SAFEr Grid
Store-and-Forward Energy Grid

Towards a reliable and sustainable power grid

Antonello Monti, Klaus Wehrle
on behalf of the SAFEr Grid Team

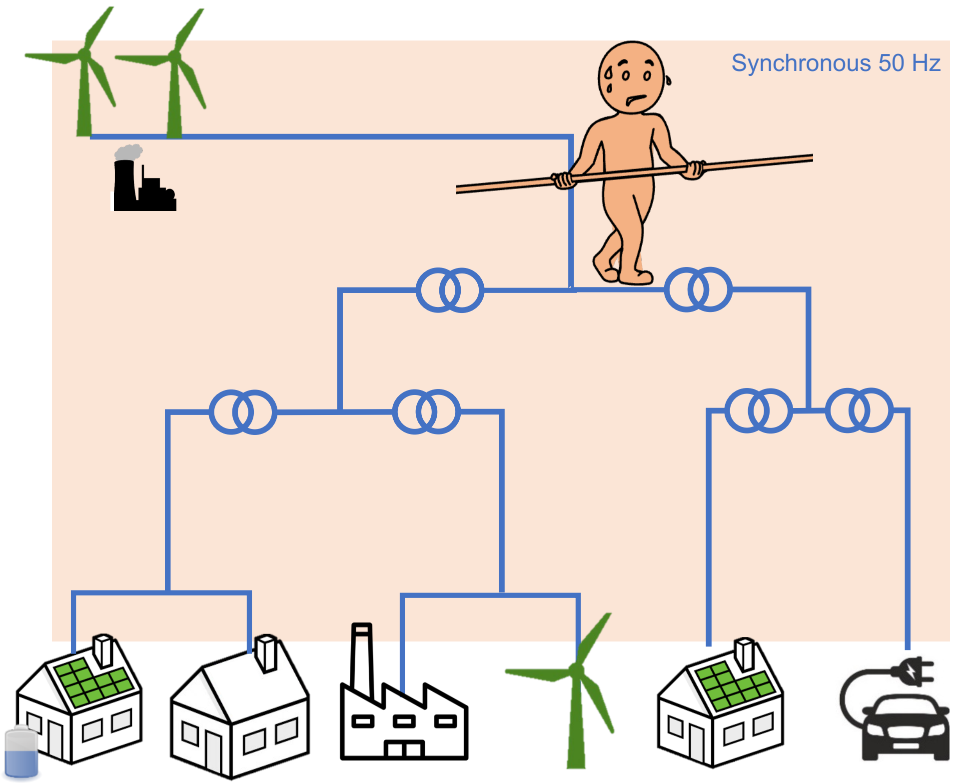
Funded by the European Union

European Research Council
Established by the European Commission

RWTH AACHEN UNIVERSITY

AALBORG UNIVERSITY

Synchronous Global Balancing of Power



Grid stability relies on
synchronous balance of power $P = \frac{\Delta E}{\Delta t}$

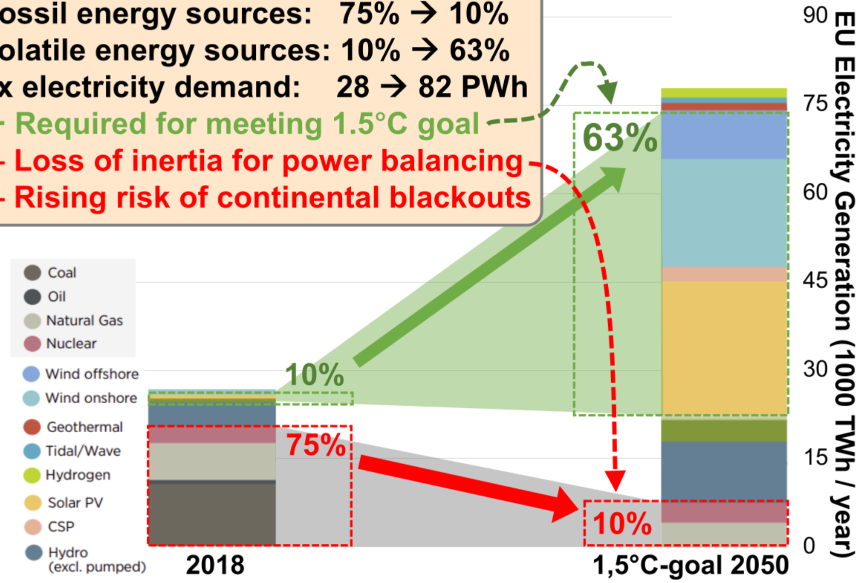
Stability Metric:

$$\frac{df}{dt} = \frac{50Hz}{Grid\ Capacity} \cdot \frac{Power\ Imbal}{2 \cdot Inerti}$$

