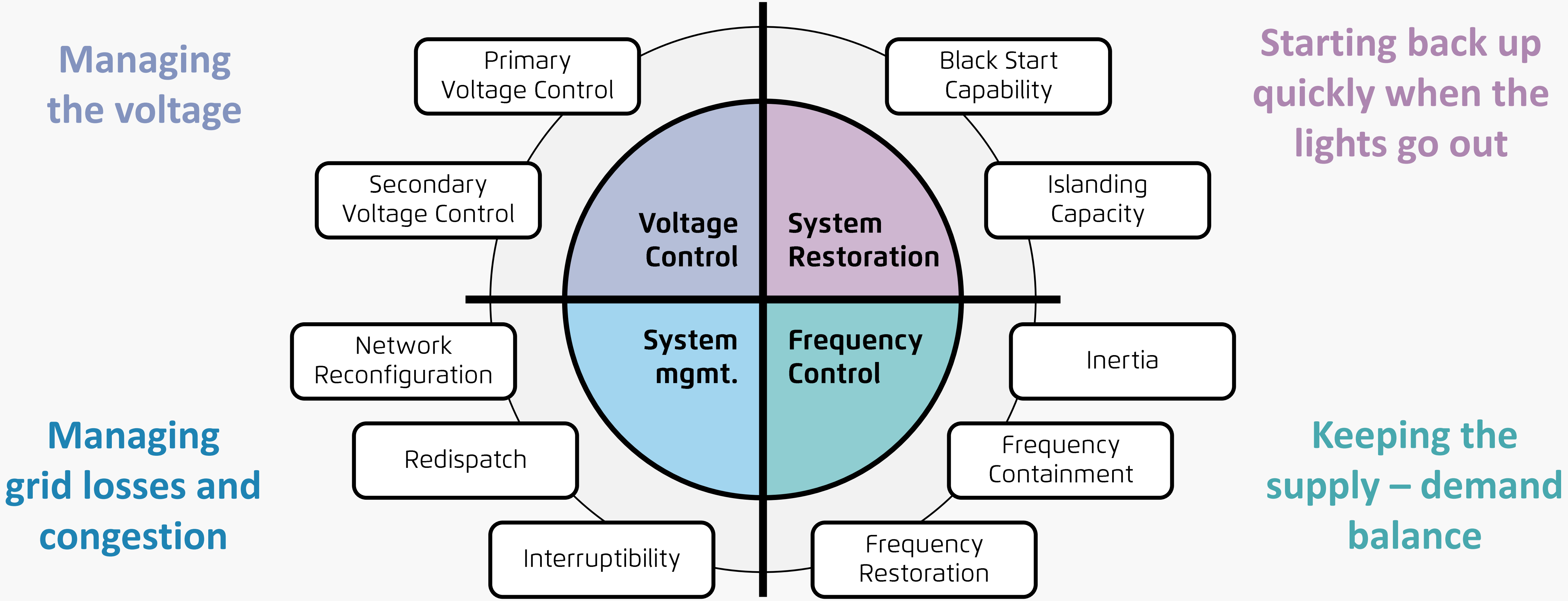
VRE and DER change the reality of the grid

From a **top-down, centralized** grid…

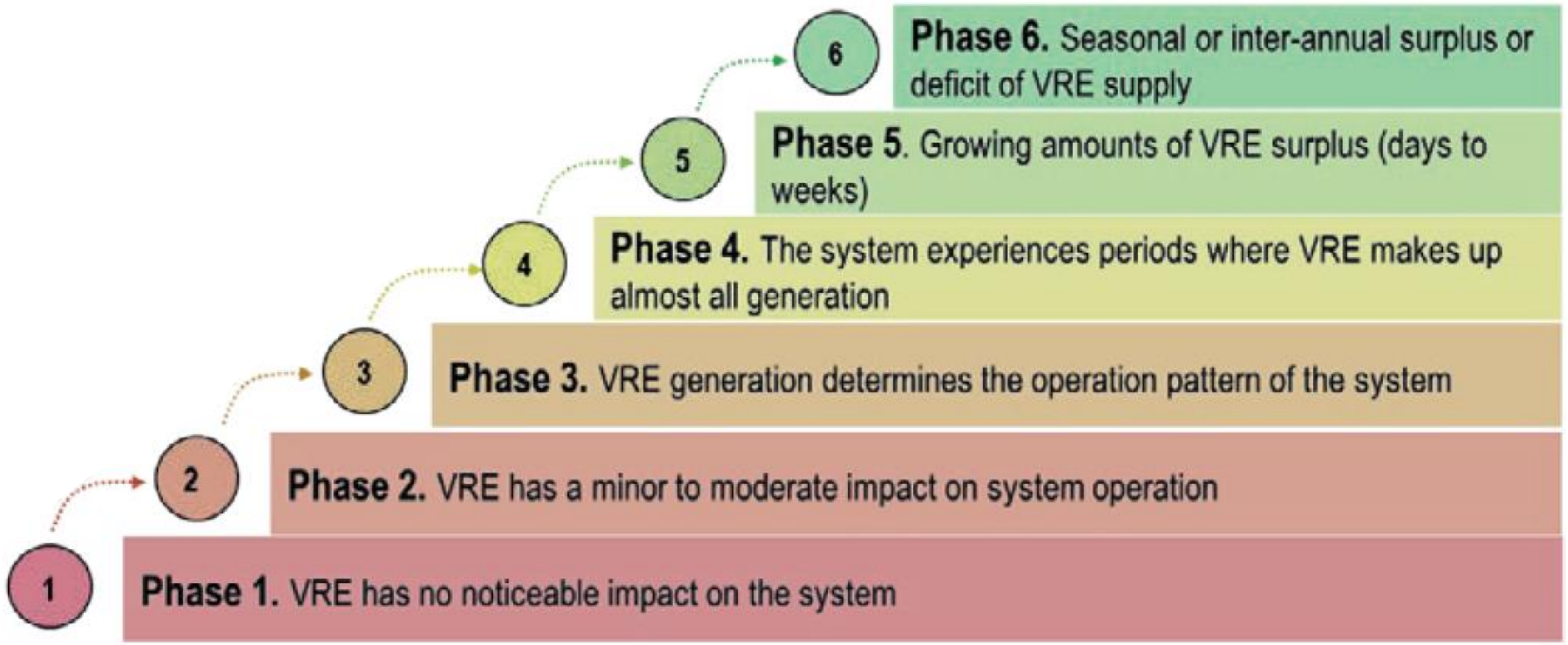
… to a **bi-directional, decentralized** grid



