International multidisciplinary discussion seminar

organized by Czech-Austrian Energy Expert Group (CZ-AT EEG)
in cooperation with the Czech Technical University in Prague, Vienna University of Technology, the Institute for Economic and Environmental Policy (Jan Evangelista Purkyně University in Ústí nad Labem)

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Electricity Markets in the Era of the Energy Transition

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Outline

- Introduction to **decarbonization** concept
- Flexibility – **Demand-side flexibility**
- **Sector coupling** idea
- Electrification of the **transport** sector
- Electrification of the **heating** sector
- Electrification of the **industrial** sector
- **Conclusions**– Future **challenges**

Introduction

- **Current situation:**
  - ✓ RES: cover an ever-larger share of the world's electricity needs
  - ✓ Decarbonize electricity supply
  - ✓ **Challenges**: variable RES **variability and uncertainty** across different time scales,
  - ✓ **1st challenge:** "**duck curve**" - first appeared in California - high penetration of solar photovoltaics, which results in very high net load ramping requirements (CAISO, 2016).

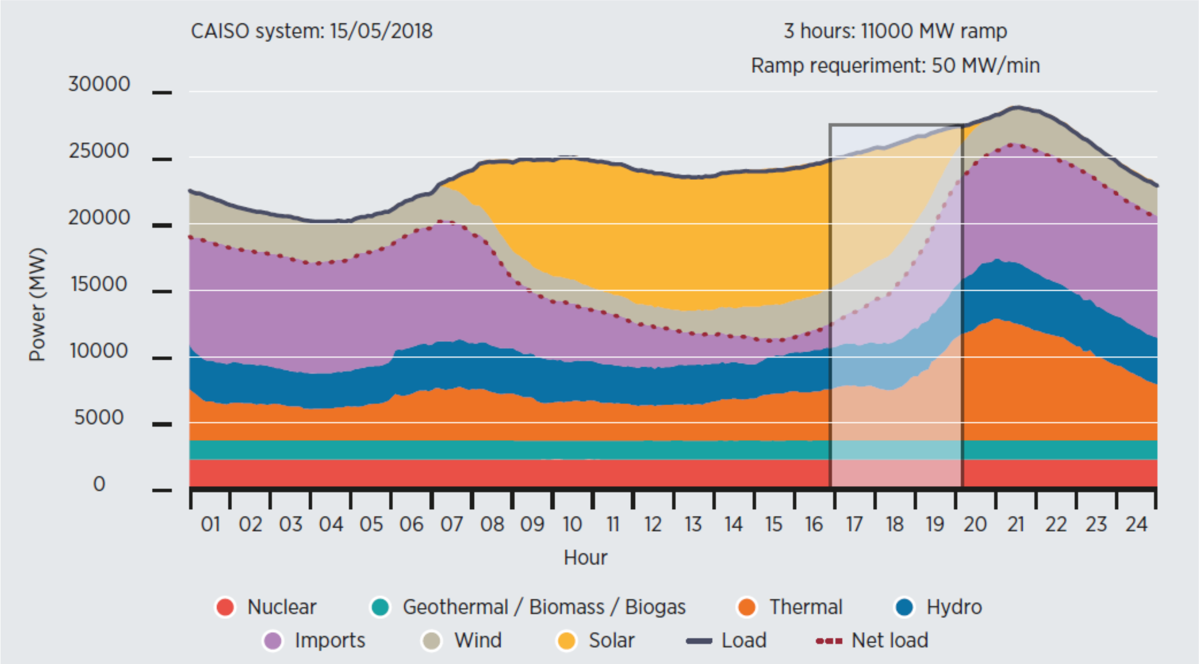


Fig. 1: Net load curve for the California power system for 15 May 2018, when high solar PV penetration resulted in the duck curve