• 20

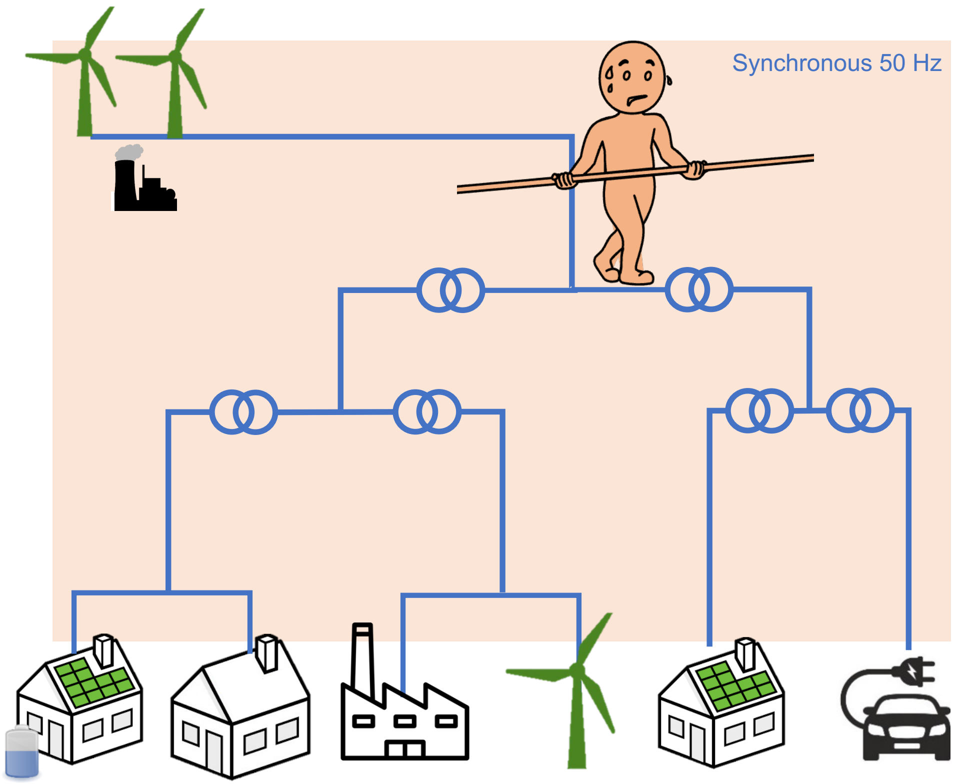
:6

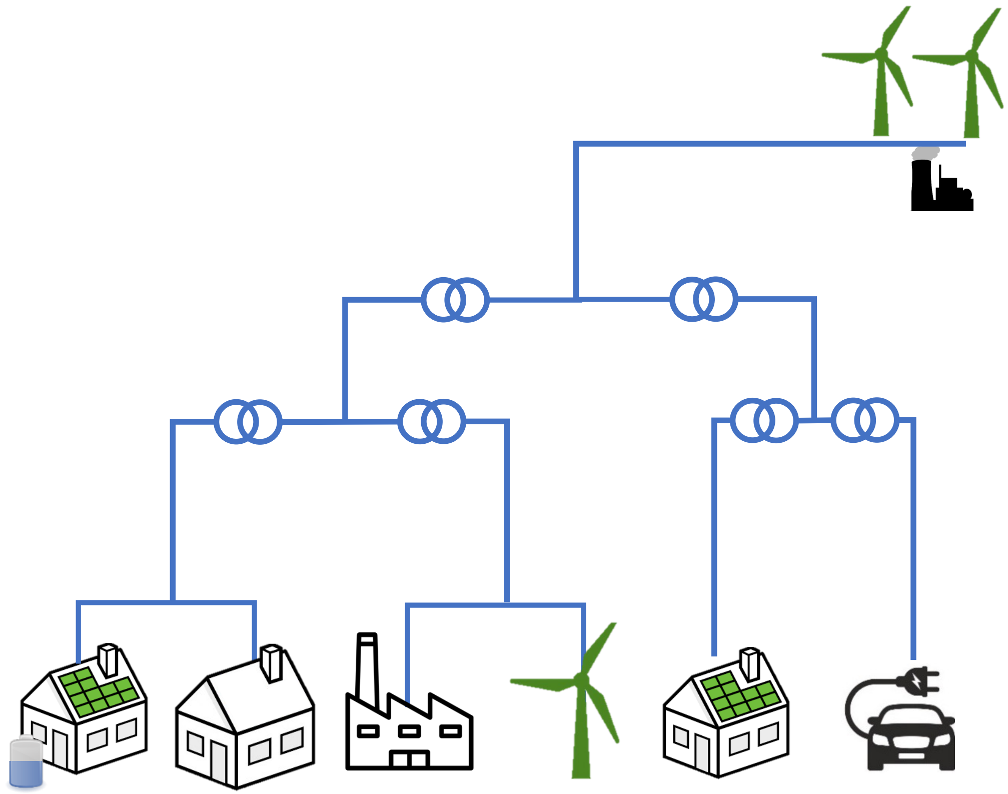
Fossil energy sources: 75% → 10%
Volatile energy sources: 10% → 63%
3x electricity demand: 28 → 82 PWh
+ Required for meeting 1.5°C goal
– Loss of inertia for power balancing
– Rising risk of continental blackouts