This changes the supply and demand for system services

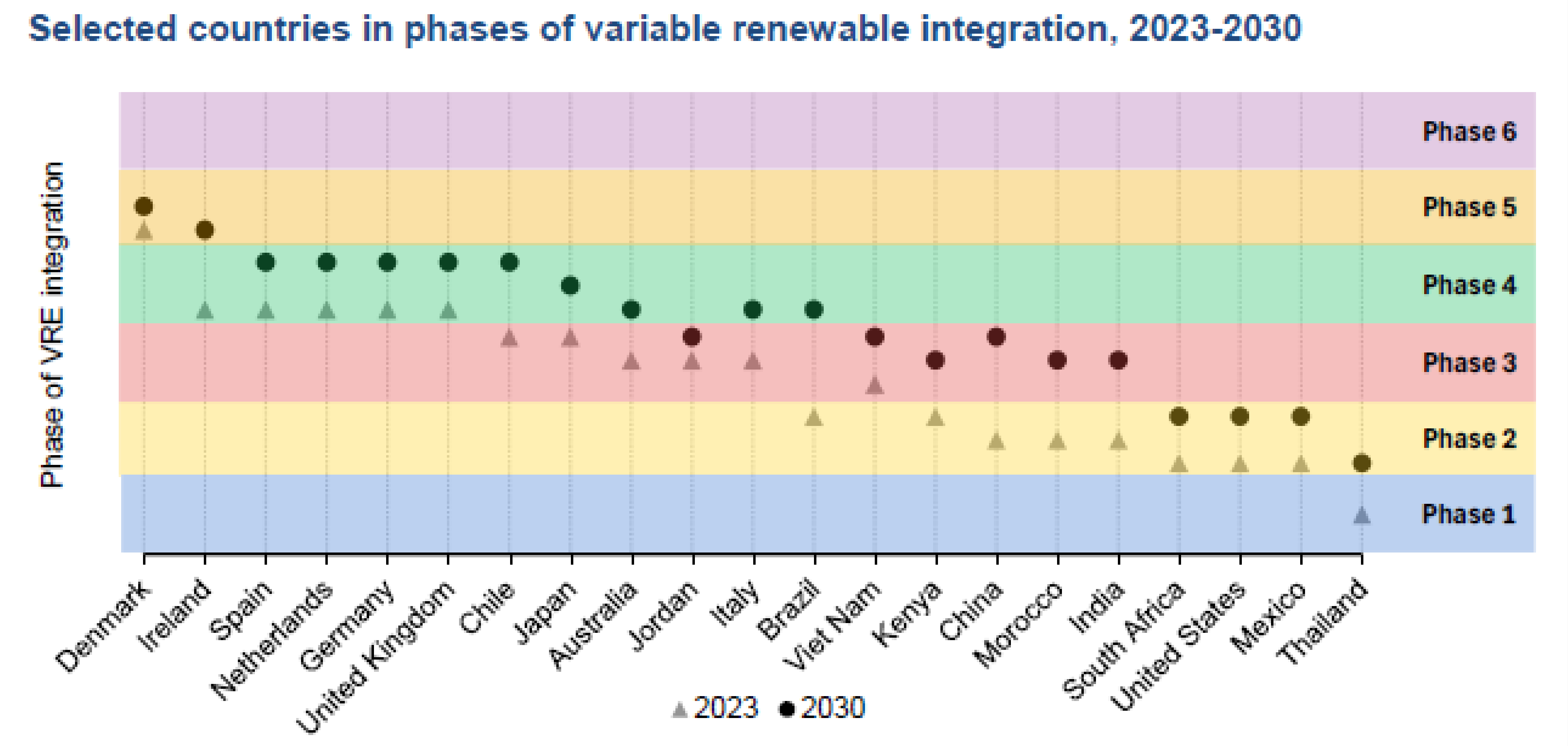


But no need to panic: VRE integration challenges come in phases, and the early phases are not that hard to navigate



 | Source: IEA (2019), Status of Power System Transformation 2019

These challenges are +/- directly linked to the % of VRE, and most SEA countries (including Thailand) are only in phase 1 or 2



 | Source: IEA (2024), Integrating Solar and Wind

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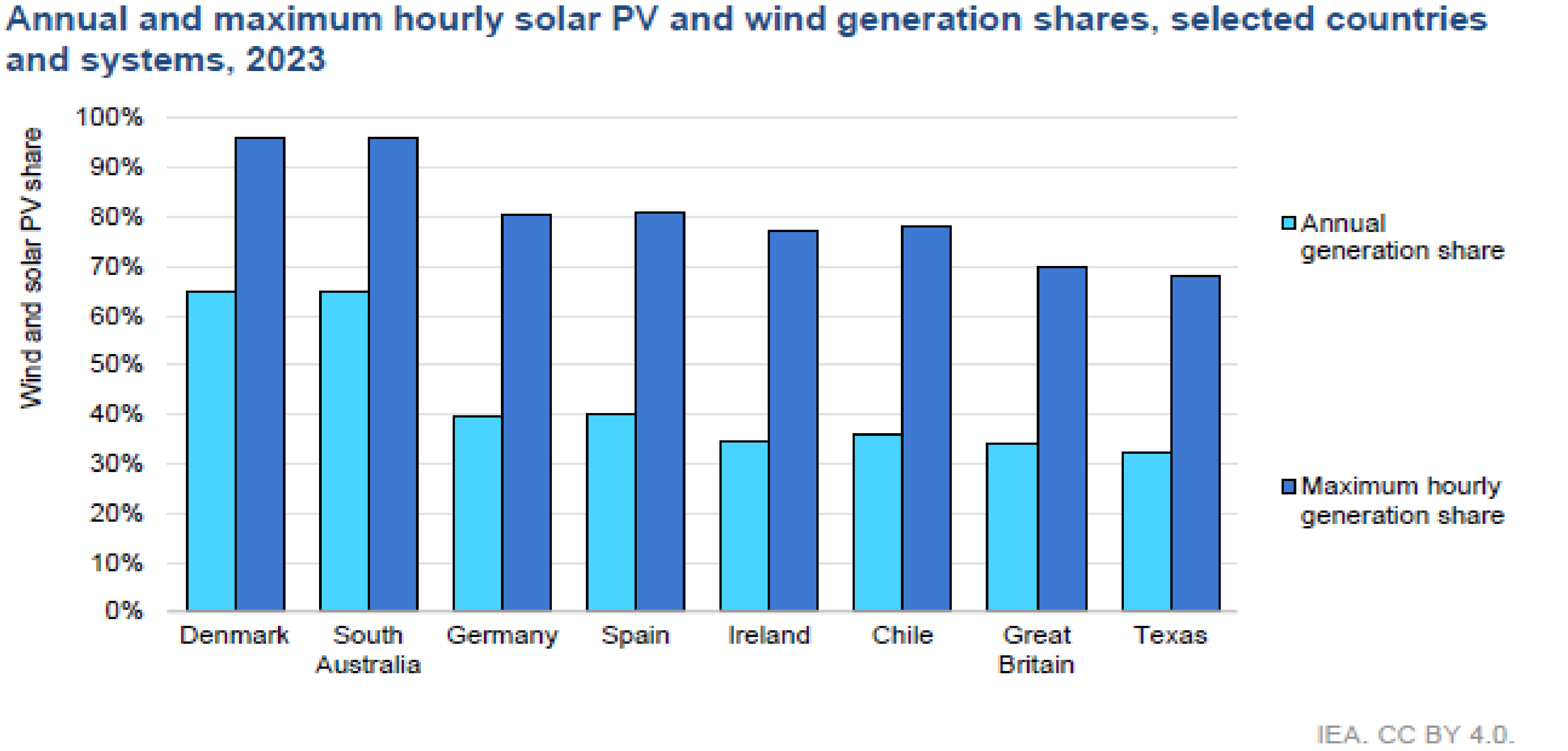
Other countries and regions (e.g., Denmark and South Australia) have already successfully integrated more than 60% of VRE (phase 5)



Sources: IEA (2024), World Energy Statistics; hourly data collected using the IEA's Real-Time Electricity Tracker.

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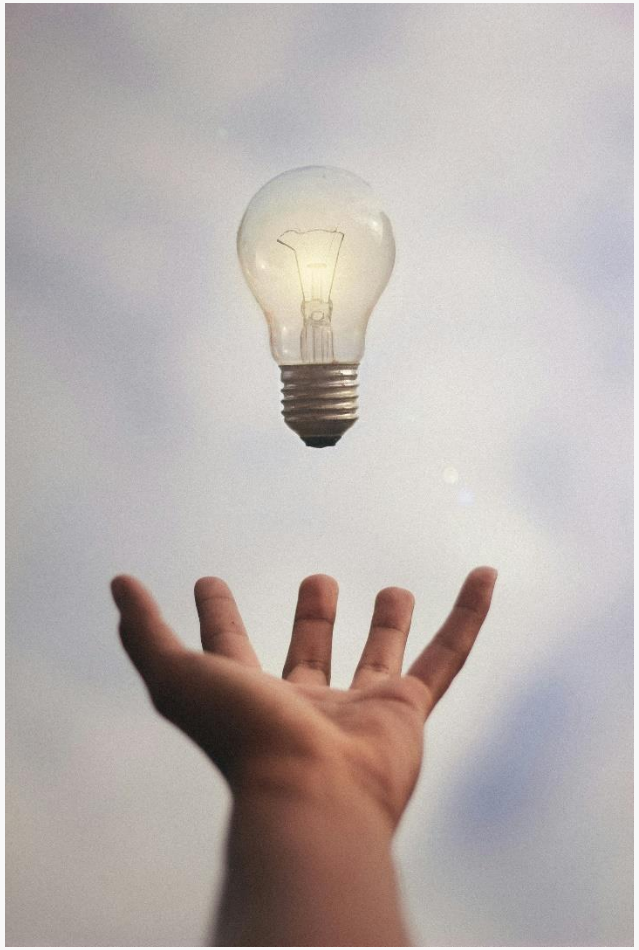

Okay, but they are advanced economies. Can we do that here?

