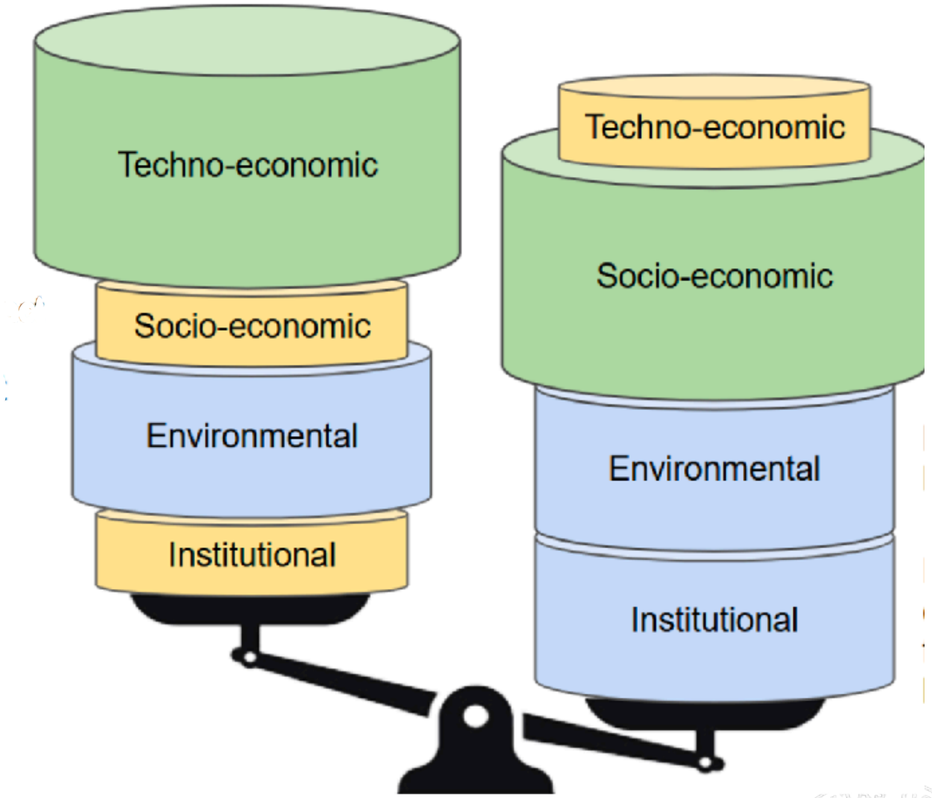
UNIVERSITY OF OSLO

i3s Sustainability Summer School , 6-11Sep2026, Karlsruhe, Germany

From centralised to decentralised energy provision

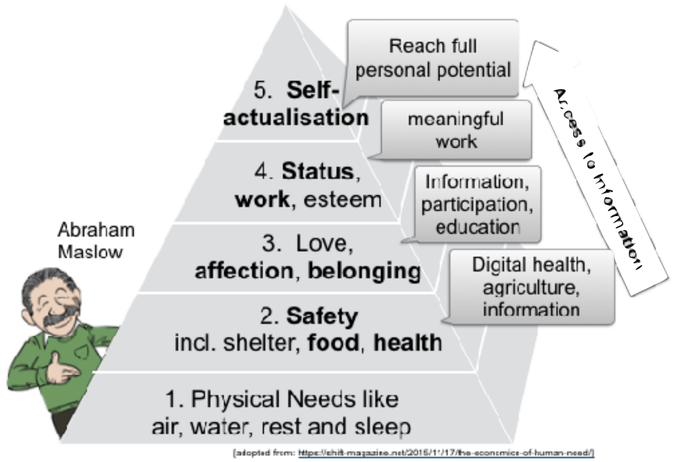


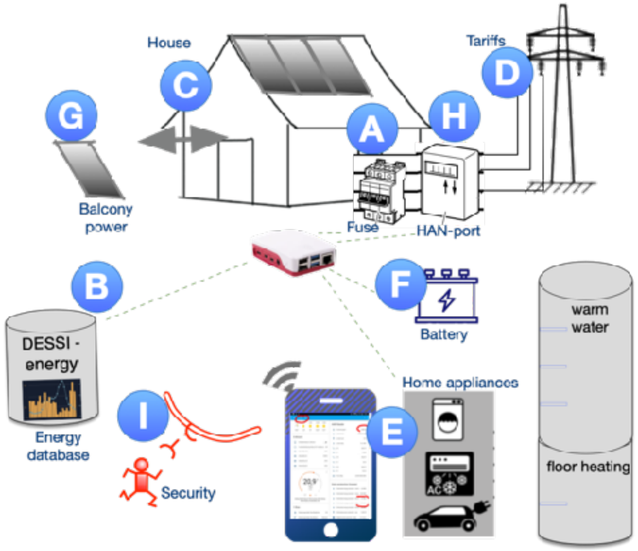
Josef Noll

Professor, University of Oslo,
Department of Technology Systems
Kjeller, Norway, m: +47 9083 8066

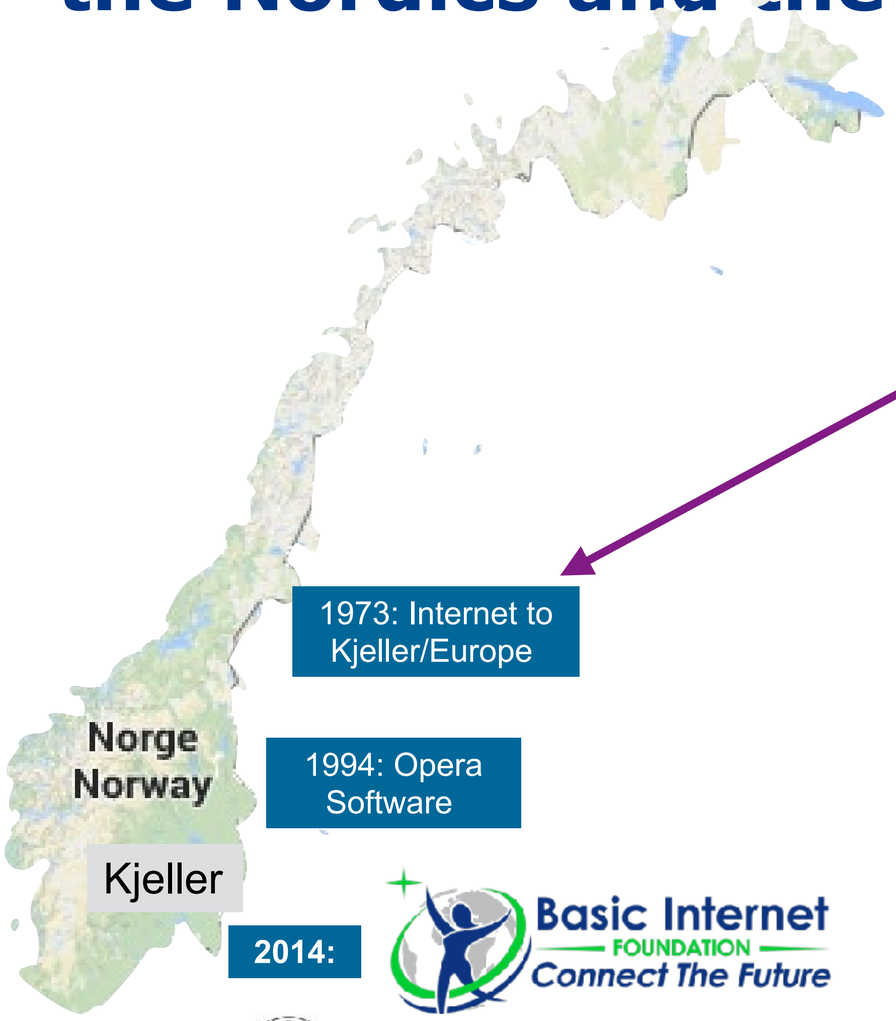
Outline

- "Why Norway"
- Societal Security - needs
- Electricity growth (demand)
  - central grid contribution
  - edge/behind the meter
- Distributed Energy
  - from techno-economic
  - to systemic model
- Research challenges