Synchronous
Global Balancing of Power

Asynchronous
Local Balancing of Energy



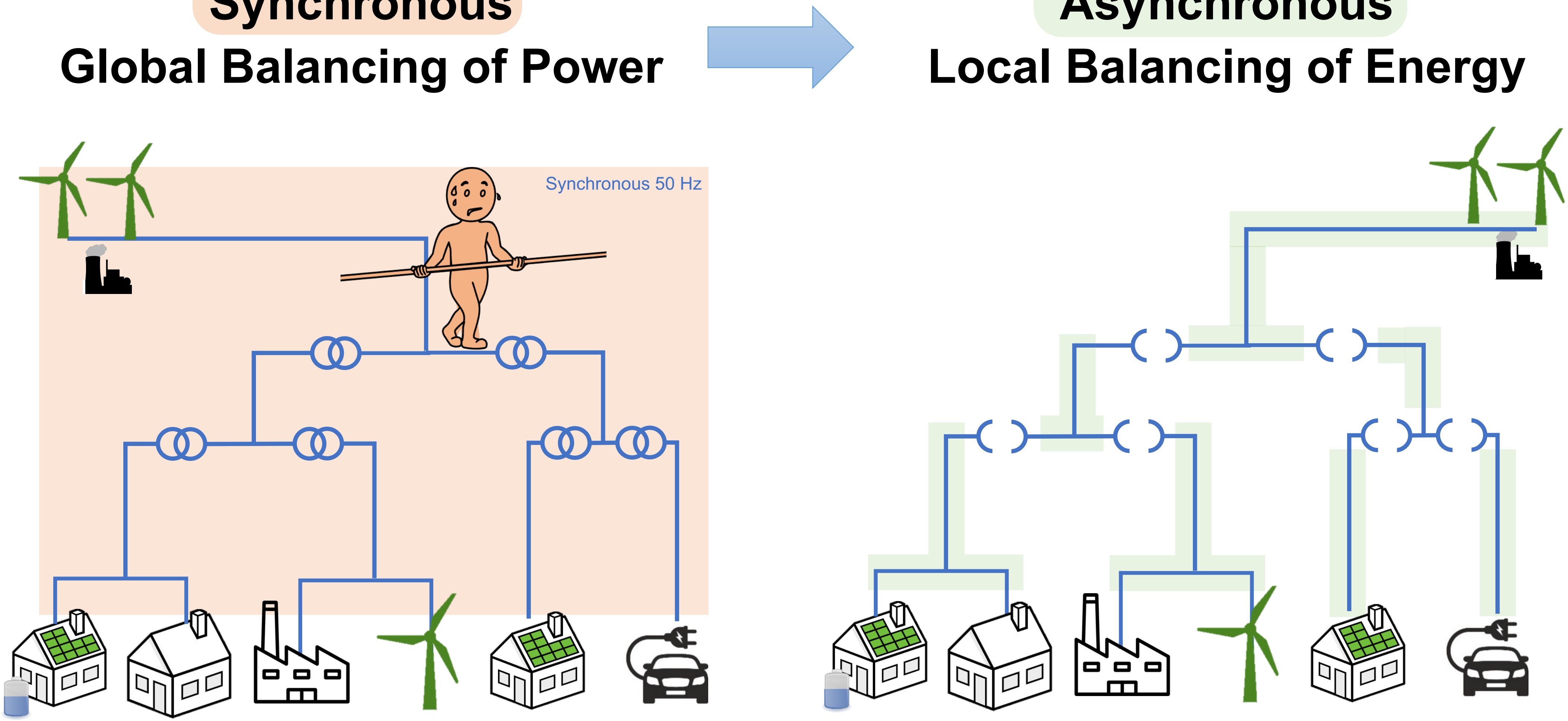


Synchronous

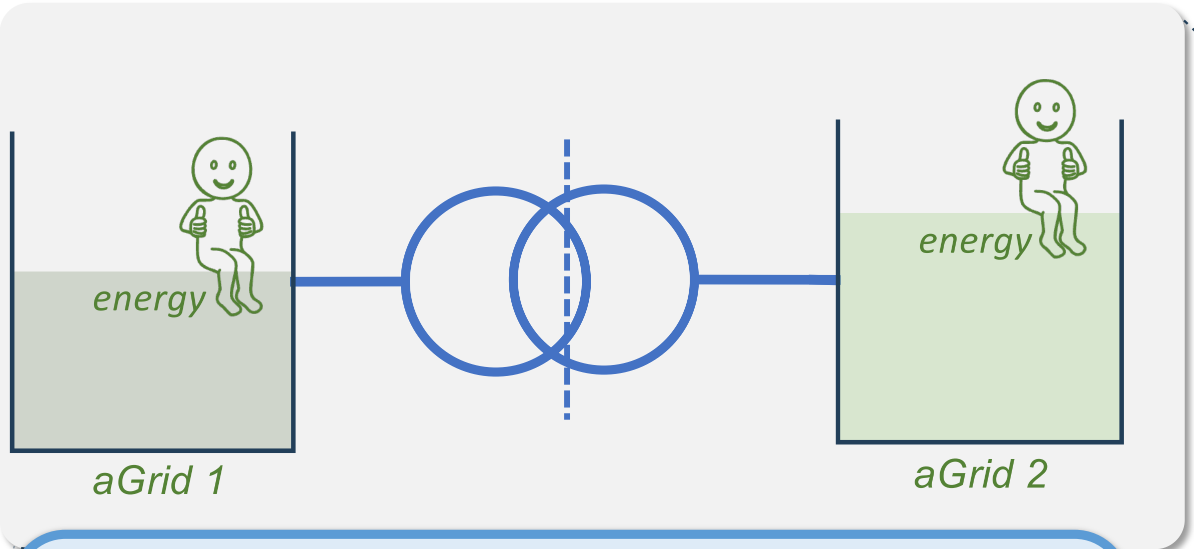
Global Balancing of Power

Asynchronous

Local Balancing of Energy

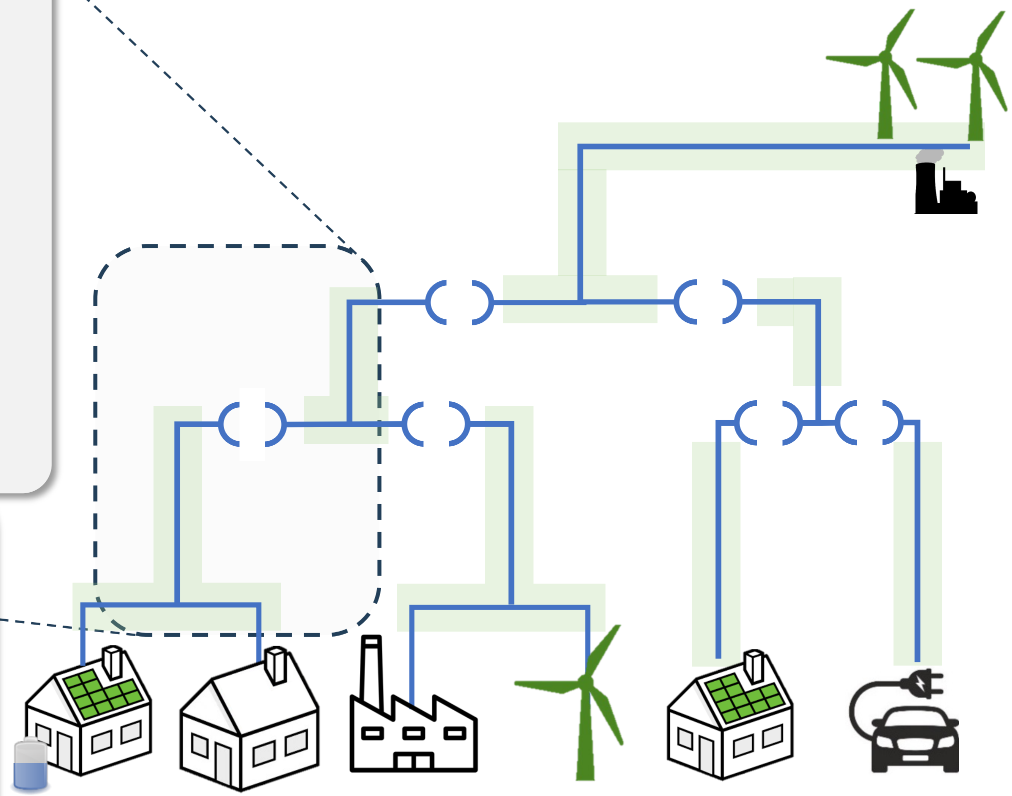


Asynchronous Local Balancing of Energy

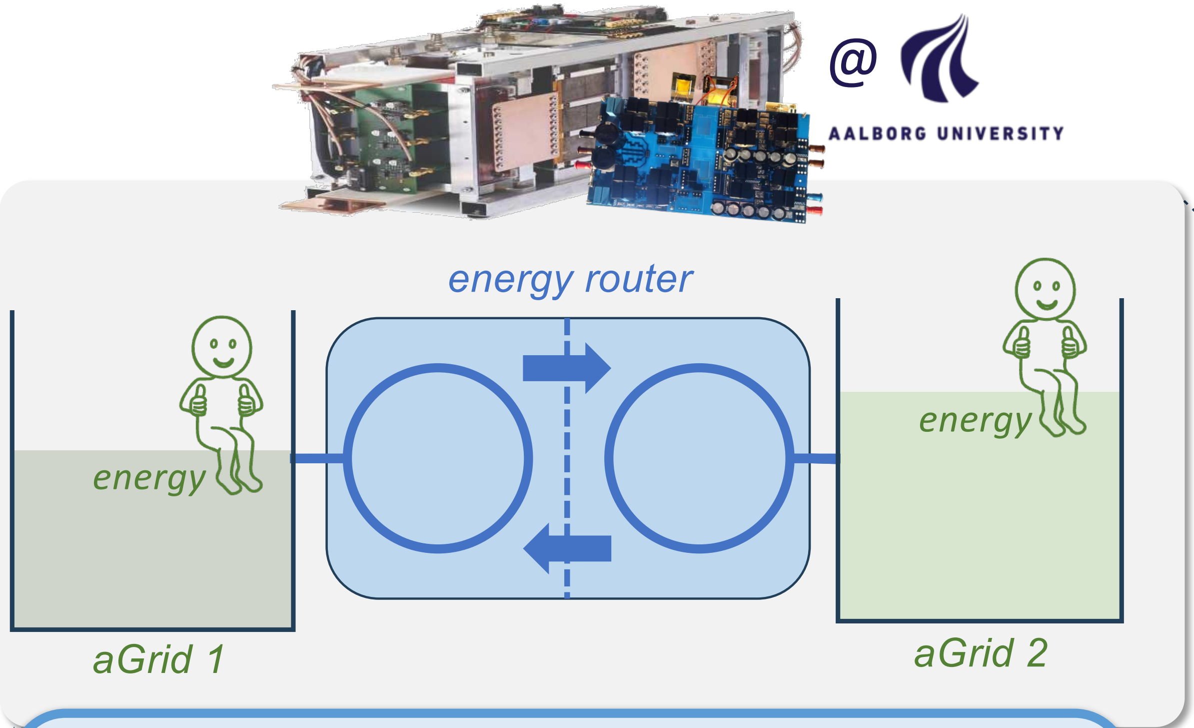


aGrids (asynchronous subgrids):

- Isolated and locally stable
- Shift from global matching of production & consumption to local aggregation
- Enabling flexible transfer of energy (not power)