Flexibility

- **2nd challenge:** increasing electrification of end-use sectors (buildings, industry and transport)
- Key solution to decarbonization
- Electrification: impact on power system adequacy and reliability - increase power demand - peak and increasing ramping requirements.
- Reshape demand profiles - demand forecasting techniques and analysis
- **Both challenges – Flexibility**: “*the capability of a power system to cope with the variability and uncertainty that solar and wind energy introduce at different time scales, from the very short to the long term, minimizing curtailment of power from these VRE sources and reliably supplying all customer energy demand*”.
- **Supply side** (for example, using thermal flexible power plants). With the increasingly urgent requirement to decarbonize energy use: **demand-side flexibility**.
- Share of VRE increases today - supply less and **less controllable -** demand needs to become a **flexible resource**

Demand-side flexibility

- **Demand-side flexibility:** reduced, increased or shifted in a specific period of time to:
    i. Facilitate integration of VRE,
    ii. Reduce peak load and seasonality and
    iii. Reduce production costs.

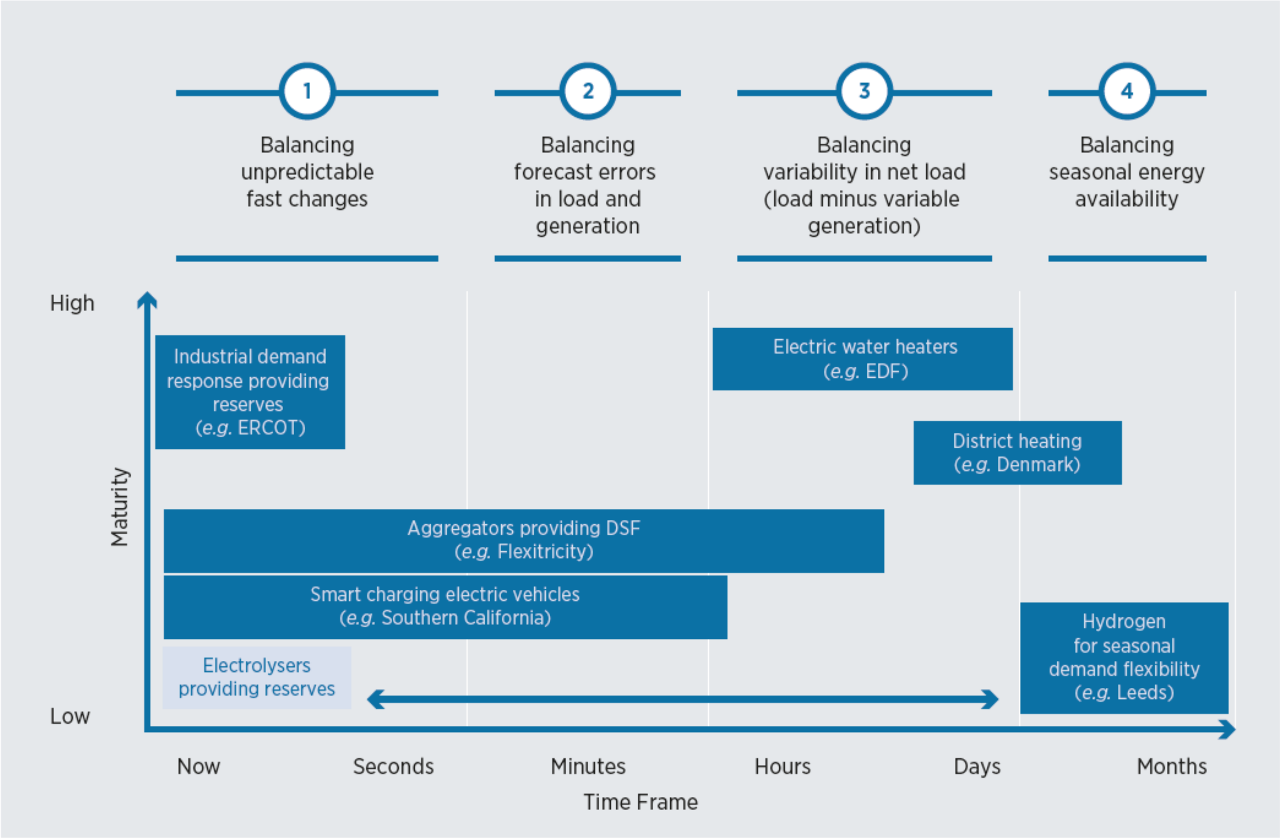
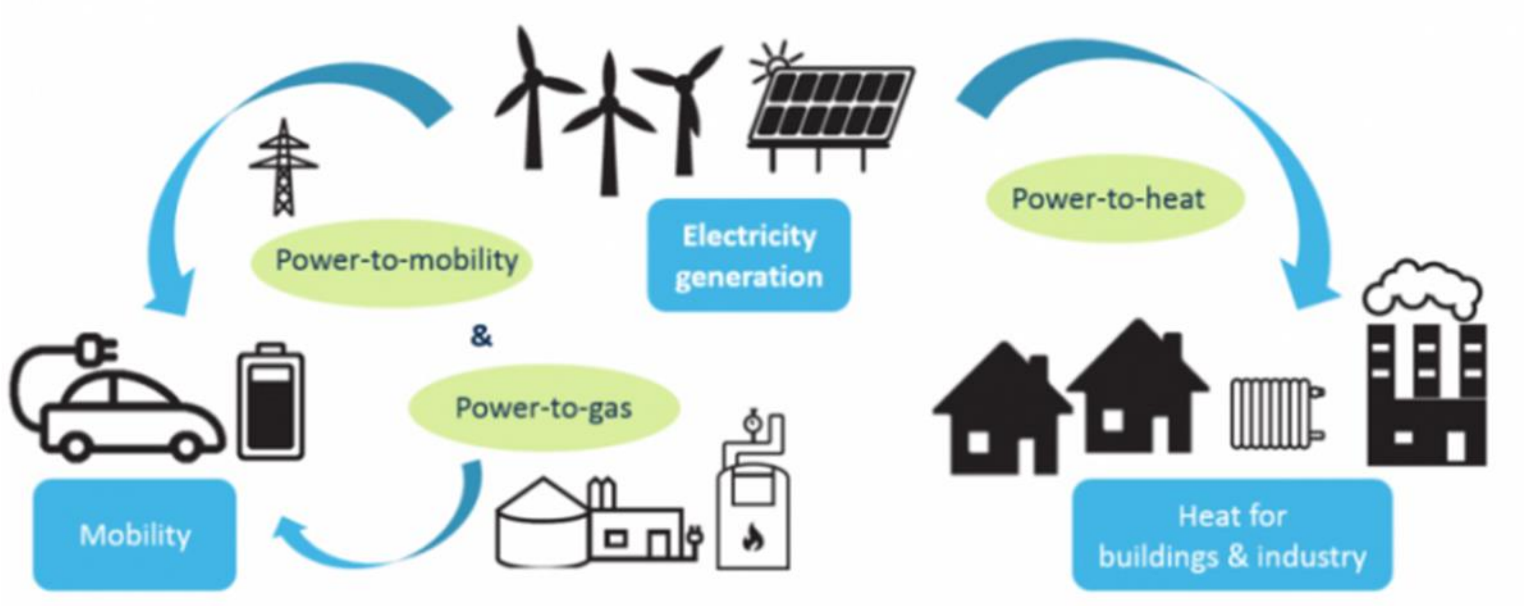


Fig. 2: Demand-side flexibility real applications classified by technological maturity and flexibility time scale

What Is Sector Coupling?