Write down the % of VRE you think could be integrated in your country's power system.

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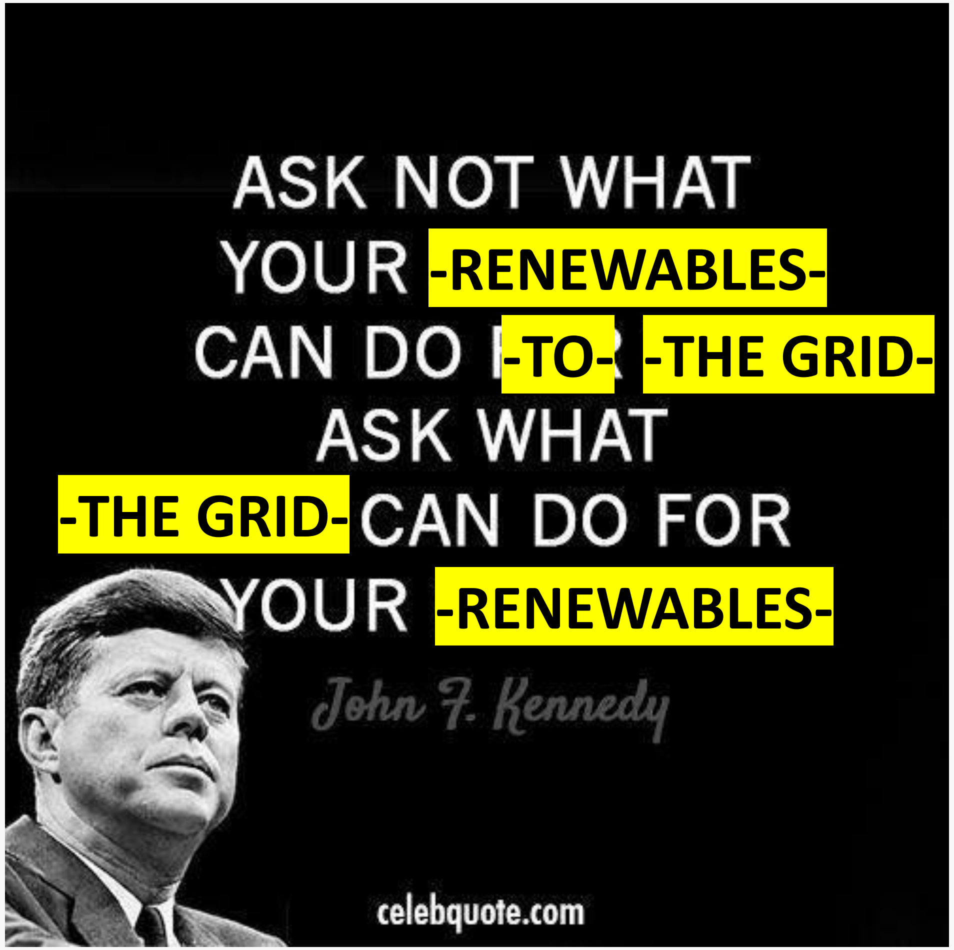
The grid's ability to integrate (V)RE is a choice we make



Integration of VRE/DER: more flexible grids!

New solutions for the power system

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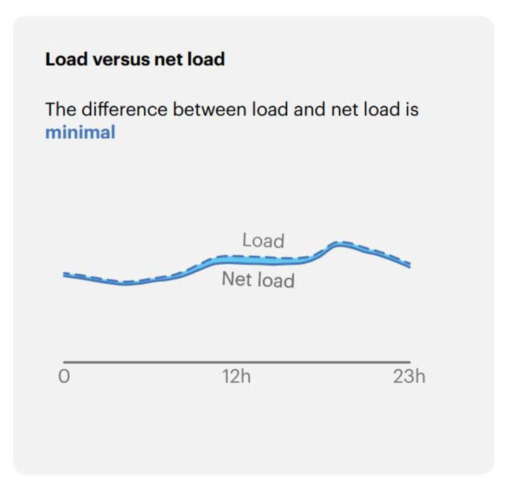
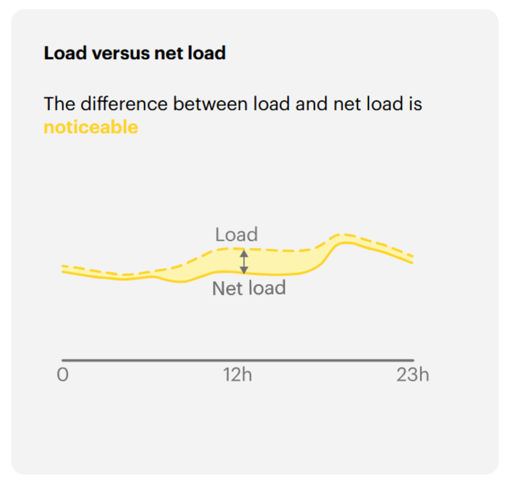
The initial VRE integration phases (where most of Southeast Asia is now) revolves mainly about 2 things: flexibility and grid capacity

1. VRE has no significant impact at the system level



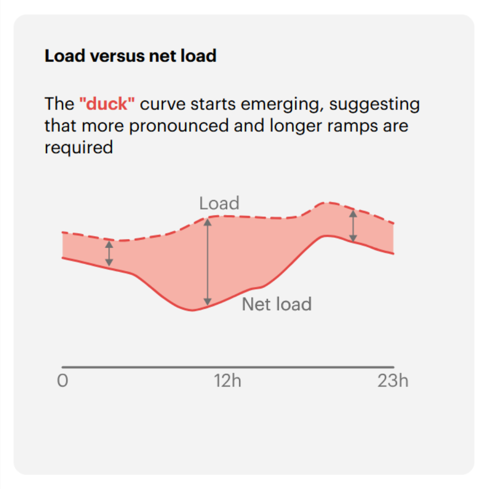
The first set of VRE plants are deployed, but their impact is **largely insignificant at the system level** and the typical operating parameters of the system remain unchanged. Any effects are very **localised**, for example at the grid connection point of plants.

2. VRE has a minor to moderate impact on the system



As more VRE plants are added, changes between load and net load become more noticeable with a minor to moderate impact on the system such as **faster and more frequent ramping of generators**. Upgrades to operating practices such as integrating forecasting into dispatch and making better use of existing system resources are usually sufficient to achieve system integration.

3. VRE determines the operation pattern of the power system



VRE determines the operation pattern of the power system and **increases the uncertainty & variability of net load**. Greater swings in the supply-demand balance prompt the need for a **systematic increase in flexible operation** of the power system that often goes beyond what can be readily supplied by existing assets and operational practice.