Inclusive digitalisation in the Nordics and the Baltics



1973: Internet to Kjeller/Europe

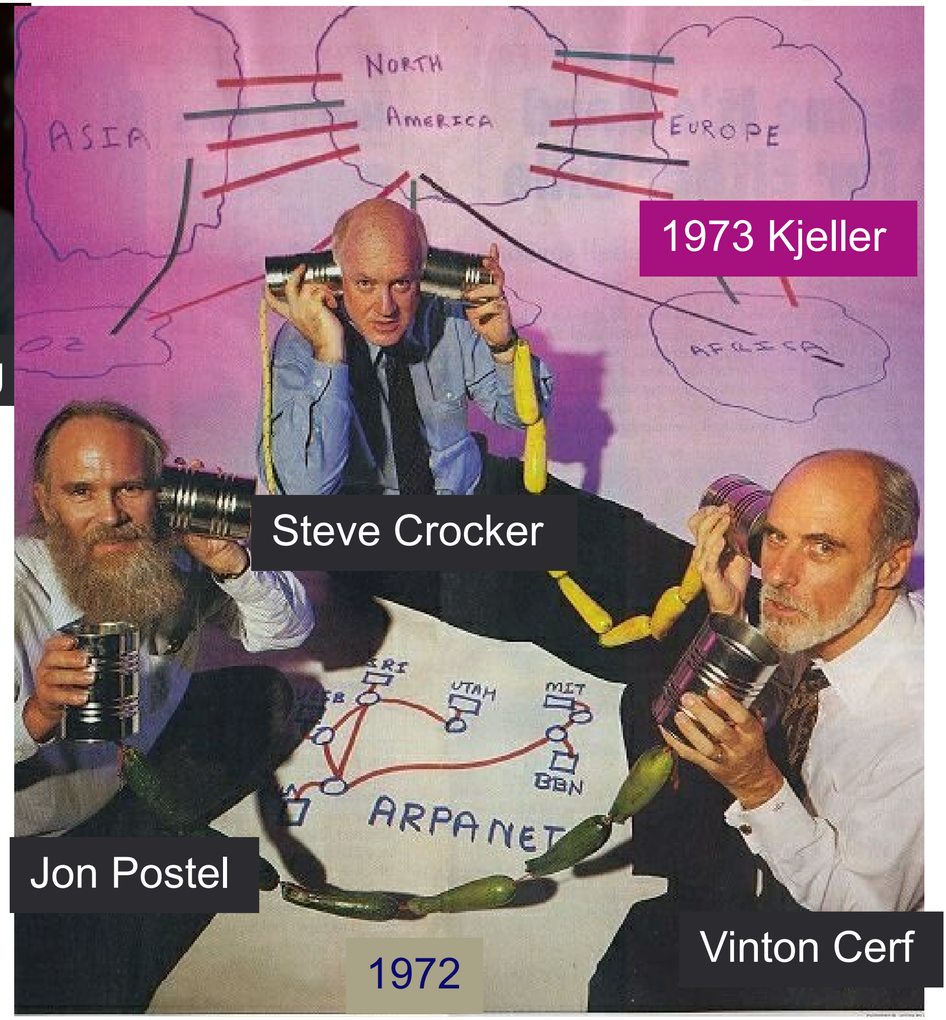
1994: Opera Software

2014:

Basic Internet Foundation — Connect The Future

University of Oslo

Kjeller Innovasjon



.php, OpenSource, Linux, Skype, Spotify
Opera Software, FAST search
Nokia, Ericsson
GSM
GovStack.global, X-Roads

Source: http://www.michaelkaul.de/History/history.htm

Energy transition

needs to be a

Societal transition

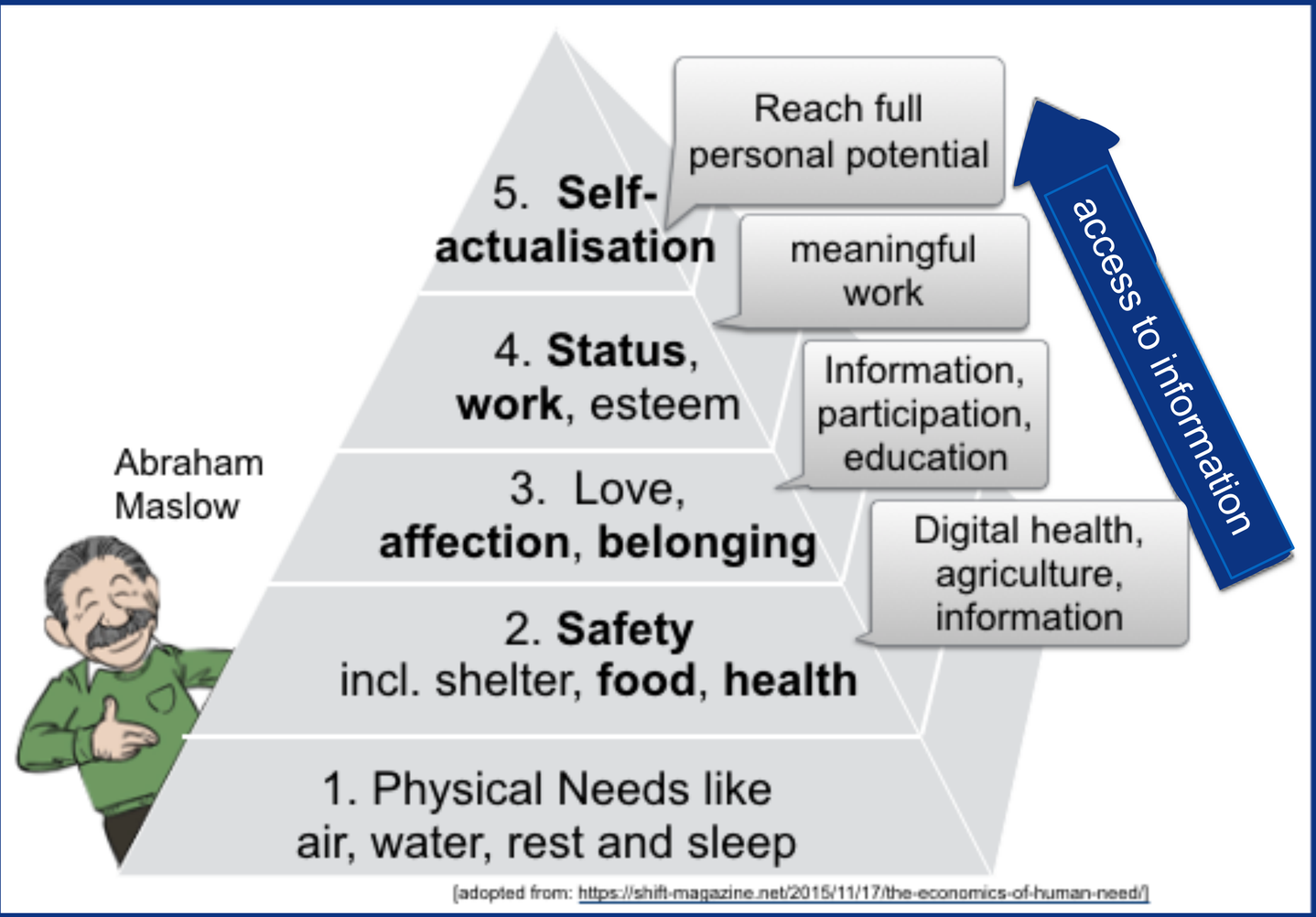
we picked the low-hanging fruits (Norway: 97% of new cars are electrical)

to reach 95% CO2 reduction by 2045 requires societal changes

Societal Security

Digital Transformation,
Resilient Communities,
Empowered People

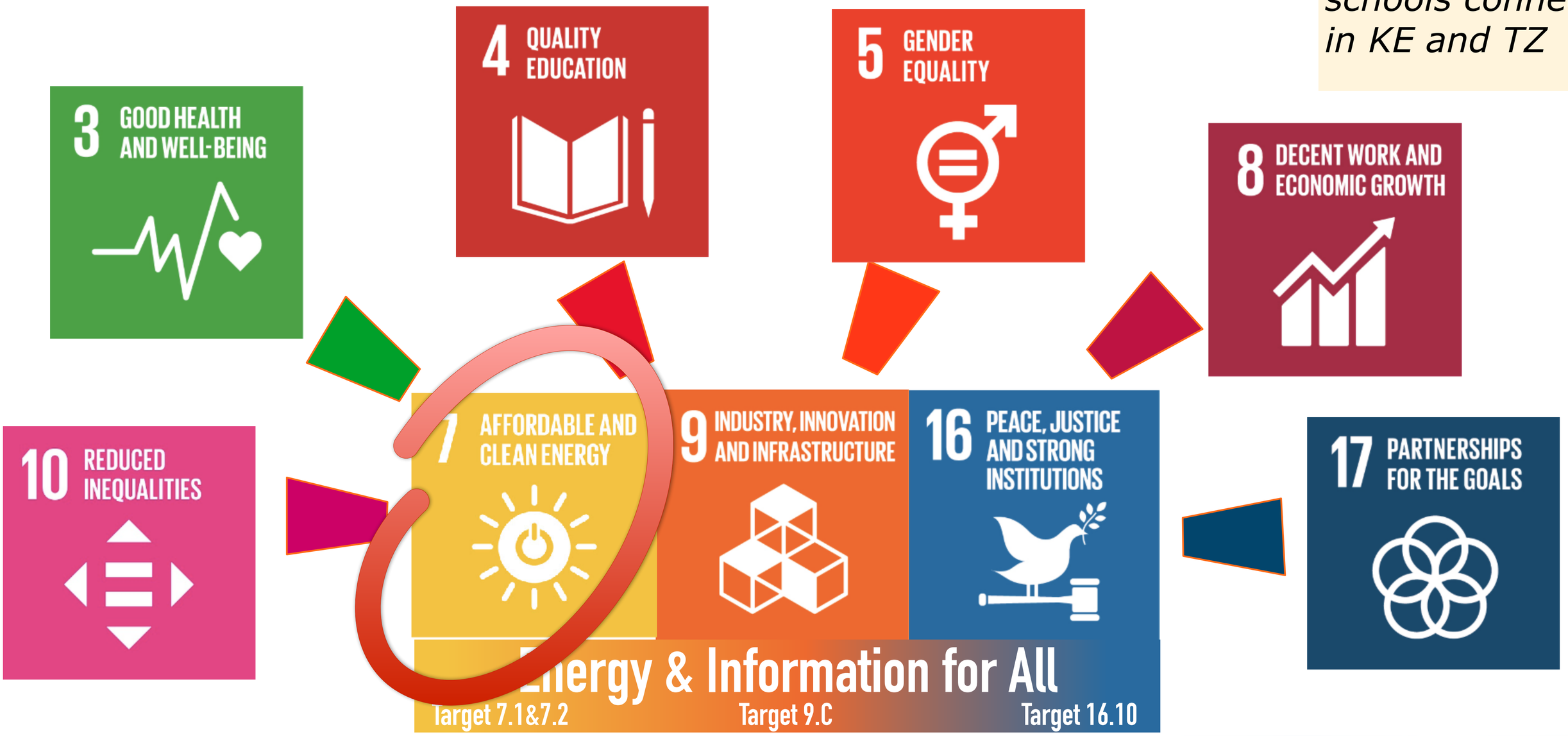
Digital Inclusion
Societal Empowerment
Digitisation