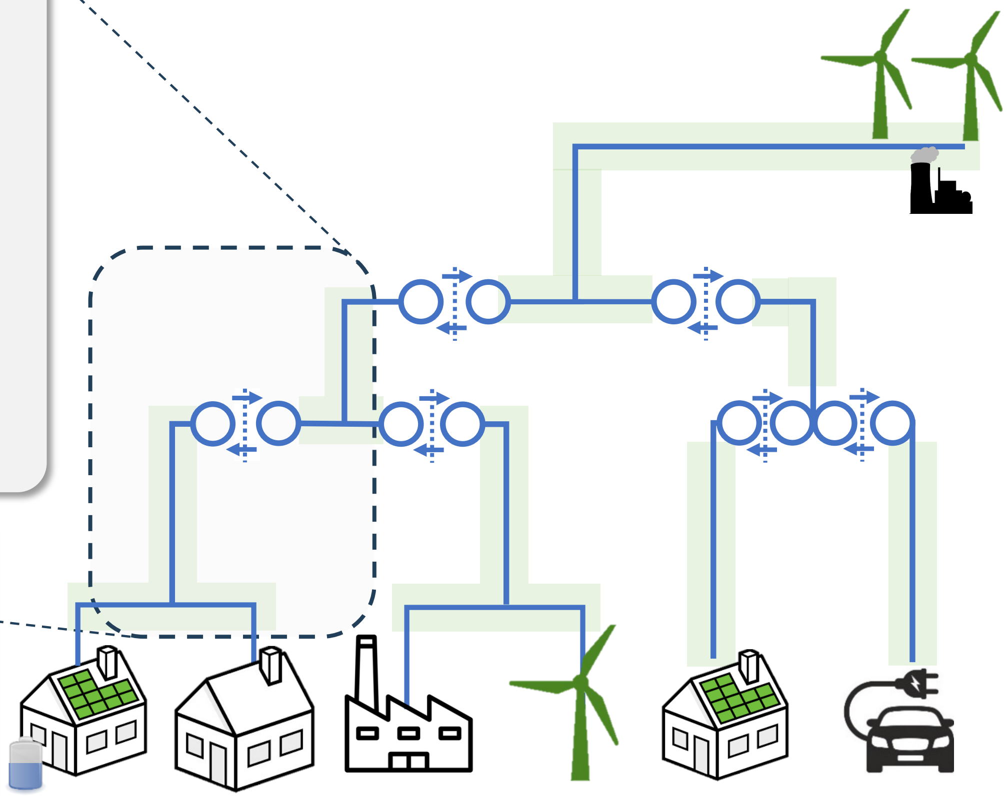


Asynchronous Local Balancing of Energy



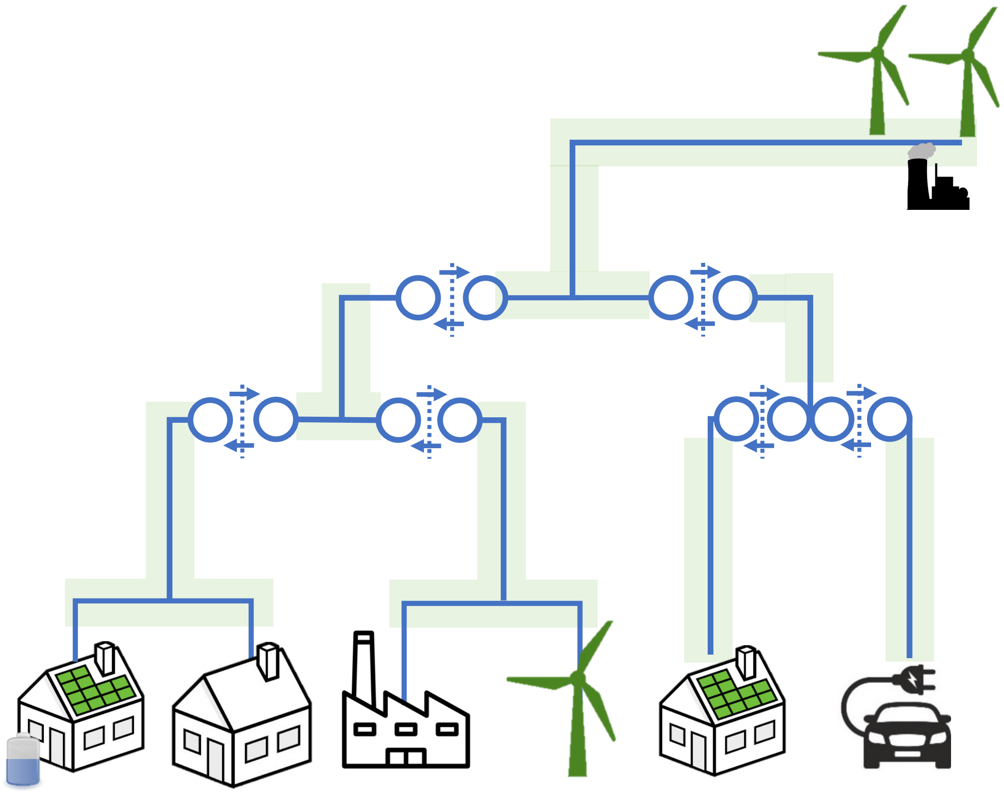
aGrids (asynchronous subgrids):

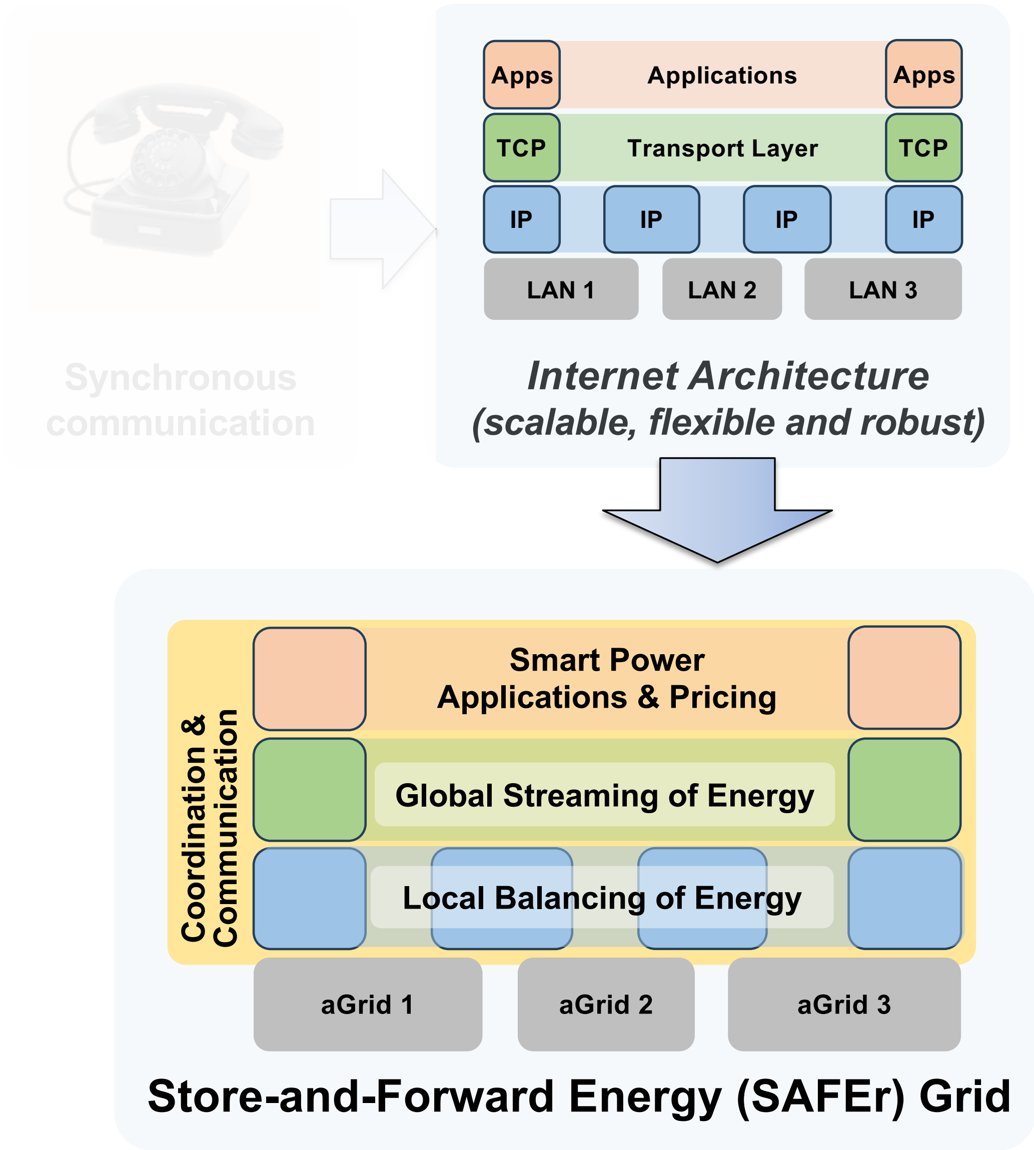
- Isolated and locally stable
- Shift from global matching of production & consumption to local aggregation
- Enabling flexible transfer of energy (not power)