 | Source: IEA (2024), Integrating Solar and Wind

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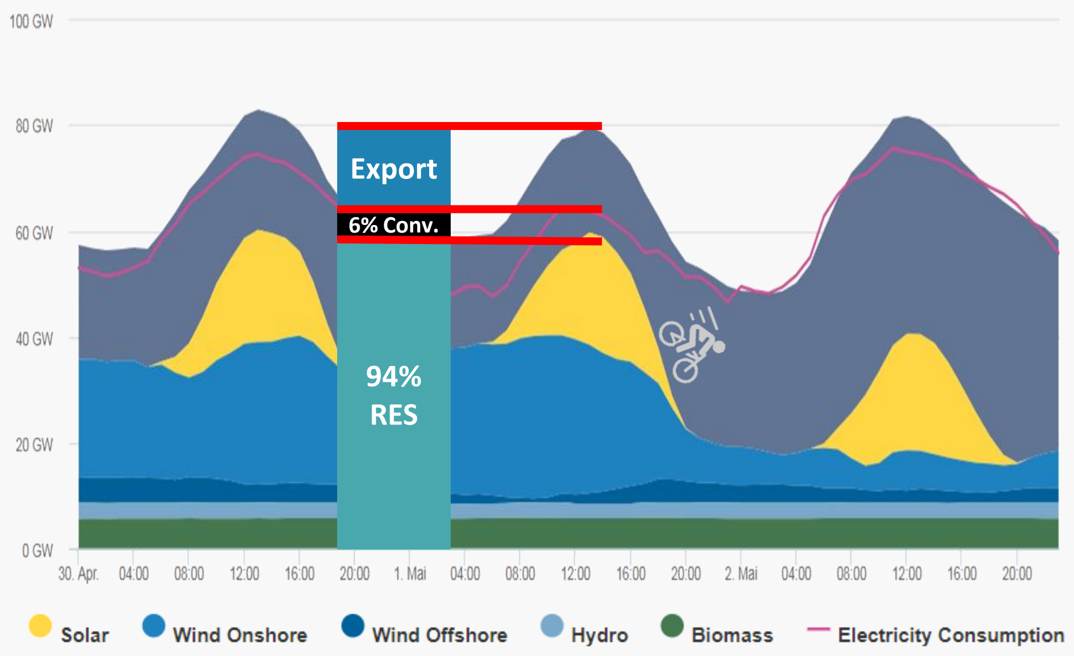
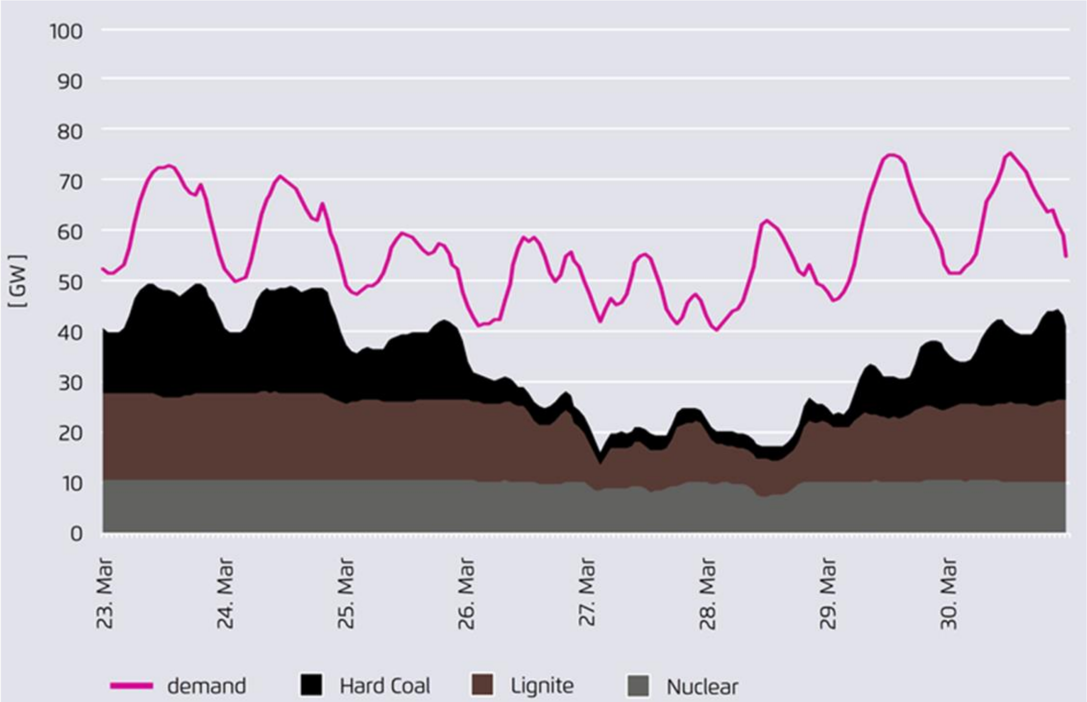
As the VRE share increases, we need *less baseload* and *more flexibility*

To follow VRE's variable output, the rest of the power system has to ramp more strongly and more frequently



VRE integration reduces net and minimum load, reducing the need for "baseload" generation



 | Source: Agora (2018), Agorameter

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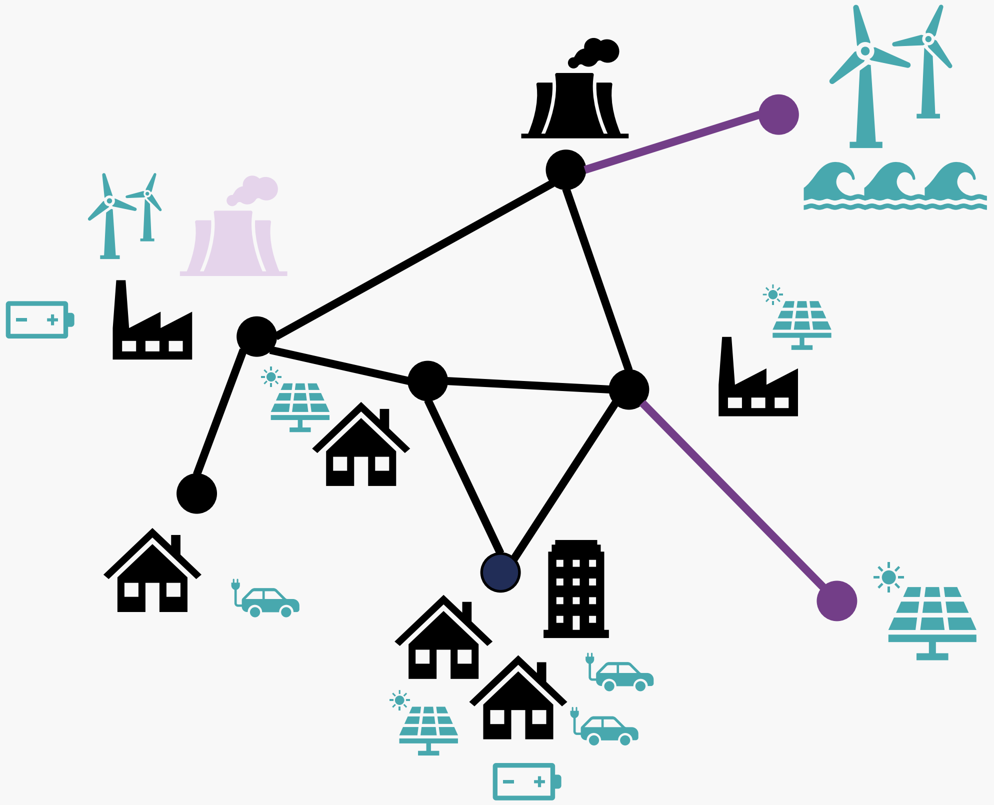
The integration of VRE requires more *transmission* grid capacity



Location

→ VRE siting depends on resource potential

→ The best locations can be far away from demand

→ Electricity transport over long distances means more active and reactive power losses

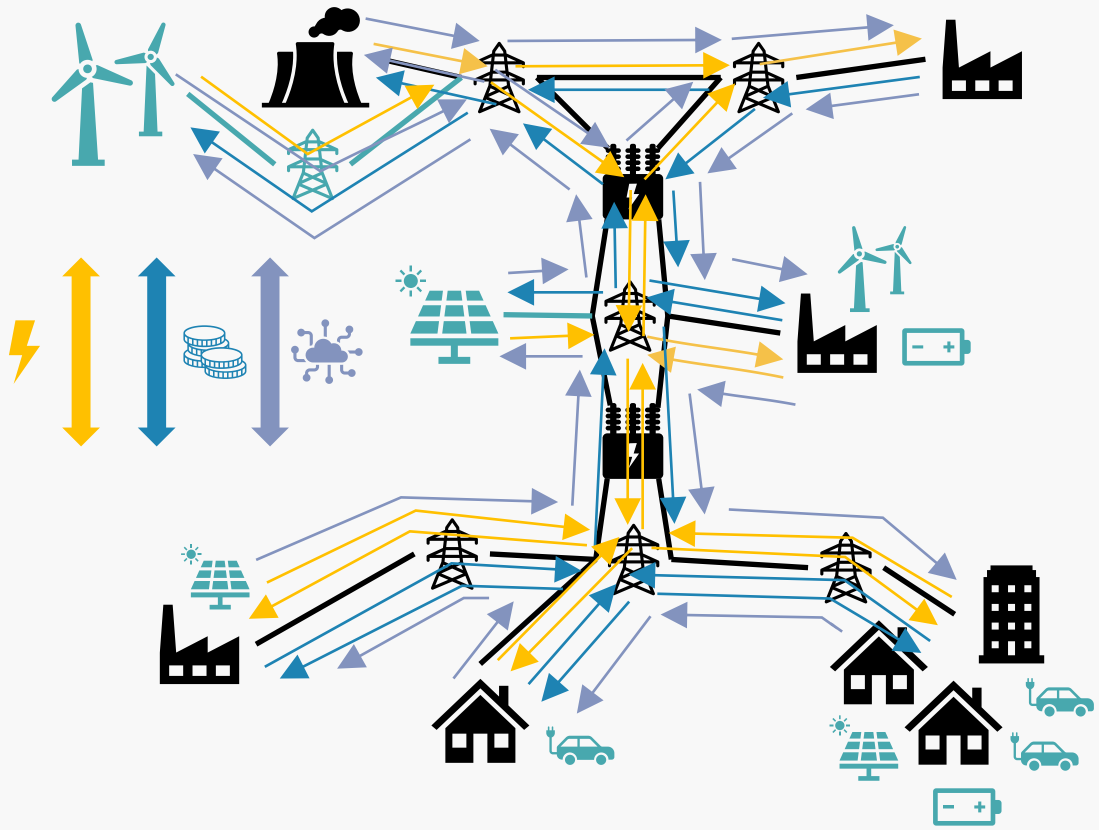
→ Capacity additions, including in places the grid wasn't planned for, can increase congestion