Affordable Energy & Internet Lite for All

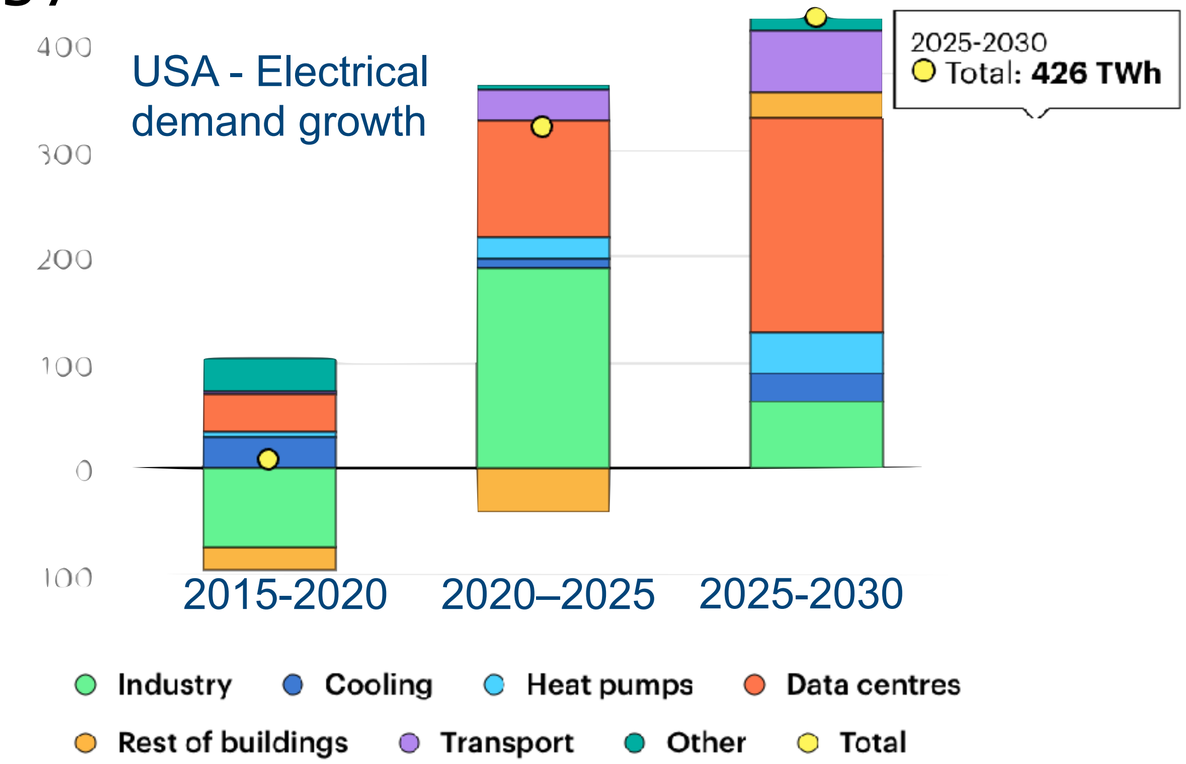
the catalysts for the goals

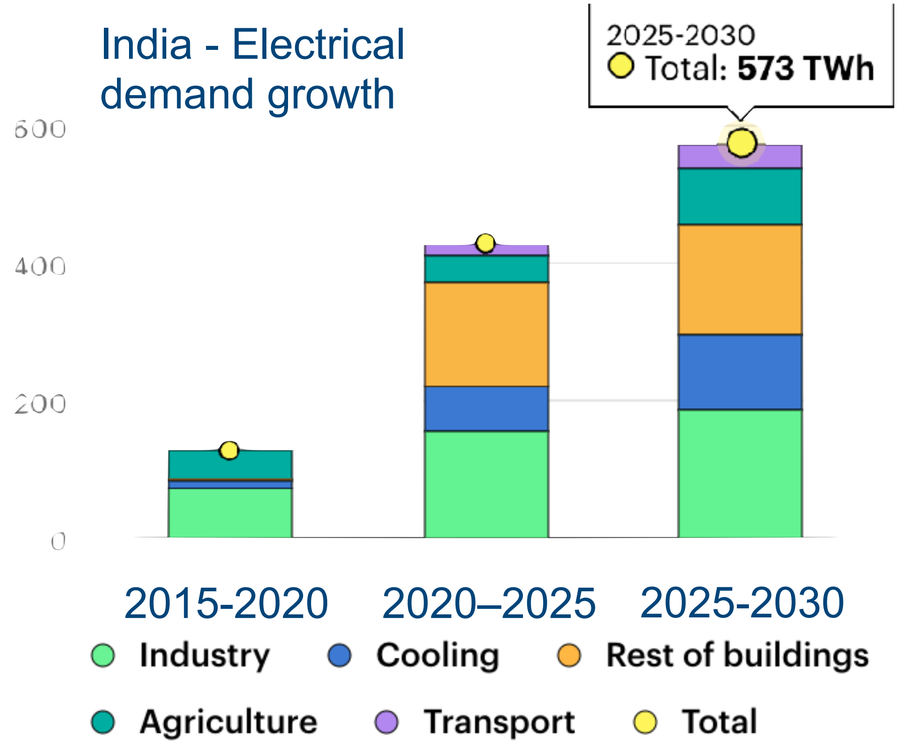
more than 250 schools connected in KE and TZ



International Energy Agency (IEA, 2026)

- "all electric" Electrical energy demand is 2.5 times other energy demand
- ~3.6% el. energy growth/year 2026-2030





IEA (2026), *Electricity 2026*, IEA, Paris https://www.iea.org/reports/electricity-2026 ,

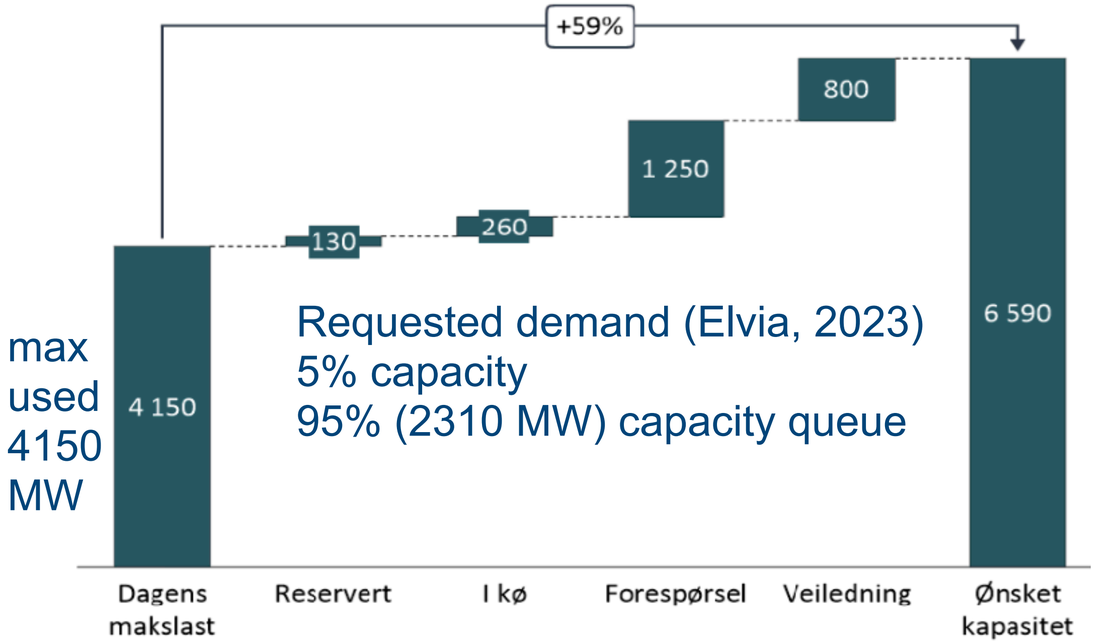
Limited Grid-capacity

[SSB, http://ssb.no/stabank/table/10314/]