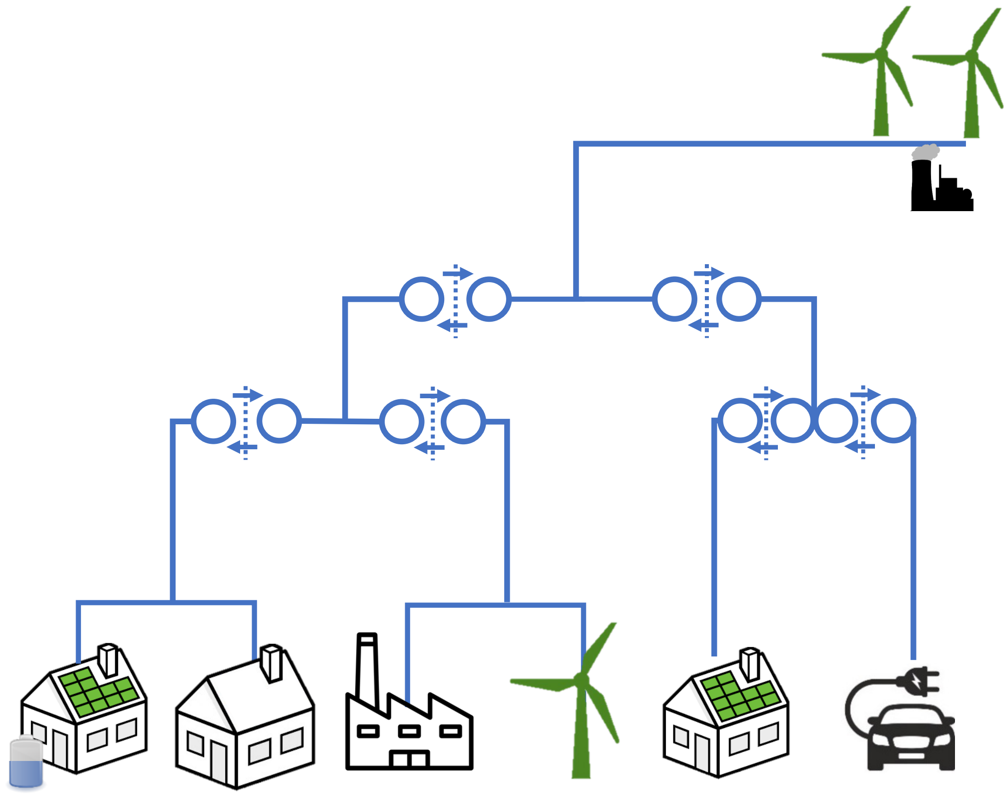
Synchronous communication

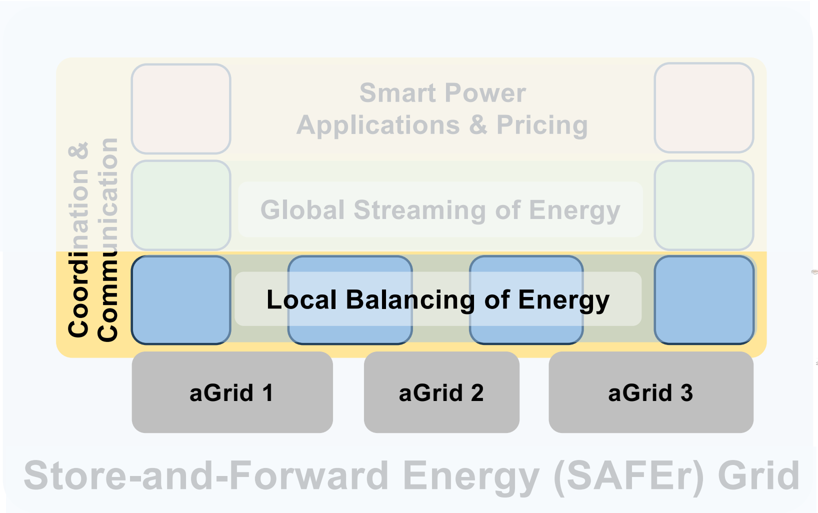
Asynchronous
Local Balancing of Energy

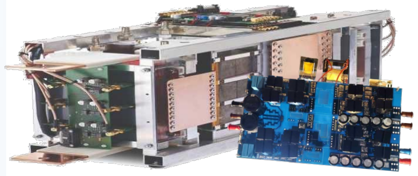




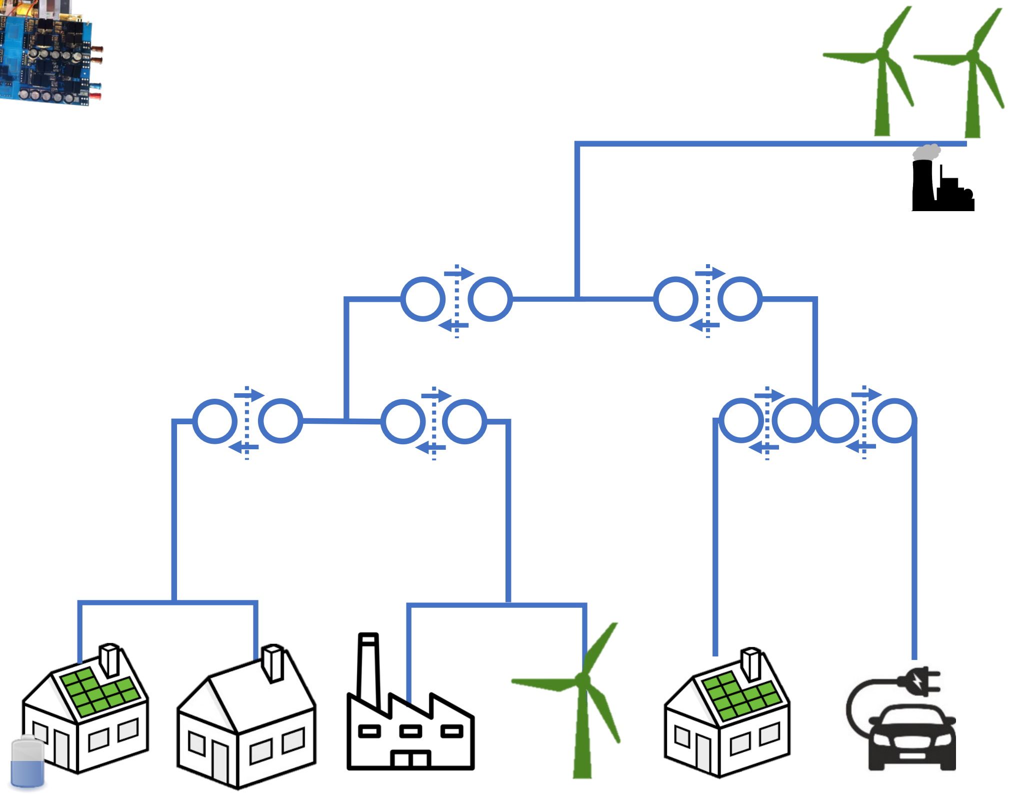
Asynchronous
Local Balancing of Energy





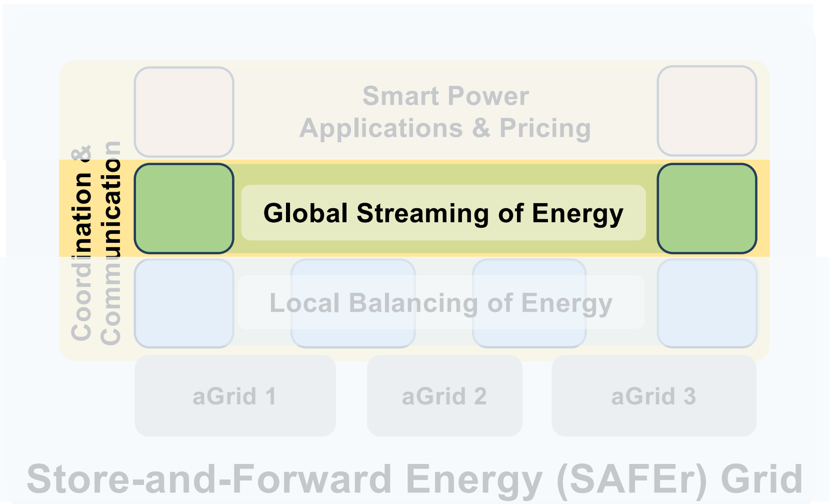


Asynchronous
Local Balancing of Energy

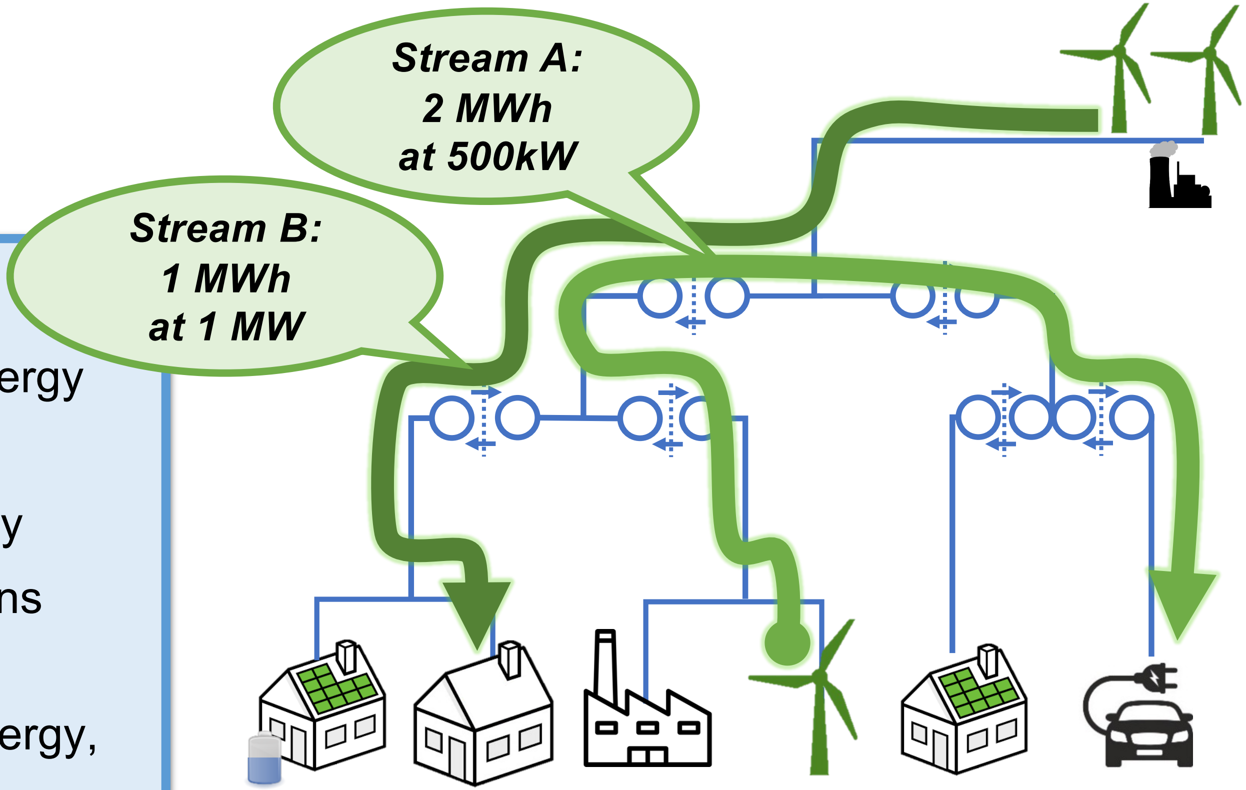


Energy Router:

- Reuse of existing grid (replacing transformers)
- Autonomous subgrids → blackout protection
- Controlled flow of energy in each direction
- Leveraging local aggregation and cooperation
- Coordination (also of buffered energy) provides great flexibility and emergency power

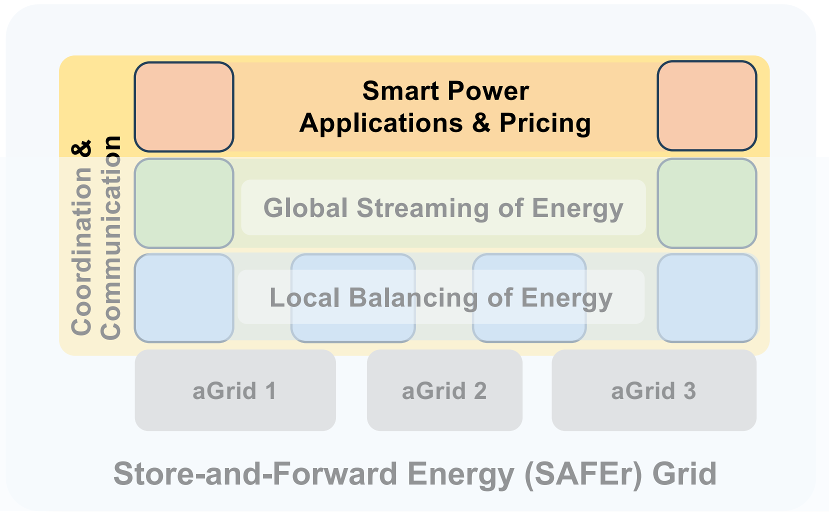


Asynchronous
Local Balancing of Energy



Streaming Layer

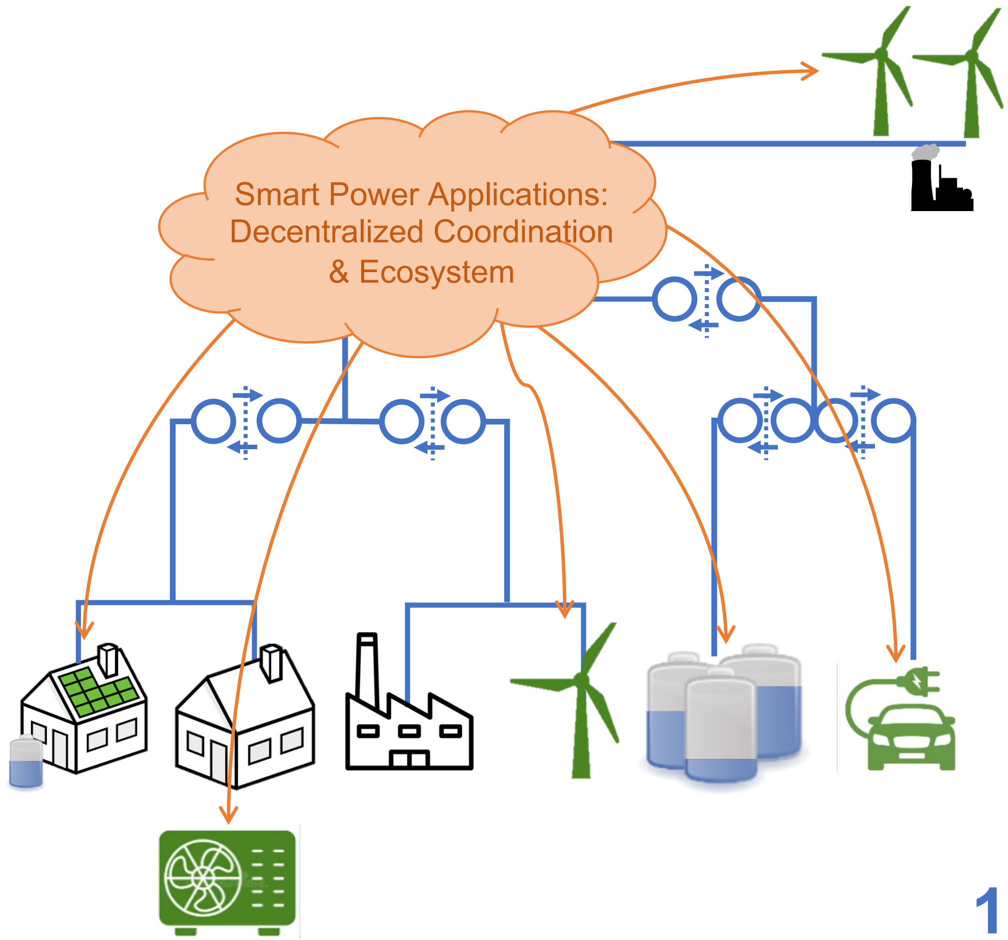
- Global and dedicated streaming of energy
  - High flexibility in strategies (tbr)
- Ensures stable and safe energy supply
  - Leveraging Internet stability solutions
  - Much less grid capacity required (temporal decoupling, routing of energy, aggregation of energy flows)
- Theory of grid stability (tbr)



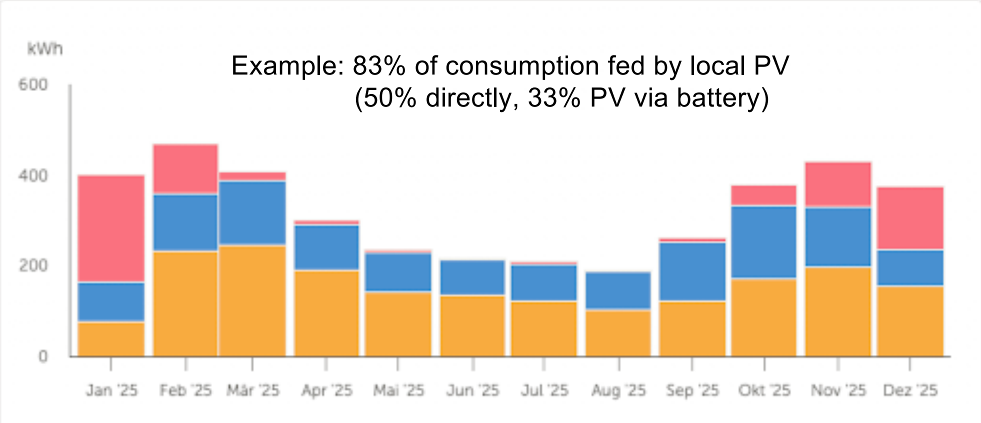
Asynchronous Local Balancing of Energy

Application Layer:

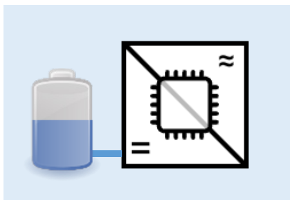
- Establish innovation ecosystem
- Volatile production → elastic consumption
  - Provide new classes of services
  - Leverage and foster elasticity
- Decentralized grid-wide coordination
  - Current is grid is far from being “smart”
- Provide incentives, e.g. energy flat rate