- Increased need for redispatch, interruptions, etc.
- VRE can have **priority dispatch**

Modular

→ VRE power plants are smaller and modular, meaning many more installations/actors must be coordinated

The integration of VRE requires more *distribution* grid capacity



Location

- → A substantial share of VRE is connected to the distribution grid (medium- and low-voltage)
- → The distribution grid is *electrically far away*: small cables mean more active and reactive power losses
- → Distribution grid operations are "set-and-forget", fewer tools to measure and manage congestion

Modular

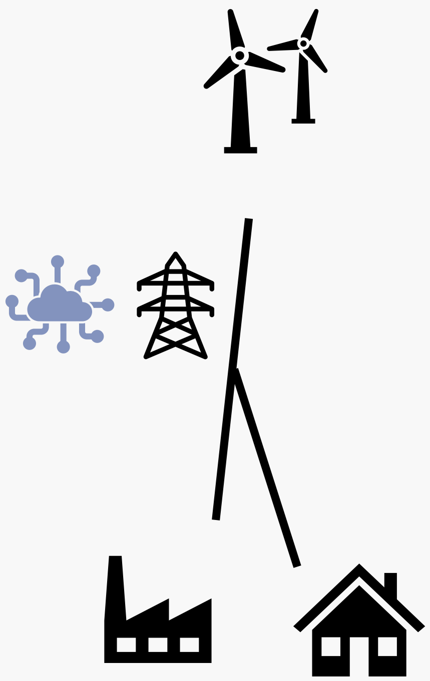
- → The control of even more small VRE and DER means an even larger coordination challenge at this level
- → Many small VRE/DER units are not controllable (now)
- → Transmission and distribution level are not used to exchanging information

There are plenty of integration solutions to tackle both challenges

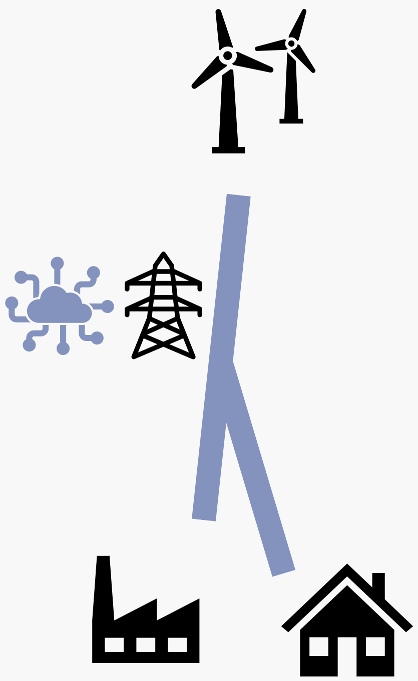
A. Enhanced grids	B. Improved operations	C. Flexible generation	D. VRE	E. Storage	F. Demand response
Advanced grid operations	Better forecasts of net load and power flows	Flexible offtake and upstream fuel contracts	Increase VRE technical requirements	Allow provision of ancillary services	Allow provision of ancillary services
Transmission grid reinforcement	Closer to real-time, higher time granularity	Retrofit plants for enhanced flexibility	Better forecasting	Pumped hydro, battery, long-duration	Industrial, commercial, residential
Transmission grid expansion	Least-cost dispatch		Allow provision of ancillary services	Sector coupling (P2X, EVs, …)	Sector coupling (P2X, EVs, …)
Install stability support devices	Establish ancillary service markets		Curtailment	Decentralization, smart grids	Decentralization, smart grids
			Strategic siting		

A. Grid enhancement: “GORE”

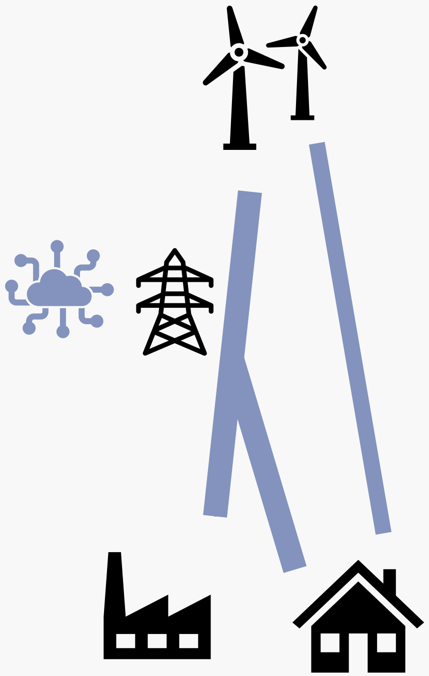
Grid **O**ptimisation before…



grid **R**einforcement before…



grid **E**xpansion



A. Grid enhancement: Provide clear plans and expectations for where new grid capacity will become available, e.g., Renewable Energy Zones

A **Renewable Energy Zone (REZ)** is a geographic area characterized by:

1. High-quality renewable energy (RE) resources

+

2. Suitable topography exclusions

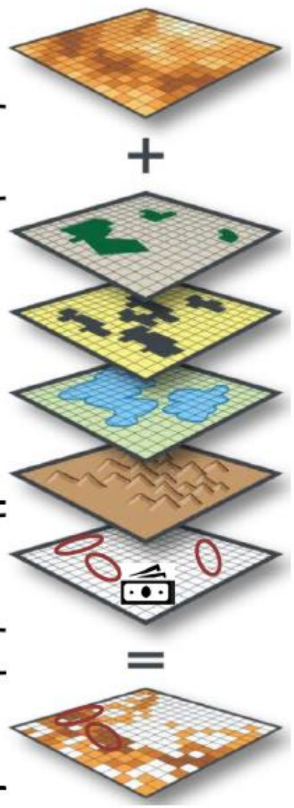
+

3. Strong commercial interest

=

Candidates for REZs

Figure 1. Components of Candidate Renewable Energy Zones



e.g., solar irradiance, wind speed, etc.

e.g., exclusions for protected environmental areas, urban areas, waterbodies, terrain features, etc.

e.g., economic development areas, demonstrated developer interest etc.

e.g., technical potential of solar PV or wind in candidate renewable energy zones, etc.

Think also of spots where coal/gas plants are retired !