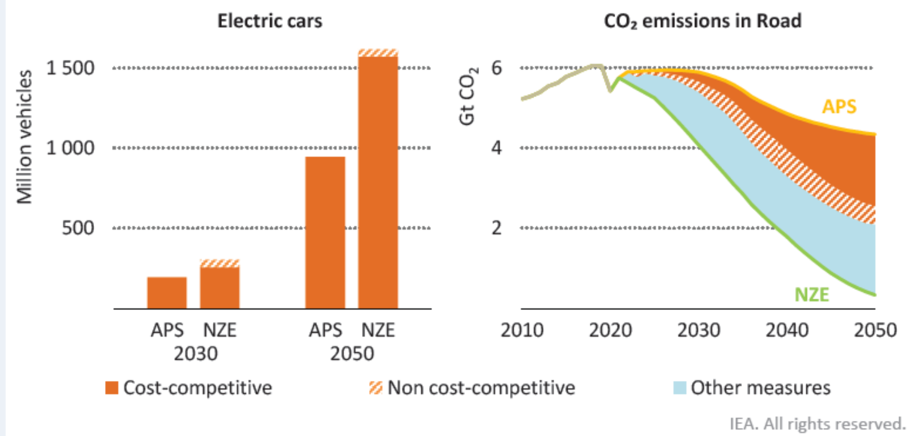
- **Sector coupling** refers to the idea of interconnecting (integrating) the energy consuming sectors with the power producing sector.
- Decarbonizing the national economy - "**All Electric Society**".
- **Complete flexibility potential** of producers and consumers as well as the storage of energy in its various forms.
- **Net zero CO_2 emissions** achievable.



Sector Coupling in Transport and Logistics

- Sector coupling: different rates in different areas.
- Research in **air, water and heavy truck transport**.
- Number of EVs: today is around 6 million - more than **1.5 billion by 2050** (World Energy Outlook 2021)
- **Different charging strategies**
- **Uncontrolled charging** - charge at maximum power as soon as they are plugged into the grid - not flexible - challenge to the power system
- **Smart charging** strategies
- **Battery concepts**
- **Vehicle-to-Grid (V2G)**
- During low wind and overcast, vehicle batteries could compensate for **minor imbalances** in the power grid

Figure 3.22 ▷ Cost-competitive stock of electric cars in 2030 and 2050, and CO_2 emissions reduction in road transport to 2050 by scenario



Electric vehicles are critical to closing the transport sector ambition gap and are largely cost-competitive

Sector Coupling in Transport and Logistics

- **Hydrogen** as a fuel source.
- For usage in motor vehicles, the storage options are comparatively simpler and cheaper.
- Problems - high-volume production using RES.
- In **Japan** particularly, large car manufacturers: hydrogen-based engines.
- In **Germany**, mainly commercial vehicle manufacturers: hydrogen as fuel
- In the **logistics sector**: logistics companies' own vehicle developments, and local authorities are also turning to electric buses and taxis with electric engines.
- **Power container ships, intercontinental aircraft and heavy trucks using electricity from renewable energies**: If an Airbus A320 Neo would be equipped with charged lithium-ion batteries to the total weight of its full kerosene tanks, it could only stay in the air for about 20 minutes. The plane could manage barely to fly straight and level, take-offs or safe landings would not be possible due to the lack of power. For the full flight time of about seven hours, the plane would have to carry 260 tons of lithium-ion batteries. This sums up to about three and a half times the maximum take-off weight of the Airbus A320 of 70 tons, not counting the aircraft itself.
- Summary sector coupling in traffic: **Aviation, shipping, and road freight transport** will be candidates for power-to-x (Power-to-Gas, Power-to-Liquids) technologies, rather than for battery-based engines.
- In the area of **individual mobility**, **public transport, car-sharing, cycling, walking and, eventually, automated driving**: development of an electricity-based mobility concept.

Examples of demand-side flexibility in actual practice: **Electric vehicles with smart charging**