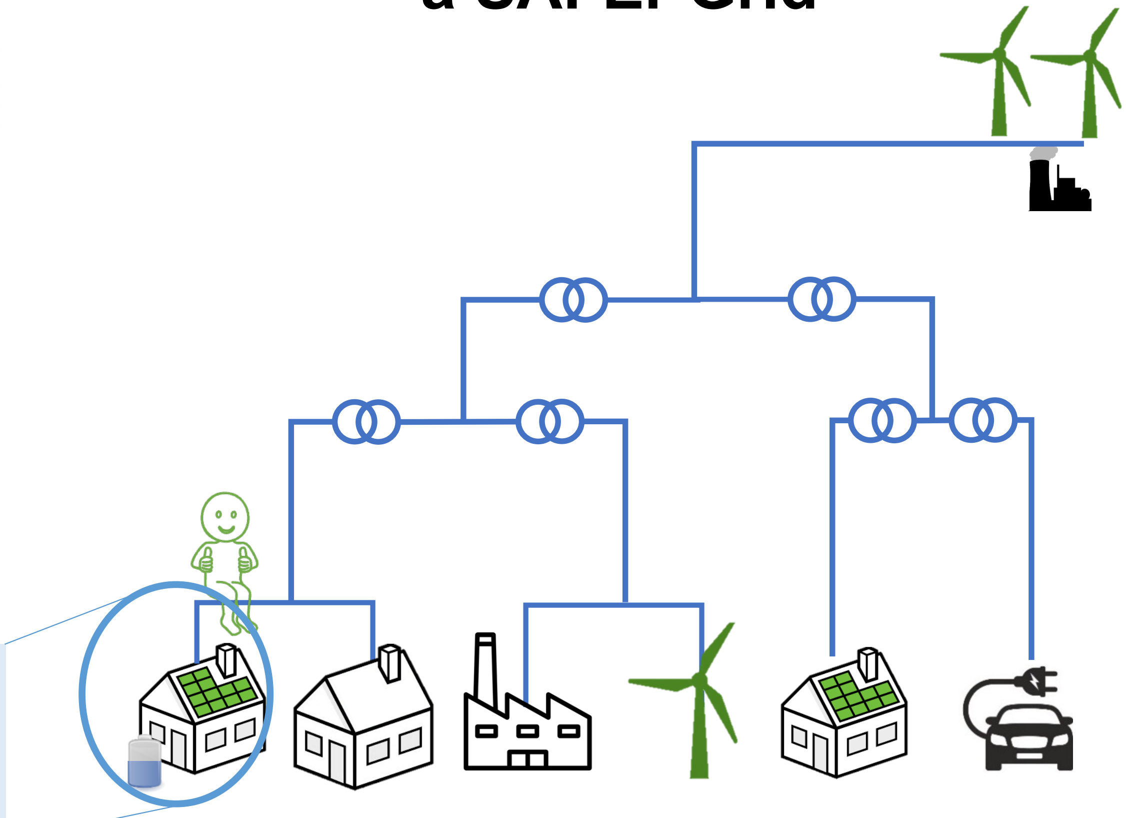


The Pathway towards a SAFEr Grid

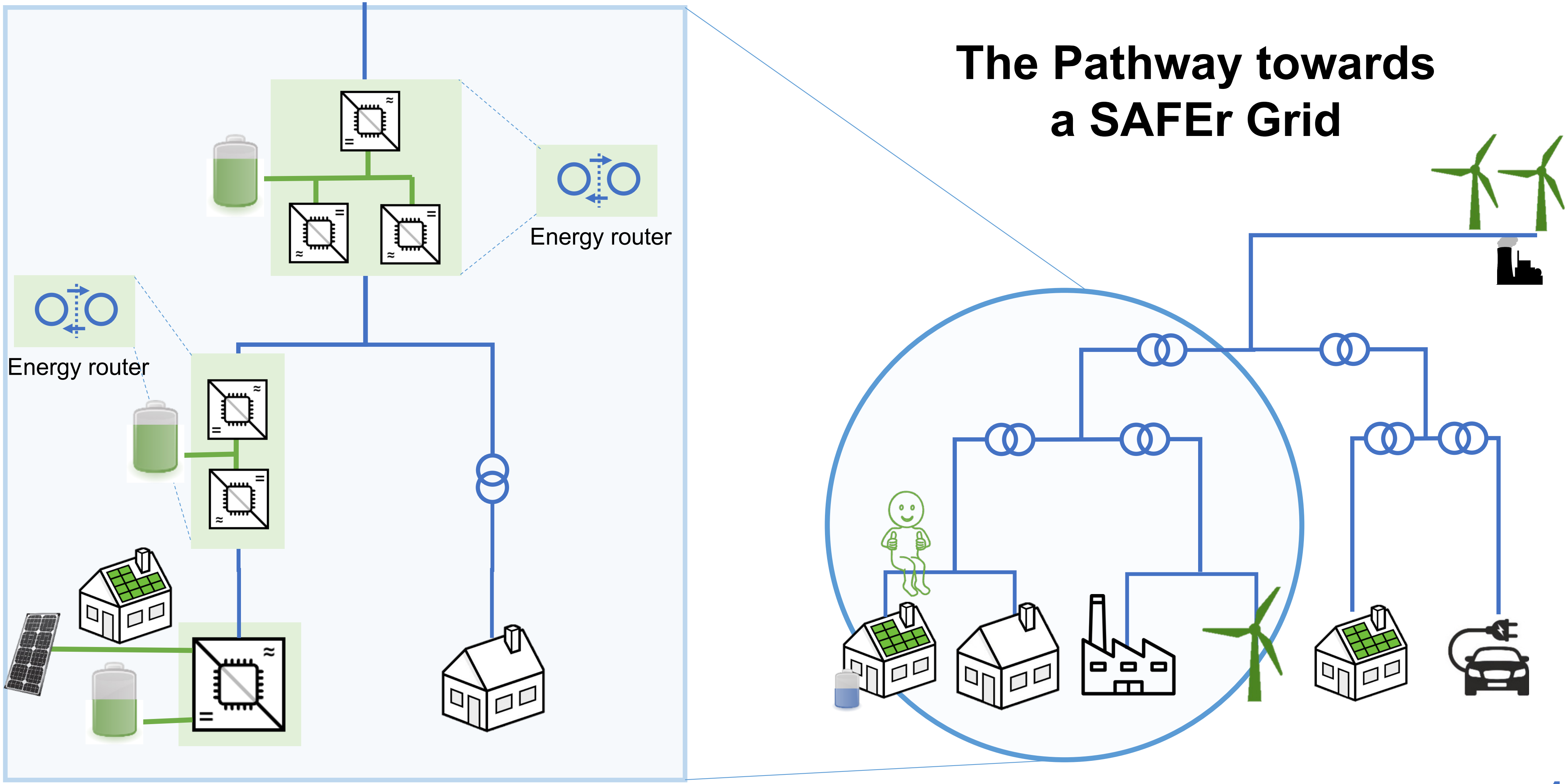


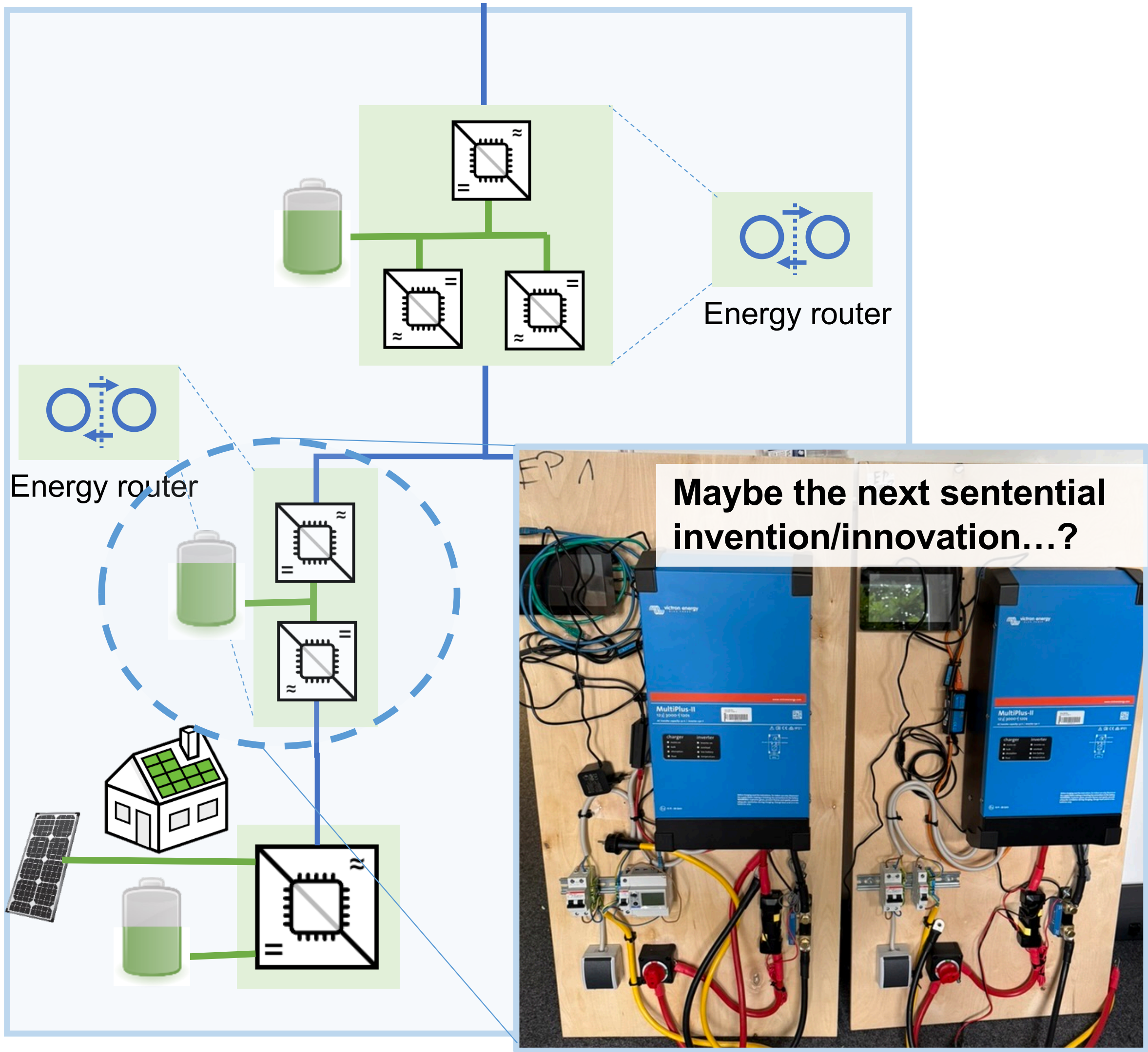
v1 of SAFEr Grid capability: grid forming PV with battery



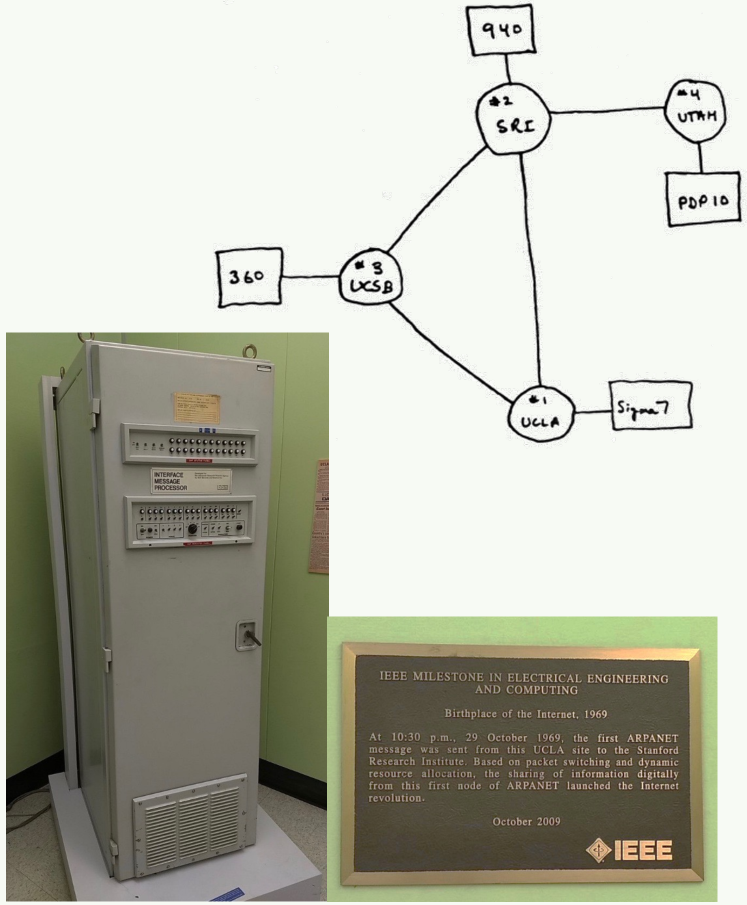


The Pathway towards a SAFEr Grid





Rember,
how the Internet began in 1969…



First packet router (UCLA) and topology, 29. October 1969

SAFEr Grid vs Internet?

- Yes, for almost all concepts, devices, procedures, control approaches there is room for an equivalent in an asynchronous energy grid
  - LAN ↔ aGrid, router ↔ smart transformer, applications ↔ usage plans, eyeball networks ↔ DSO, Tier 1 ↔ TSO, and many more
  - Even for NAT there is a counterpart
  - Many more to be developed for an asynchronous grid
    - Equivalent to congestion control ↔ how to organize energy streams in a fair share
    - How to globally organize the routing and streaming of energy (in flows, not in packets)
- The Internet is perfect role model how to design a versatile, flexible and robust infrastructure
- And, we hope to prove that we can also switch to flat rate pricing models

- But, there are also severe differences …

SAFEr Grid vs Internet?

- Differences between the Internet and asynchronous energy grid
  1. Energy ≠ information
     - This undermines the analogy's charm.
     - But, it simplifies things a lot (we can aggregate a lot, instead of queueing stuff up)
  2. Discretized energy exchange is not necessary (implication from (1))
     - Makes things again much simpler (keep it simple and stupid)
  3. The core may not be stateless, but will (likely) not harm sclability
     - Subject to our current research
  4. Overprovisioning vs. quality of service
     - There will be QoS in SAFEr Grid
     - Customers demand it
  5. There is still far more regulatory (mis)steering in the grid than on the internet

Many thanks for your attention !

- Please contact us to be invited to our SAFEr Grid stakeholder workshops

nature reviews electrical engineering
https://doi.org/10.1038/s44287-025-00256-5

Perspective

Check for updates

Resilient low-inertia power systems through asynchronous energy balancing