Source: Hurlbut et al. (2016)
Figure by Billy Roberts, NREL, adapted from: Lopez (2016)

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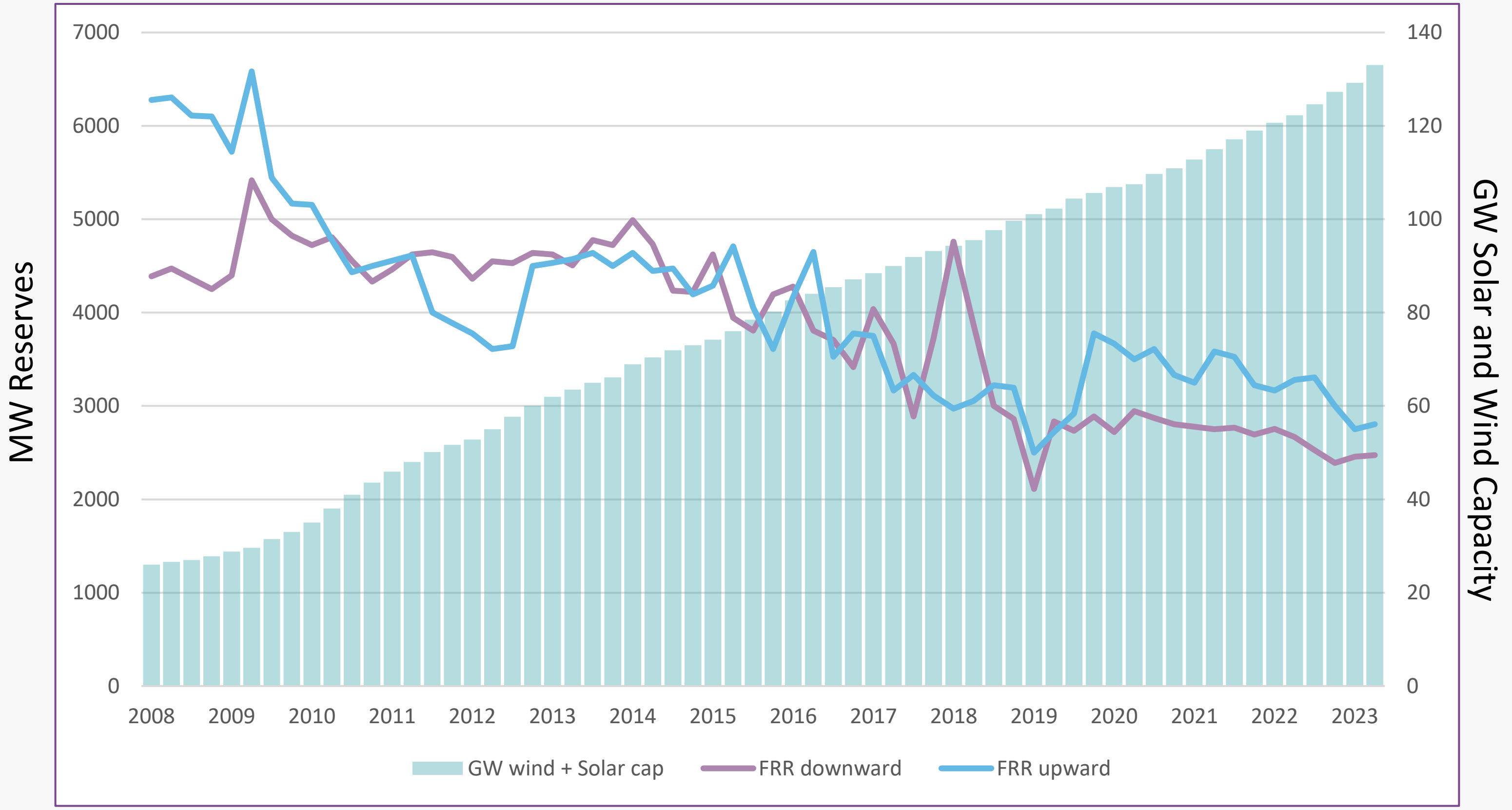
B. Improved operations: Frequency control can be provided at lower costs, even with an increase of variability in the system

The German Balancing Paradox



Between 2008 and 2023

- → Wind & solar capacity quintupled! (increased x5)
- → While balancing reserves decreased by -50%

Several factors contributed:

- → Improved coordination between transmission system operators
- → Improved weather models (better forecasting)
- → Decentralised balancing played a crucial role
- → …

C. Flexible generation: it is key to unlock existing flexibility by addressing contractual inflexibilities (for offtake and upstream)

→ **Dispatching assets in a least-cost manner leads to a more cost-effective power system**

- VRE has very low marginal costs: once installed, it is beneficial to use as much of its supply as possible
  - Priority dispatch is a useful tool to achieve this
- Giving clear price signals (e.g., negative prices) with high temporal and geographical resolution is key:
  - Can unlock flexibility in the system as actors respond to prices
  - Incentivizes investments in the right assets (e.g., storage)
  - Be mindful of subsidy (re-) design: it is possible to protect vulnerable consumers while not giving out the wrong dispatch and investment signals

→ **Conventional power plants have a key role to play in integrating VRE**

- These plants are dispatchable, meaning they can provide a certain flexibility within technical limits
- To unlock this flexibility, in certain cases contractual arrangements may need to be revised
  - Take-or-pay clauses encourage dispatchers to prioritize conventional power plants and take away plant owner’s incentives to respond to system conditions
  - Certain subsidies (e.g., upstream) artificially increase competitiveness of these plants vs. VRE
  - These effects can lead to increased VRE curtailment and higher costs for end-users

D. VRE: Inverter-Based Resources, like VRE, can provide a range of ancillary services given the right regulation

→ Inverter-Based Resources can manage active and reactive power output and thereby contribute to ancillary services provision

→ **Voltage** regulation (reactive power mgmt.)

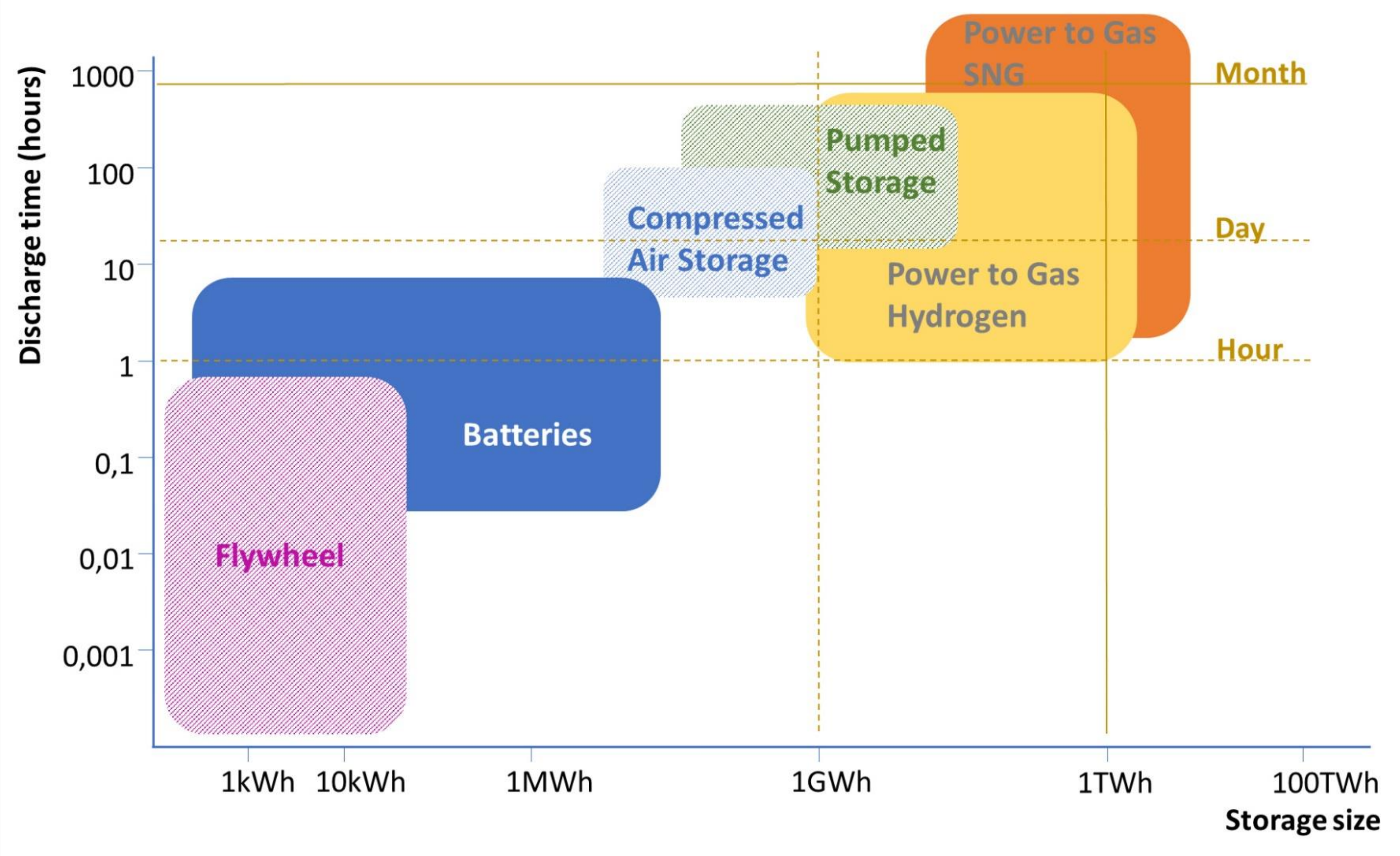
→ Synthetic **inertia** (mimicking the ultra-short-term frequency response of conventional power plants)