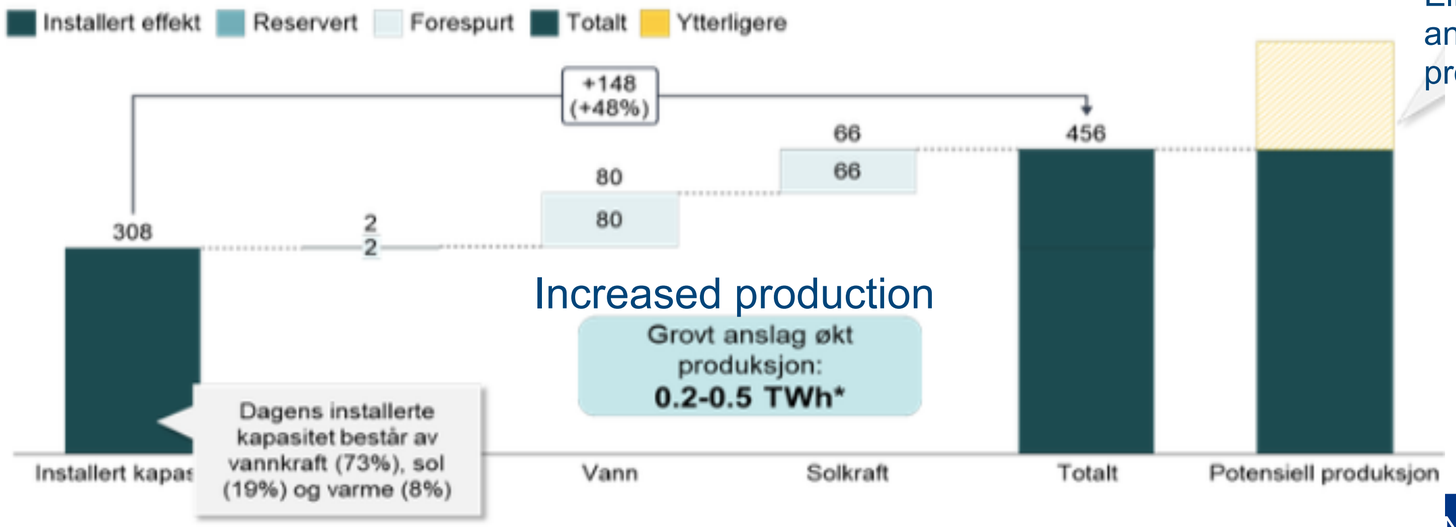
- "No capacity for new usage in Oslo, Østfold and Akershus until 2030-2035"

[Kraftløftet Oslo Akershus, LO & NHO, 2023]

- Green business development?