- **EVs**: **demand-side flexibility** if smart charging is enabled.
- In Southern California, Honda, Southern California Edison and eMotorWerks: **SmartCharge programme**
  - ✓ **Price signals** renewable energy at the lowest cost.
  - ✓ Determines **when** the EV will be connected to the grid
  - ✓ **EV demand will be shifted in real time** without impacting the consumer
- **Vehicle-to-grid (V2G):** adjust the load based on price signals and feed energy back to the grid.
- **Nuvve:** first V2G technology company - Denmark in 2016, in collaboration with Nissan and Enel.
- Under this project Nuvve installed **10 V2G chargers** in the headquarters of the Danish utility Frederiksberg Forsyning with a maximum power of 10 kilowatts each - aggregated under one platform that allows the EVs to become active participants in Denmark's power system.
- Other interesting ongoing V2G projects are those developed by **TenneT in the Netherlands**, using the aggregator **Vandebron: aggregates a fleet of EVs to provide automatic frequency restoration reserve (aFRR) to the TenneT grid** - temporarily stops and restarts the charging sessions of customers with EVs. This service is facilitated mainly to Tesla drivers, who receive a payment in exchange.
- An increasing number of EVs: significant increase in global electricity demand.
- Smart charging: further on-site testing and research to fully understand its costs and value

Sector Coupling in Heat Generation

- **Heat generation**: advantage over the transport sector
- Heat is **generated stationary** in buildings - **not dependent** on a transportable fuel supply. Many different technologies are well established in this sector.
- **Heat pumps:** heat from low-temperature sources to high-temperature heat sinks by using a compressor that consumes electricity.
  - ✓ Highly efficient devices (one unit of electricity can produce 4 to 5 units of useful heat).
  - ✓ Variable output - although their costs are falling, their capital costs are still high.
  - ✓ Supply space heating and cooling for residential, commercial and industrial uses.
- **Electric boilers or electric water heaters:** use electricity to heat water.
  - ✓ **Efficiency:** much lower than that of heat pumps (typically 1 unit of electricity produces 1 unit of heat) but higher than conventional fossil-fueled boilers.
  - ✓ **Capital costs:** much lower and therefore they are increasingly common today.
- **Thermal storage:** absorbs and releases heat (or cold), when needed.
- B**alance the supply and demand** for heating or cooling more efficiently.

Sector Coupling in Heat Generation

- **Power-to-heat**
  - **Decentralised**
  - **Centralised**
- **District heating**: is a way to supply residential and commercial buildings and industrial users
- **Combined heat and power (CHP) plants**, electric boilers and centralised heat pumps are in this case some of the most relevant technologies for heat generation.
- Excess heat from **biogas plants** can also be used in such heating networks.
- **Synthetic gases**: heating sector instead of fossil natural gas.
- Massive investments: sustainable **thermal insulation systems**.
- Power-to-heat concepts could then also be implemented in perfectly insulated apartments.

Examples of demand-side flexibility in actual practice: **Residential electric water heaters**

- Residential consumers in France: **electric water heaters** at home to cover their demand for hot water.
- According to Électricité de France (EDF), **more than 13 million of these heaters** - around 50% of residential hot water systems
- **Annual consumption of 20 TWh and a peak demand of 8 GW**, which occurs during early evening periods in winter.
- Flexible if **price signals** are reflected in retail tariffs.
- **Time-of-use tariffs** that are also called "peak/off-peak" hours tariffs
- **Incentivise consumers** to use the electric water heaters to heat water during off-peak hours and to avoid peak hours.
- **Reshaping of the French demand curve** since the 1950s.
- Demand-side flexibility: **flattened electricity prices**
- Electric water heaters **foster VRE integration**