→ **Downward reserves** (strategic curtailment)

- Example: in several European countries, wind farms participate in fast downward reserve provision

→ **Upward reserves** (continuous curtailment, i.e. generate power below maximum potential output to be able to regulate upward)

E. Storage: Different technologies fit different system services



→ **Battery Energy Storage Systems** are also inverter-based resources and can therefore also provide numerous system services, and have very fast response times

→ **Pumped Storage** has been one of the most used solutions for managing variability and uncertainty

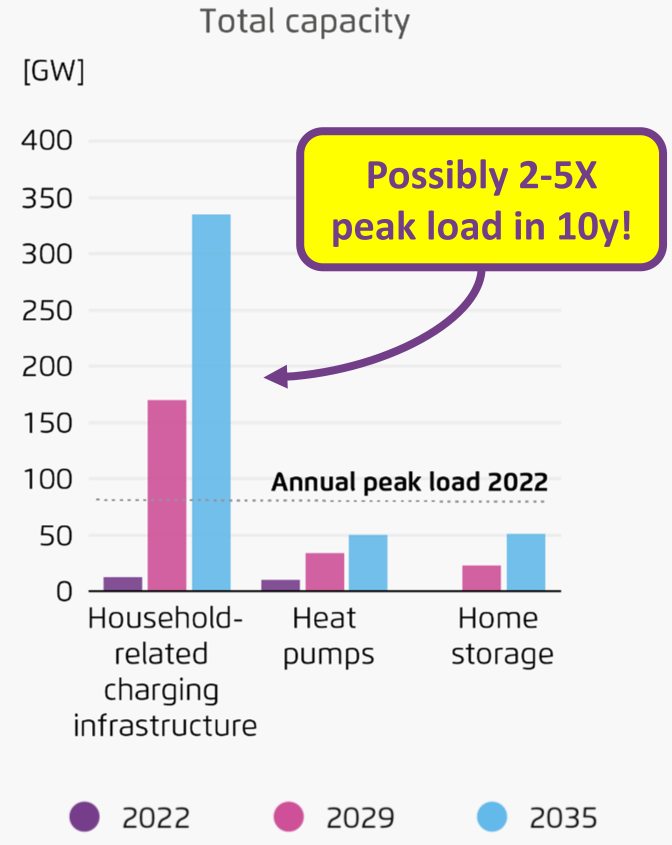
→ **P2X** technologies mostly have a role to play in highly renewable systems (phases 5-6) to manage seasonal VRE output variations

F. Demand response: key to unlocking existing & new flexibility in the power system from residential, commercial and industrial end-users

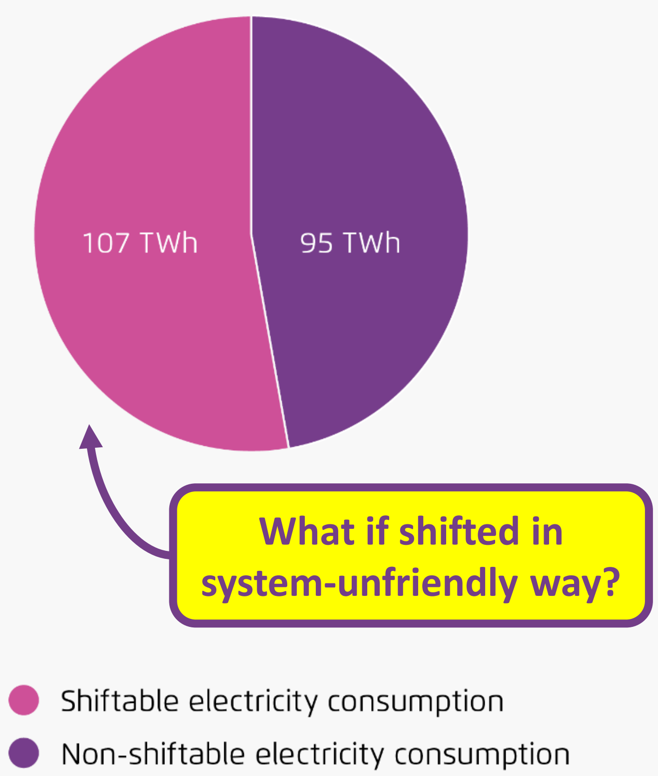
- → Demand can be incentivized to follow VRE availability, through signals like Time-of-Use tariffs (from fixed multi-hour price blocks to real-time prices)
- → Large end-users (**commercial & industry**) can shape their demand (e.g., via process mgmt.)
  - Can participate directly on wholesale markets or participate in dedicated demand response programs
  - Can receive incentives on bills
  - Can provide “interruptibility”
- → **Residential** demand response can unlock DER flexibility for overall system balancing
  - Coordinating EV charging
  - Smart thermostats (HVAC, heat pumps)
  - Often inverter-based resources (e.g., ACs, EV chargers), hence can also provide certain system services, e.g., synthetic inertia, voltage control, etc.

Residential demand response present a great opportunity to integrate VRE by utilizing flexibility to balance system, but also a great risk in not doing so

Development of household-related flexible assets in Germany



Household electricity consumption in Germany in 2035



- → Agora research shows that German household-related flexibilities could total 100 TWh in 2035
- → In this context, the increasing share of wind and solar power generation is an advantage as it means that, e.g., surpluses can be utilized well
- → However, the maximum peak supply/demand of these new flexible assets far exceeds current maximum peaks, meaning that not coordinating this carries great risk