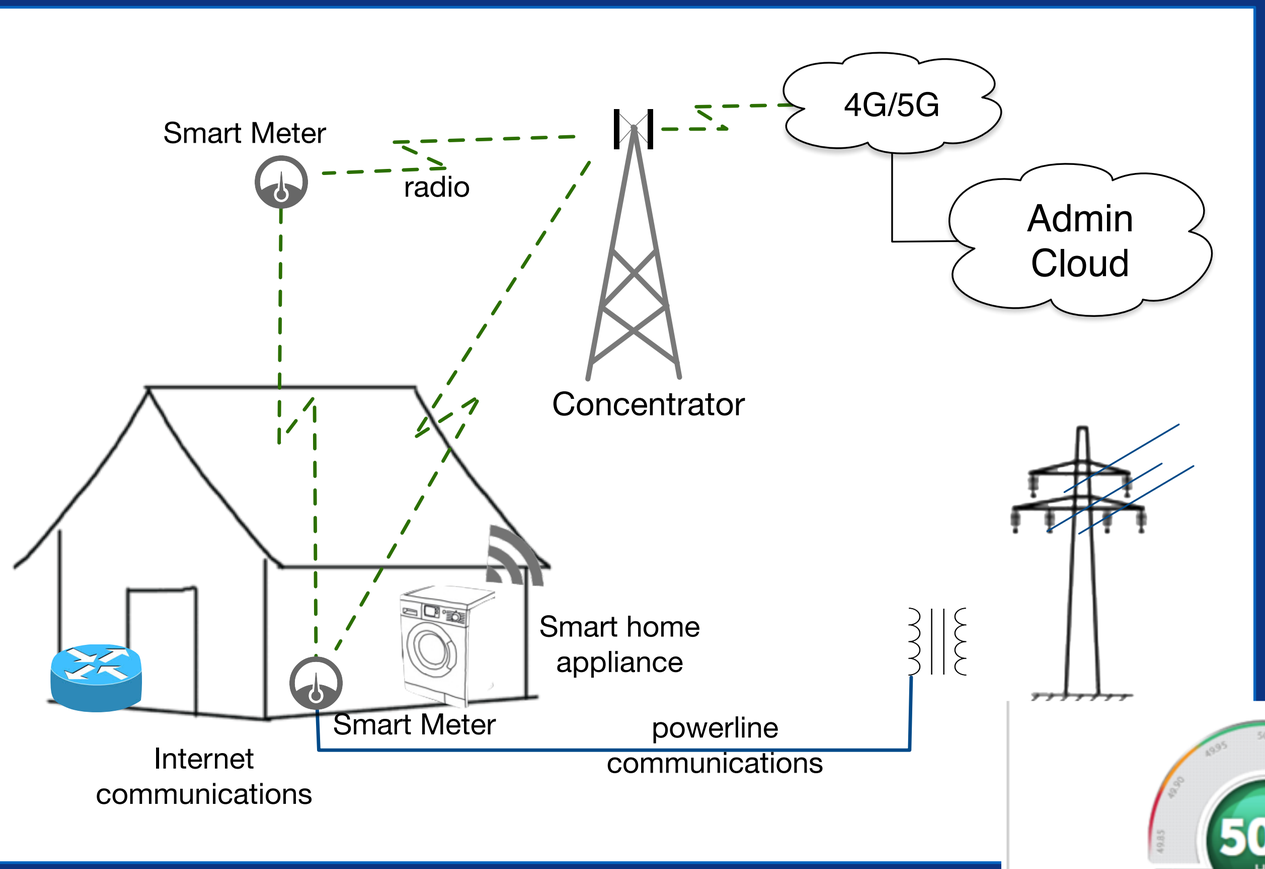


51% requested capacity increase

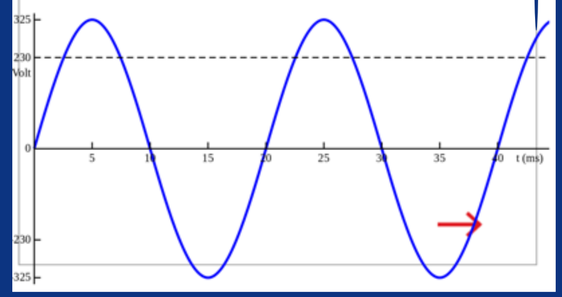


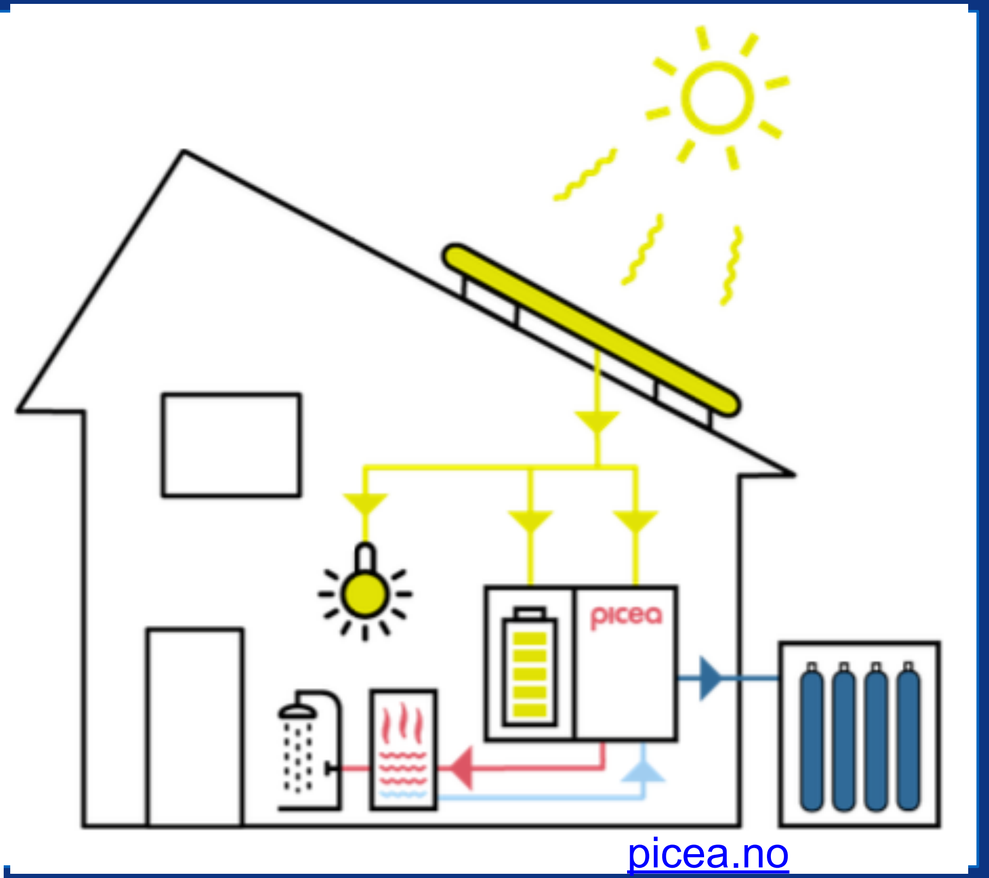
Eliva: 1180 MW and other future production

The electrical grid



+/- 0.1

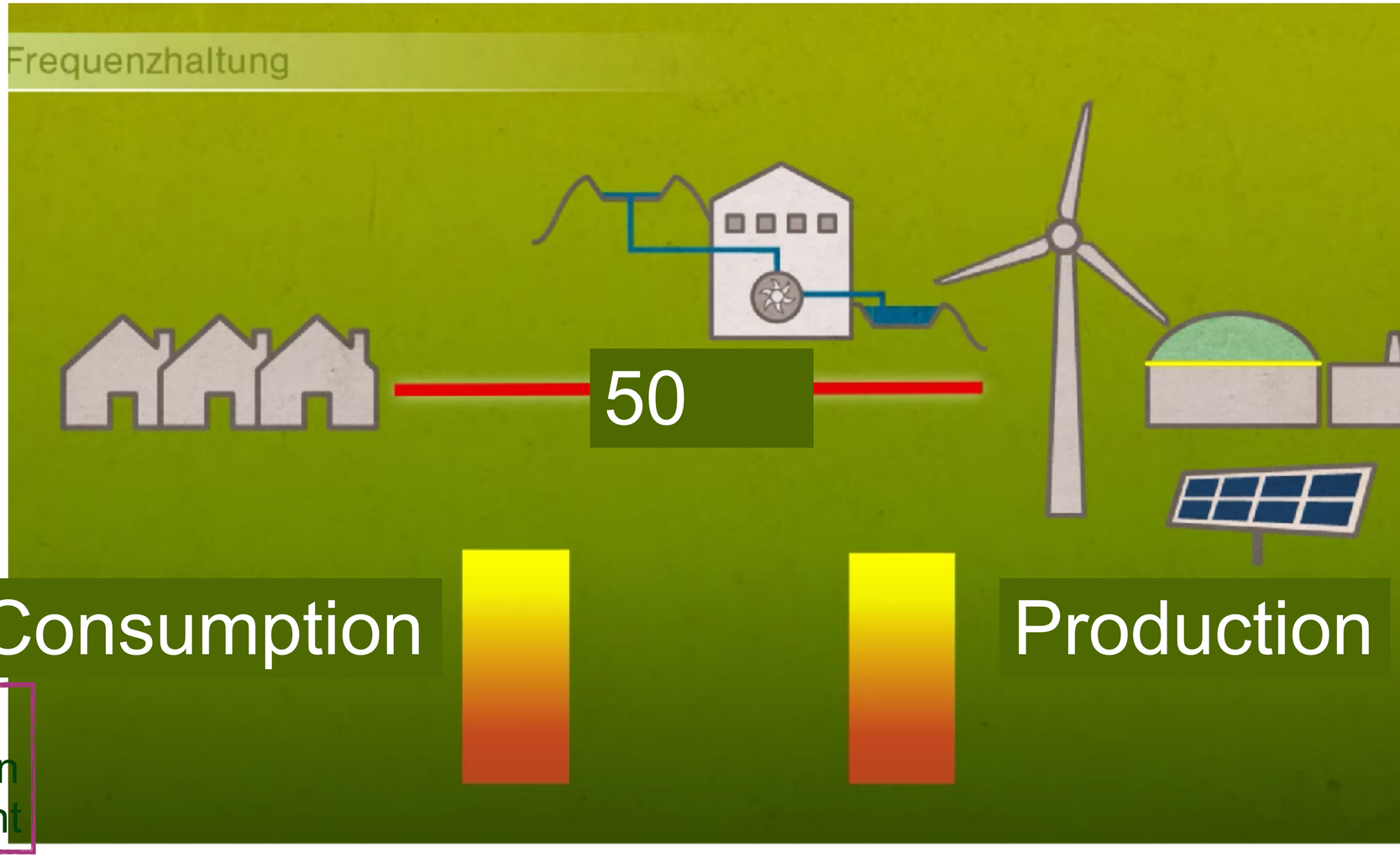




picea.no

Frequency and Voltage - control and stabilisation

- 50,2 Hz too much energy
  - switch off photovoltaic
- 49,8 Hz too little energy
- 230 V (400 V)
  - drop due to resistance in the line

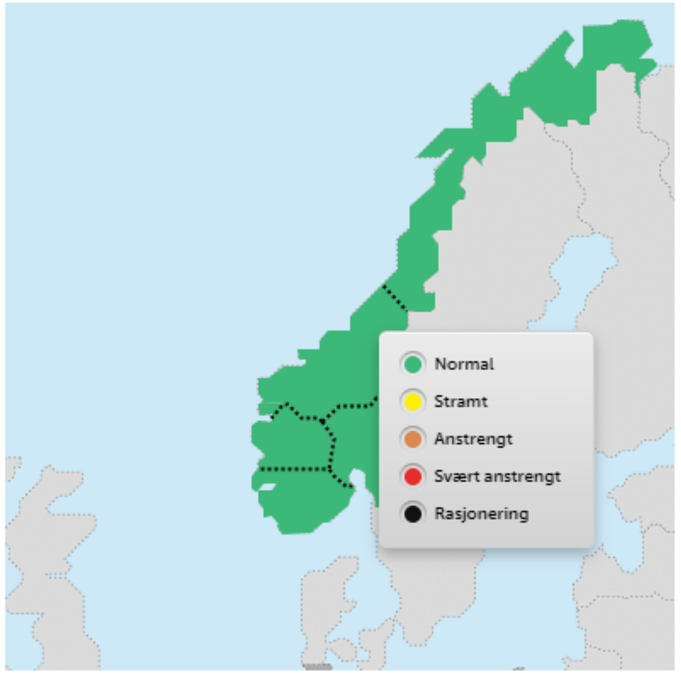


To understand:
- complexity of grid and grid regulation
- complex numbers Voltage vs Current