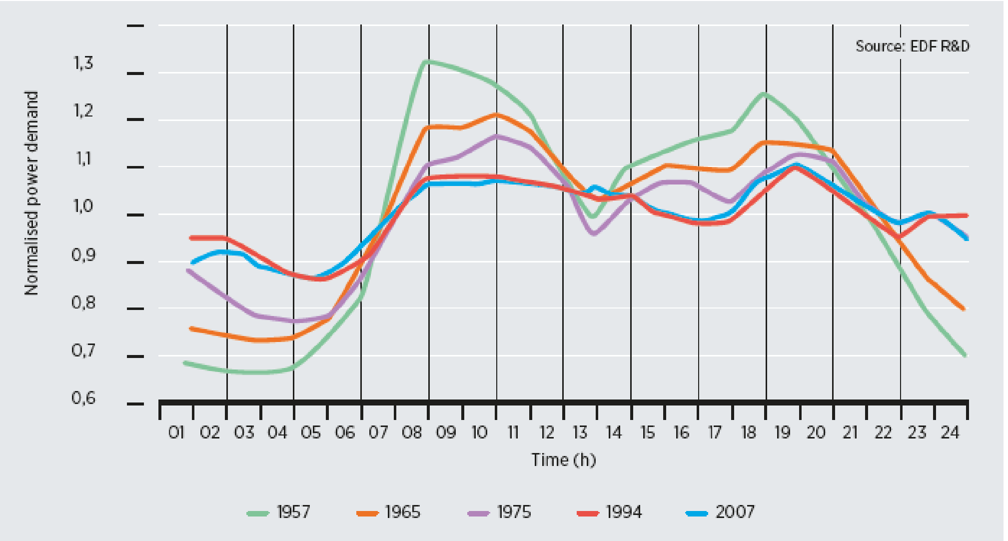


Fig. 3: Impact of residential electric water heaters on the daily load curve of France

Examples of demand-side flexibility in actual practice: **District heating systems**

- Denmark: highest numbers of **district heating networks** in Europe ¾ of the country's demand for space heating.
- **Variety of fuels**, such as biomass, waste and natural gas.
- CHP, geothermal and solar sources, as well as from RES using heat pumps or electric boilers.
- **Surplus heat from industry** can also be used in the district heating network.
- Thus, district heating networks basically act like giant **thermal energy storage devices**
- The production is **driven by heat demand**, and the electricity generated is sold in the wholesale market. The issue is that with high instant penetrations of VRE, market prices tend to be extremely low and CHP electricity output is squeezed out of the market – **inflexibility**
- Coupled with heat pumps, water heaters, electric boilers or thermal storage, the **flexibility** of these CHP plants will increase
- When coupled with heat pumps or electric boilers, CHP could **generate electricity** (and heat) when electricity prices are high and use electricity for heat generation when electricity prices are low.
- **Injected** to the district heating network or **stored** for later use
- **Heat-only mode** - no electricity generation and no impact on the power system.

Sector Coupling in Industry

- **Industrial processes** are responsible for a significant amount of final energy consumption in each country.
- Gas, hard coal, and electricity - Only a **small percentage comes from RES**.
- Energy needed in the industry sector - processing heat, and the rest for running engines and machinery.
- **Emissions** come from processes not related to energy use
- Depend on the **specific manufacturing processes** and recycling strategies.
- Depending on whether an industrial process needs gases, mineral oil, chemicals, heat, or power, all the **power-to-x technologies** applicable in the other sectors can be used to electrify the industry sector as well.
- However, **not all industrial and agricultural processes** can be decarbonised entirely.
- To reach **carbon neutrality**, greenhouse gas emissions from industry could be **captured and utilised**, or **stored** (CCU/CCS), or **offset** by CO_2 sinks.

Examples of demand-side flexibility in actual practice: **Industrial demand response providing reserves**

- Since 2002, electricity markets in Texas: large industrial customers - in the **ancillary services market**.
- Maximum share for **load participation in responsive reserve service** (RRS): 50% in 2005 (VRE penetration was less than 2%) and 60% in 2018 (VRE penetration around 19%).
- RRS: VRE integration by helping to **compensate for the imbalances** produced by these sources
- Load resources: **RRS from the industrial sector** with very few large commercial sites In 2018, ERCOT had in total **300 load resources** - 4200 MW.
- Quickly respond and help balance the **frequency of the system under large contingencies**