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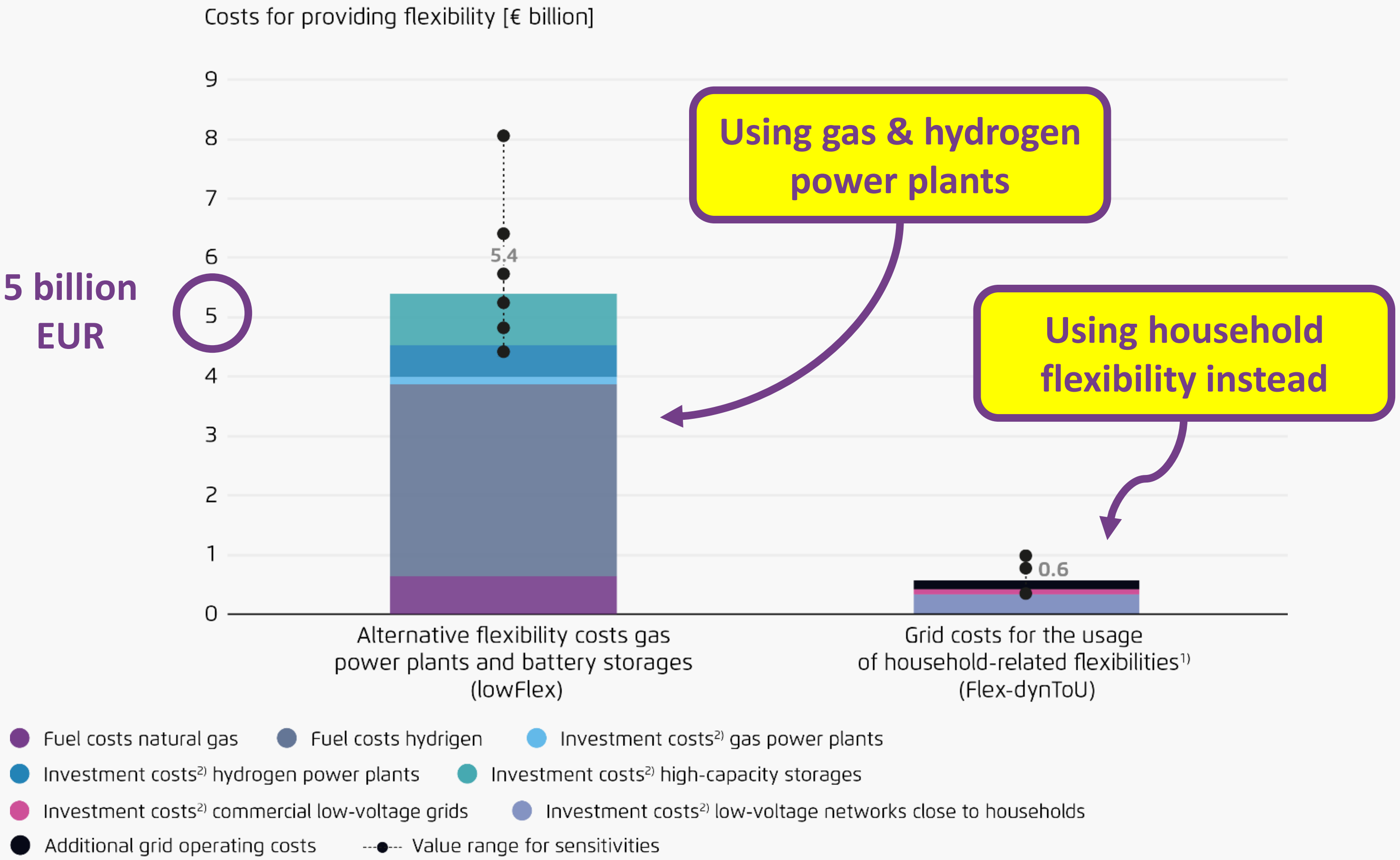
Example: a study by Agora shows that the use of household flexibility via dynamic tariffs can save Germany 4.8 billion EUR in a single year (2035)

Cost comparison of the flexibility options in 2035 (annuities)

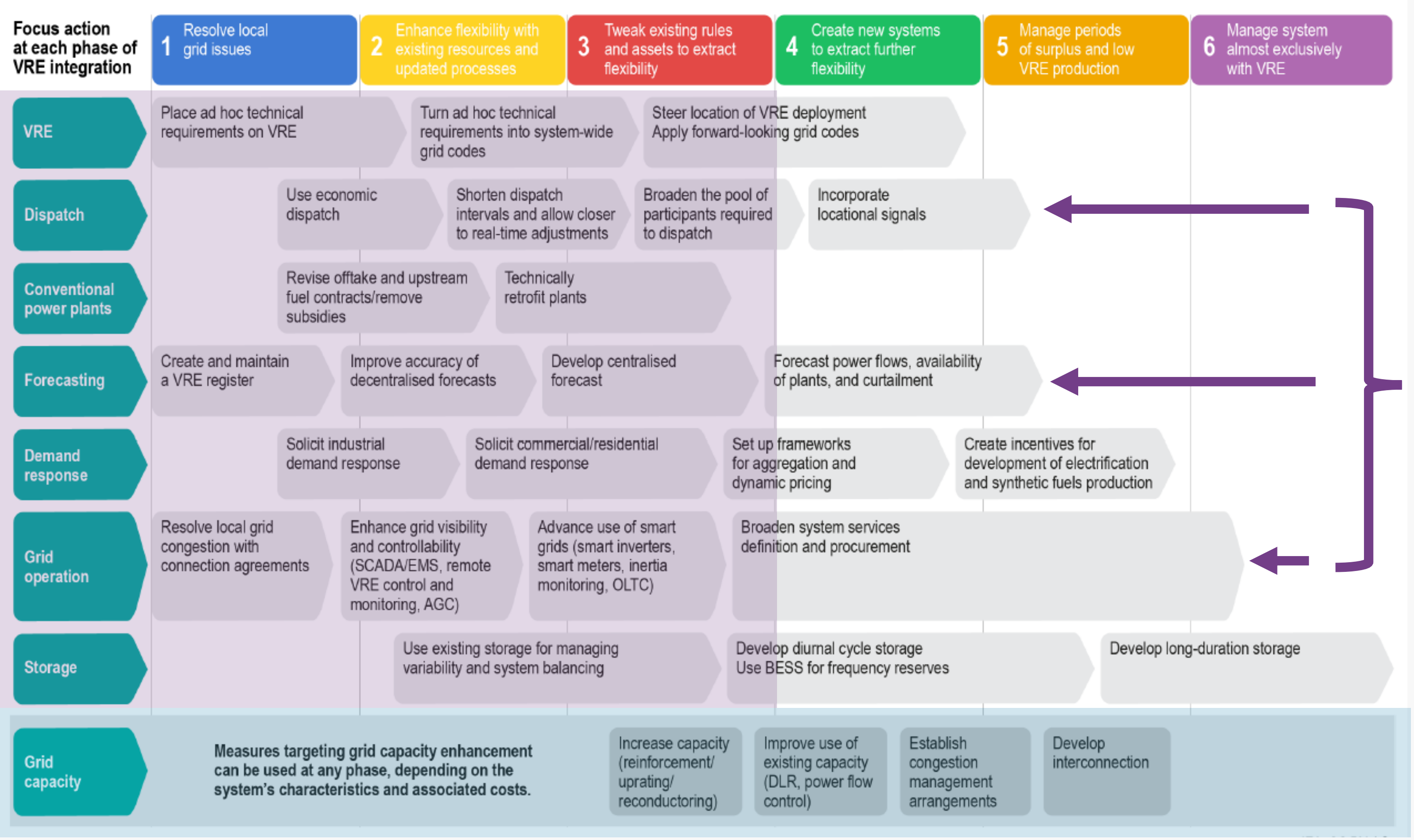


→ Activation of load-shifting flexibility in households:

- Saves 20 TWh of power generation per year
- Reduces need for (fossil) fuels
- Increases the need for distribution grid expansion (10-20% above historic levels)
- Additional grid expansion costs (1) can be limited thanks to dynamic grid fees and (2) are vastly offset by system savings

→ Our analysis shows total system cost savings of 4.8 billion EUR/year in 2035 alone → **well worth figuring out the implementation complexity**

Overview of solutions: focus on issues of early phases now while in parallel preparing for the issues of later phases



Most often changes in processes are the cheapest solutions

→ Better VRE, net load and power flow forecasting

→ Shorter-timescale, closer to real-time system operations

→ Allowing non-conventional providers of ancillary services

→ Good ancillary service design (requirements, sizing, sourcing, compensation, etc.)

Conclusions

Grid modernization for the transition

November 2024

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Photo by Andrey Metelev on Unsplash

Key Takeaways:

1 **The integration of large shares of VRE/DER challenges traditional power system operations and planning, but those challenges come in phases.** VRE/DER have particular characteristics that require an update in power systems operations and planning. tradition. It’s important to note that those challenges come in phases. It’s key to focus on the right challenges at the right time. Southeast Asian countries are in phases 1-2. Problems of phases 3-6 are no reason to halt VRE deployment now.

2 **What is needed now is a paradigm shift from baseload to flexibility and enhanced grids. There are a range of solutions available today to make that happen.** A range of new solutions (e.g., VRE providing system services, use of batteries, coordinated EV charging) are being used in power system operations in several countries already today. Changes in processes and making use of existing flexibility (e.g., by restructuring contracts with existing conventional power plants) are often the most cost-effective way forward.

3 **To get this right, thorough cross-sectoral planning and significant institutional capacity-building are key.** Policy-makers, regulators and system operators have to pro-actively prepare for large-scale VRE/DER integration. Among other things, this means identifying high potential VRE zones and building the required grid infrastructure to make use of them, aligning sectoral plans (power, transport, industry, etc.) to anticipate the effects of electrification, and accelerating the modernization of distribution grids. This will most likely require numerous new skills in the related stakeholders.

Thank you for your attention.

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