Sebastian Schwarz[1], Subham Sahoo[2], Mirko Stoffers[3], Patrick Pollok[4], Leonardo Pompe[3], Arthur M. Fibich[3], Amila Kaharević[1], Klaus Wehrle[3], Antonello Monti[1,5], Frank Piller[4] & Frede Blaabjerg[2]

Abstract

Low-carbon power systems with decreasing inertia are challenging traditional operational principles based on a global synchronous frequency, turning rigid synchronism into a growing threat to power system stability. In this Perspective, we discuss a bottom-up vision for compartmentalizing power systems into multiple asynchronous and independent subsystems. These subsystems, operating under different technologies, can form an asynchronous power system architecture that balances energy through a store-and-forward-like approach. Building on advances in smart power electronics, the proposed asynchronous conjecture avoids synchronism by proactively routing dynamic energy streams between those asynchronous subsystems, drawing inspiration from the principles of the Internet and telecommunications. Cyber–physical system theory, low-latency communication systems, novel abstraction and modelling principles, and the growing availability of energy storage emerge as enablers for this shift. The new paradigm can enhance power system resilience, support long-term sustainability goals, maximize energy independence and energy security, and create socio-economic opportunities.

Sections

Scan me!

[1]Institute for Automation of Complex Power Systems, RWTH Aachen University, Aachen, Germany. [2]AAU Energy, Aalborg University, Aalborg, Denmark. [3]Chair of Communication and Distributed Systems, RWTH Aachen University, Aachen, Germany. [4]Institute for Technology and Innovation Management, RWTH Aachen University, Aachen, Germany. [5]Fraunhofer Center Digital Energy, Fraunhofer FIT, Aachen, Germany. e-mail: sschwarz@eonerc.rwth-aachen.de; sssa@energy.aau.dk; fbl@energy.aau.dk

Nature Reviews Electrical Engineering | Volume 3 | February 2026 | 101–110 101

RWTH AACHEN UNIVERSITY

AALBORG UNIVERSITY

Funded by the European Union

European Research Council
Established by the European Commission