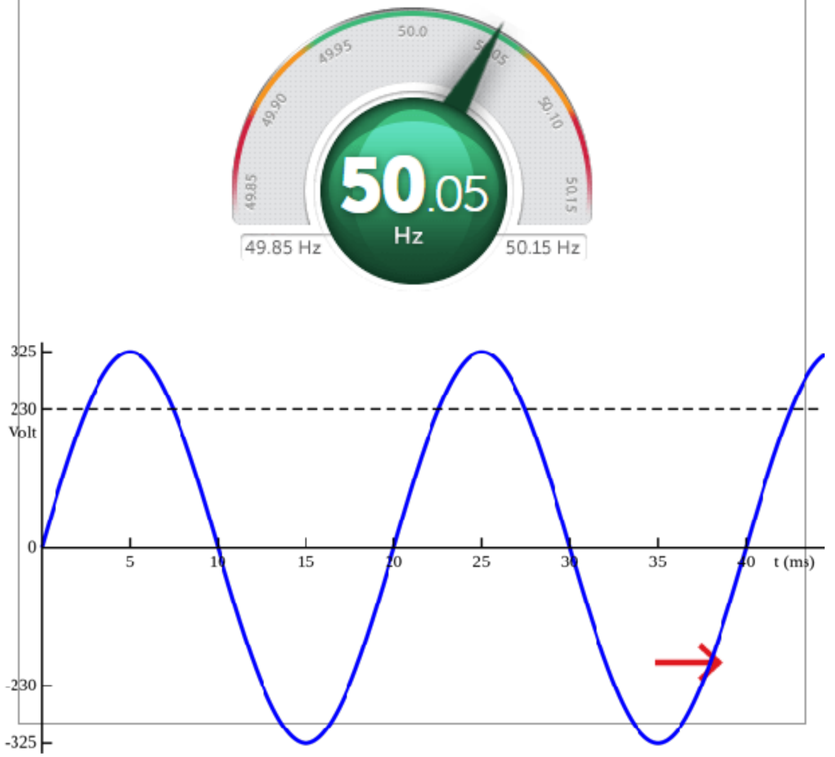
Norwegian grid

KRAFTSITUASJONEN AKKURAT NÅ

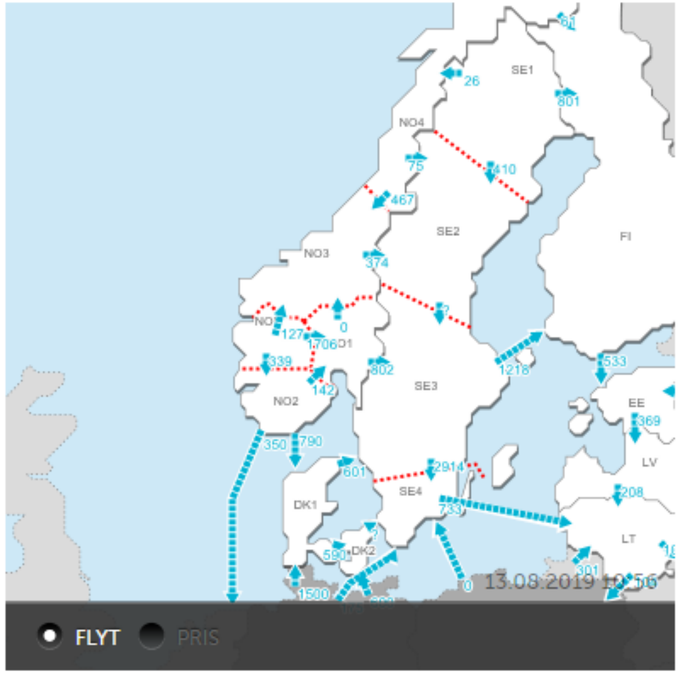
Power situation (arbitrary day)



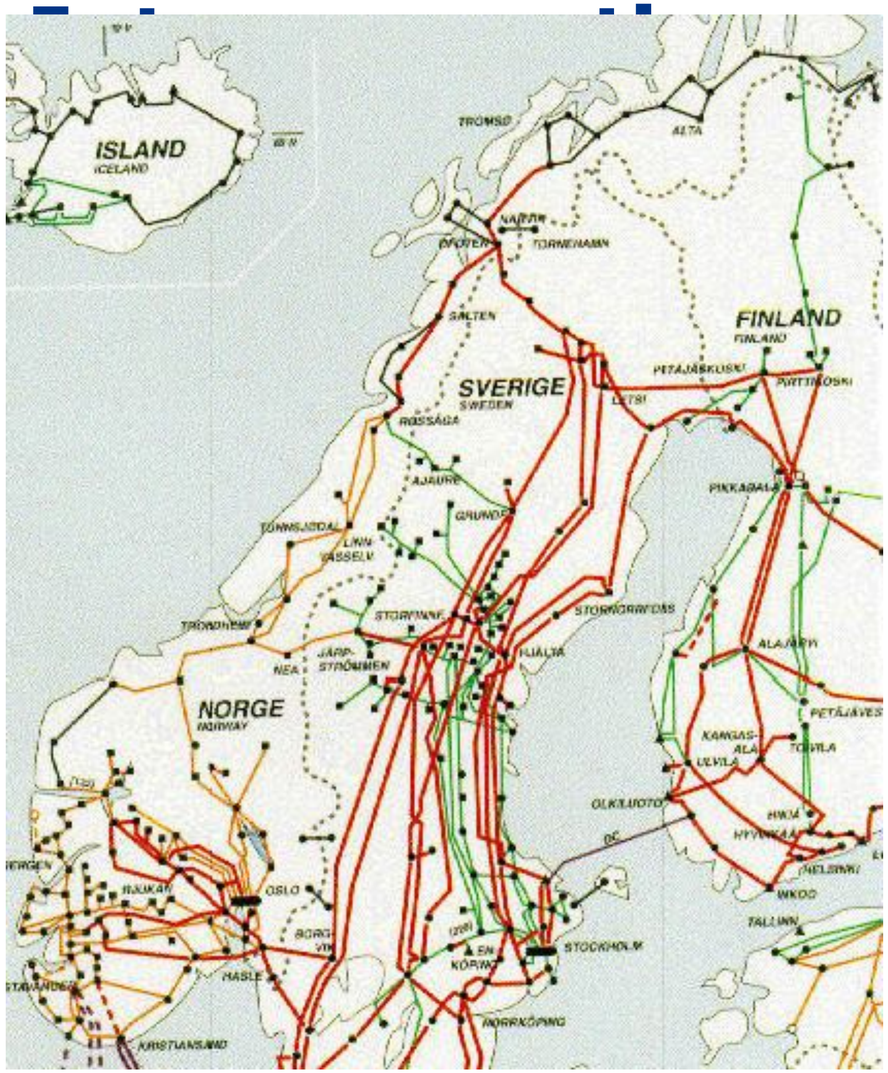
Nordic Power Balance



Nordic Power Flow



The Norwegian Grid and



Interchange to
SE ~3200–3600 MW
- 9 cables
DK ~1700 MW
- 4 cables
DE: 1400 MW NordLink
UK: 1400 MW North Sea Link
NL: 700 MW, NorNed

FI 70–120 MW
- Varangerbotn cable
SU 50 MW
- Pasvik cable

https://snl.no/kraftutveksling_med_utlandet

Using the NordNed cable with a diameter of 100 mm^2, 580 km long, 450 kV and 700 MW - how big are the losses?

Power Grid 2024

US electric grid growing more vulnerable to cyberattacks, regulator says

By **Laila Kearney**

April 4, 2024 11:48 PM GMT+2 · Updated 9 months ago

A local resident walks by the power grid towers at Bair Island State Marine Park in Redwood City, California, United States, January 26, 2022. REUTERS/Carlos Barria/File Photo Purchase Licensing Rights

https://www.reuters.com/technology/cybersecurity/us-electric-grid-growing-more-vulnerable-cyberattacks-regulator-says-2024-04-04/

Home / 2024 / May / Ukraine blackouts caused by malware attacks warn against evolving cybersecurity threats to the physical world

Ukraine blackouts caused by malware attacks warn against evolving cybersecurity threats to the physical world

May 17, 2024

By Emily Cerf

SHARE THIS STORY:

On a cold winter night in 2016, Ukrainians experienced the first-ever known blackout caused by malicious code (malware) designed to autonomously attack the power grid. One-fifth of Kyiv's citizens were plunged into darkness as attackers used malware to target the capital city's power grid. Six years later, in the early months of the ongoing Russia-Ukraine war, a second attack attempted to combine kinetic and cyber attacks to take down Ukraine's power grid.

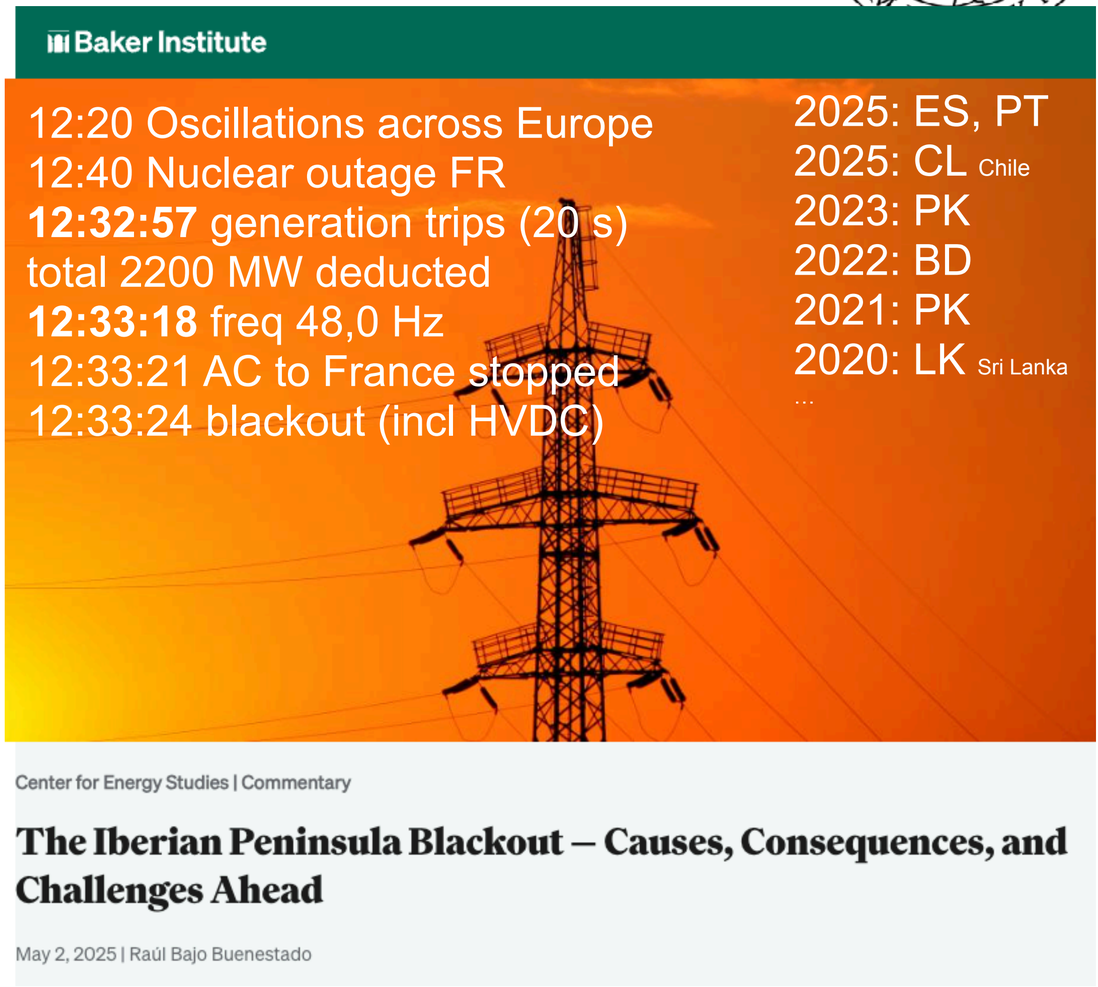
Power lines in Ukraine. Photo credit: Mny-Jhee, iStock.