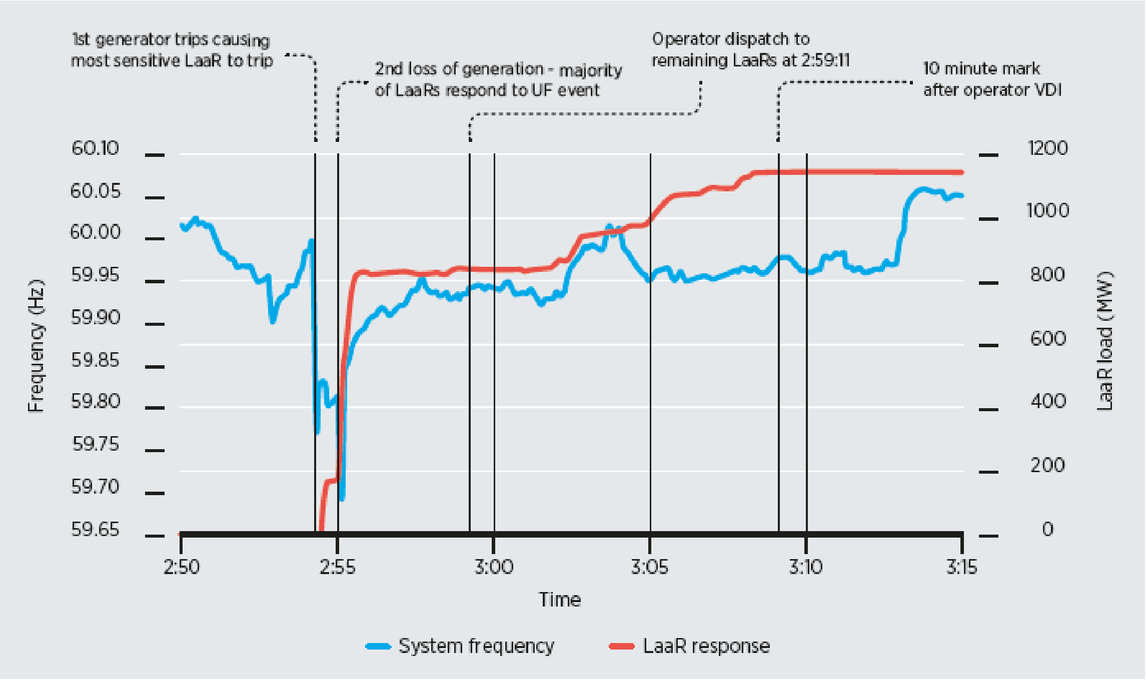


Fig. 4: ERCOT (Electric Reliability Council of Texas) load resources providing RRS to stop frequency from decreasing

Which one is the "right" technology for sector coupling

- **Which of the many technologies** that use electricity directly or indirectly the different sectors will eventually adopt in the future.
- **Direct electrification** of most sectors **VS** use of **power-to-x** technologies
- **Using electricity directly** in heating, transport, and industrial processes
  - ✓ most **energy efficient** solution
  - ✓ **fewer renewable** installations
  - ✓ **less energy** will have to be **imported**
  - ✓ overall **costs** will be **lower**.
  - ✓ private cars, trains, buses, and private houses: **electricity**,
  - ✓ larger vehicles and industrial processes: **hydrogen, methane, or other synthetic fuels** - long-term storage of energy.
- Against substituting petrol with synthetic fuels and gas in **personal transport** in particular because such cars would consume around five times as much power as battery electric vehicles.

Which one is the "right" technology for sector coupling

- **Power-to-gas technologies**:
  - ✓ **Gas** (e.g. in the form of methane) can be **stored in quantities** needed by the power system as backup in times of low renewable electricity generation.
  - ✓ Existing gas network can be used not only for storage but also for **transporting gas**
  - ✓ Several existing applications and processes: **no need to introduce new technologies**
  - ✓ **Biogas plants** could provide the CO_2 needed to create methane from hydrogen.
- **Mix of many technologies**: decarbonise and interconnect the different sectors.
- Predictable **framework conditions** - **level playing field**
- **Market design** - system operation
- **Practical and legal questions**: creation of an integrated energy system.
- Power generators, grids, storage devices, and electrolysers are **taxed and/or subsidised**;
- Who is allowed to **operate** them;
- Who is in **charge of managing** the power flow from and to renewable installations and households to stabilise the grid
- **Rules** on how, when, and where people are allowed to charge e-cars.

Thank you very much for your attention! Questions?