Malware attacks against physical infrastructure have long been a looming threat in the realm of cybersecurity, but these two in Ukraine were the first attacks of their kind, and have received little attention from the academic community. Carried out by a Russian intelligence agency against Ukraine, they warn of the evolution of cyber attacks to the built world, and highlight the need to better understand and defend against this type of malware.

https://news.ucsc.edu/2024/05/ukraine-cybersecurity.html

28Apr2025 Spain & Portugal blackout

- Cause:
  - 60% solar energy,
  - 1. solar park switched off, 1.5 s later 2. solar park
  - interconnection to France stopped (f < 48,0 Hz)
- Conventional: inertia (rotating generators)
- Solar: sudden death (DC/AC converters)
- Challenge:
  - distributed respond to grid fluctuations



https://www.entsoe.eu/news/2025/05/09/entso-e-expert-panel-initiates-the-investigation-into-the-causes-of-iberian-blackout/

https://www.bakerinstitute.org/research/iberian-peninsula-blackout-causes-consequences-and-challenges-ahead

https://en.wikipedia.org/wiki/List_of_major_power_outages

Distributed Grid
- solar, PV, wind
- storage (electrical & thermal)
- nuclear

[Source: TU Oct2024, Willy Kramer]

https://www.thenationalnews.com/business/energy/2026/07/06/syrias-solar-boom-is-redefining-middle-easts-energy-model/

Example: Bulgaria

- 16% of the production capacity of the country is available as battery capacity
- 1/3 public, 2/3 privat funded
  - Lowetsch: 500 MWh
- result: el. price 5-10 EUR/MWh cheaper than in surrounding countries

https://www.mdr.de/nachrichten/welt/osteuropa/politik/energiewende-solarenergie-pv-anlagen-,bulgarien-batteriespeicher-rekord-100.html

Examples:
Syria & Pakistan

- Pakistan
  - PV largest energy producer
  - 25% of total production in 2025
  - ~2.8 GW not metered rooftop installation
  - net-metered 5.3 GW
- Syria
  - off-grid growth: 0.25 GW (2022), 1.5 (2024), 2.06 (2025) - 10x in 3 years

https://www.reuters.com/markets/commodities/pakistans-solar-surge-lifts-it-into-rarefied-25-club-2025-06-17/

https://www.thenationalnews.com/business/energy/2026/07/06/syrias-solar-boom-is-redefining-middle-easts-energy-model/

Neighbourhood

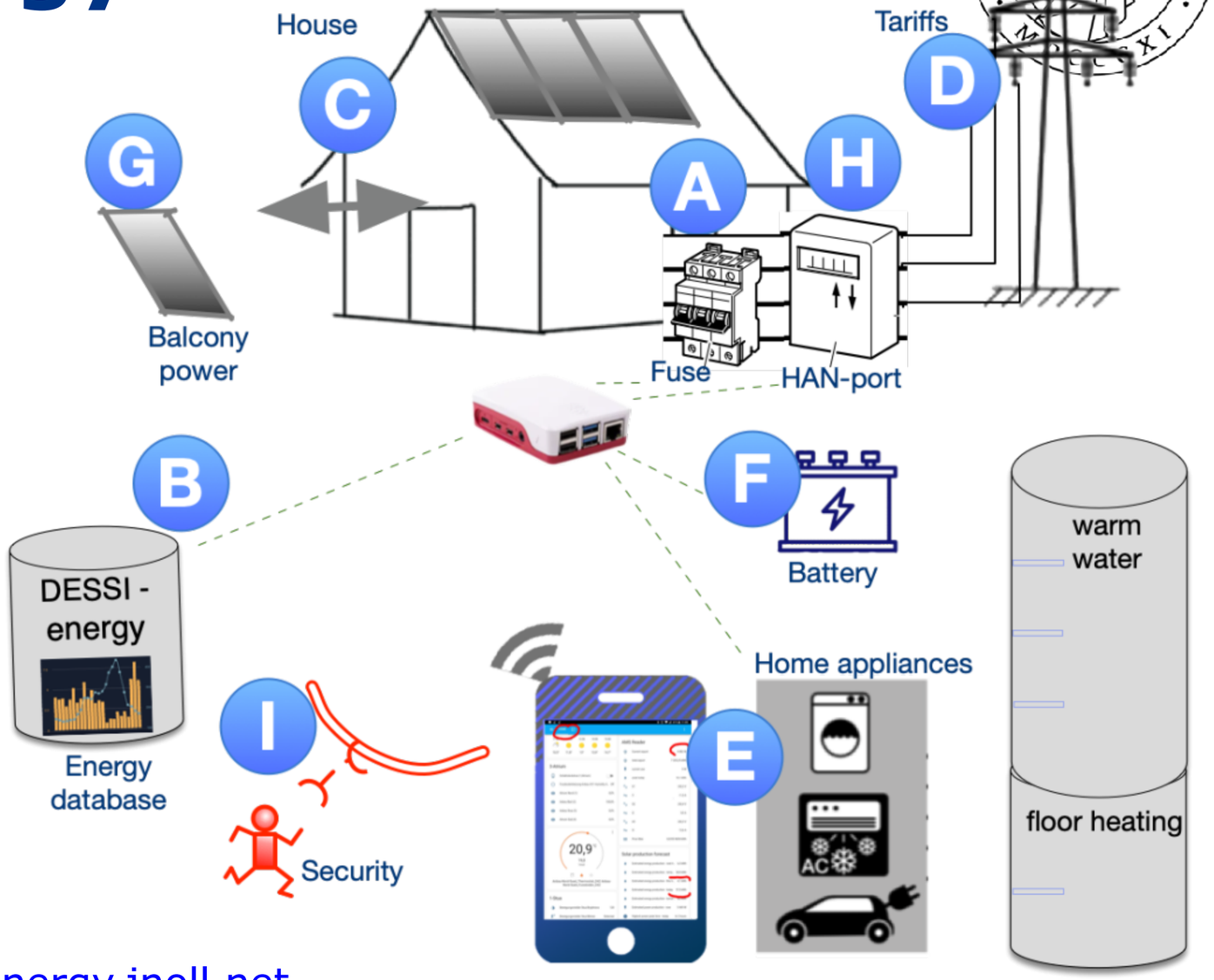
“Energy-neighbourhood”

“sharing?”

kilde: Juliana Zhang, UiO

Components of energy

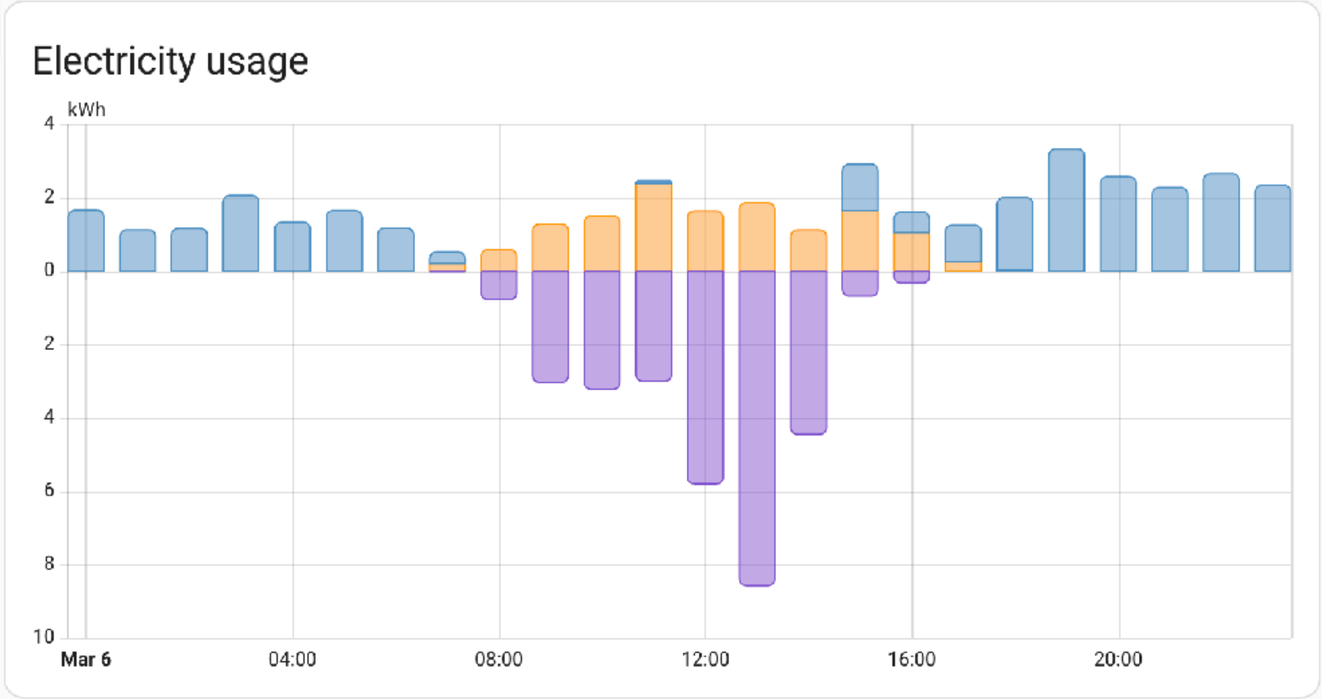
- Cost of installation “smart”
  - heat pump
  - car charger
  - V2G charger
- Convenience modelling
  - temperature
  - car mobility
- Seasonal storage
  - Thermal storage
- Psychology
  - Neighbour, Incentives, Fear, …

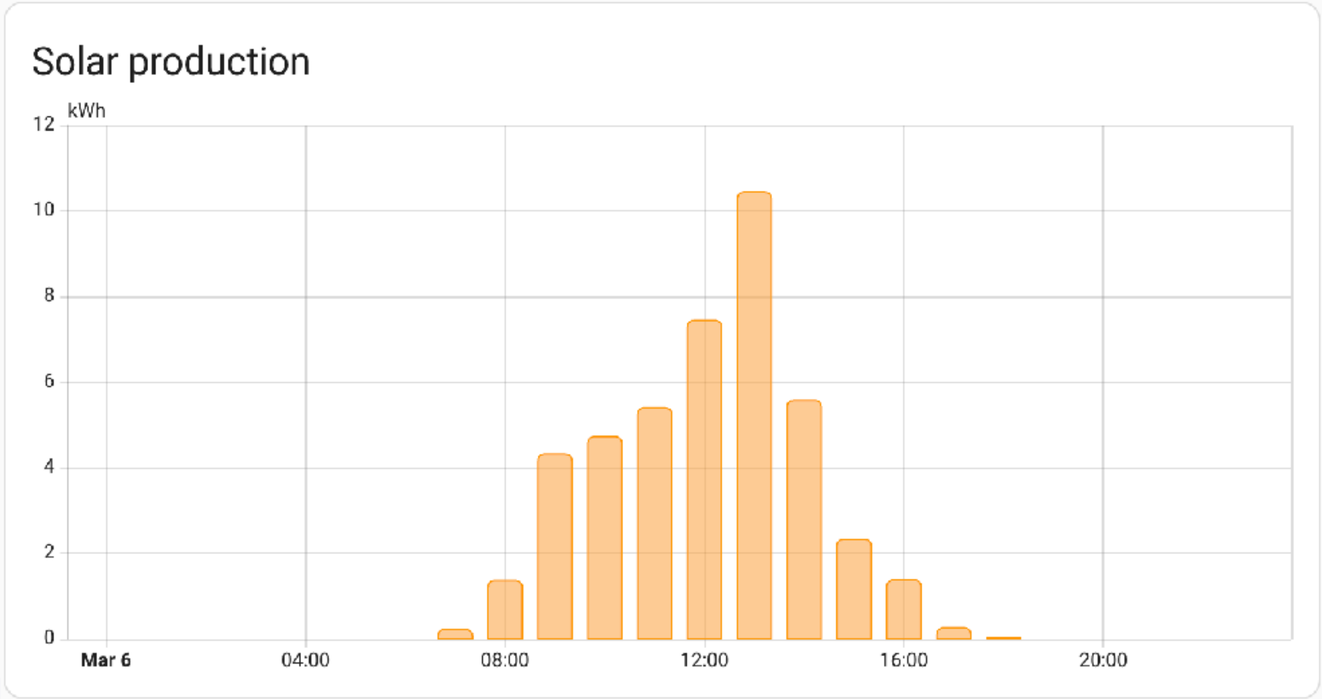


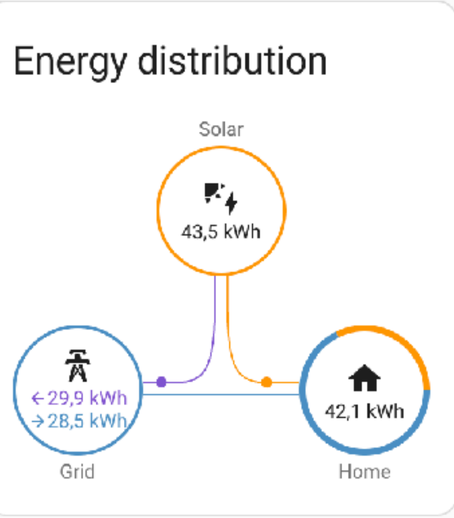
energy.jnoll.net

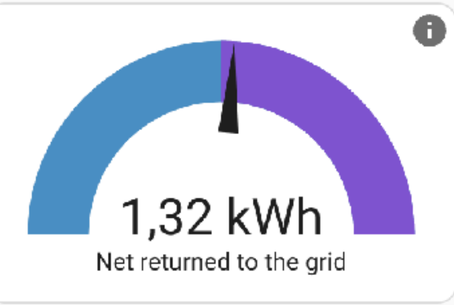
Energy control
6Mar2025

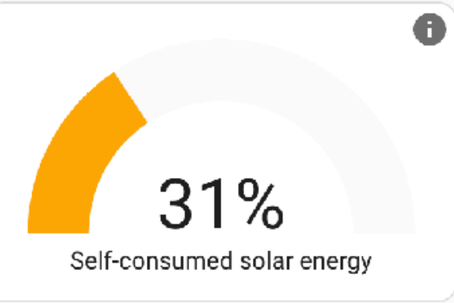
- typical
  - 31% self consumed
  - 43,5 kWh produced (orange)
  - 29,9 kWh to the grid (pink)

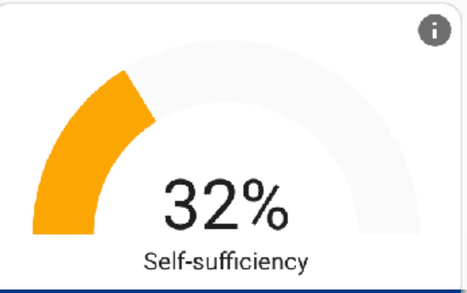








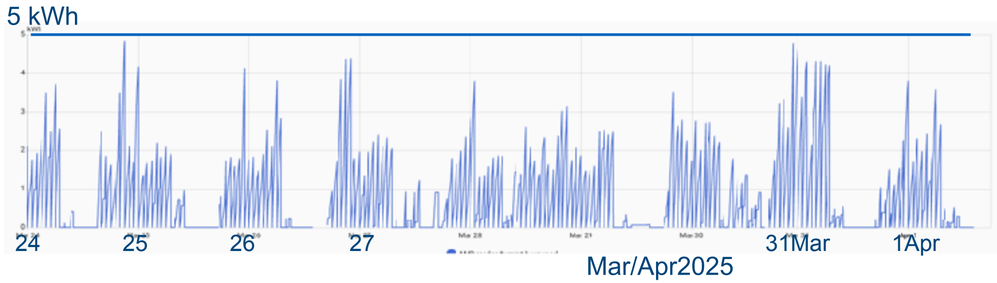




DESSI infrastructure by ITS@UiO

https://www.mn.uio.no/its/english/research/projects/dessi/index.html

- busy hour reduction
  - 0700-0900: 84%, 96%
  - 1700-1900: 69%, 25%
- Peak shaving
  - below 5 kWh/h



Austria - new tariffs for energy neighbourhood

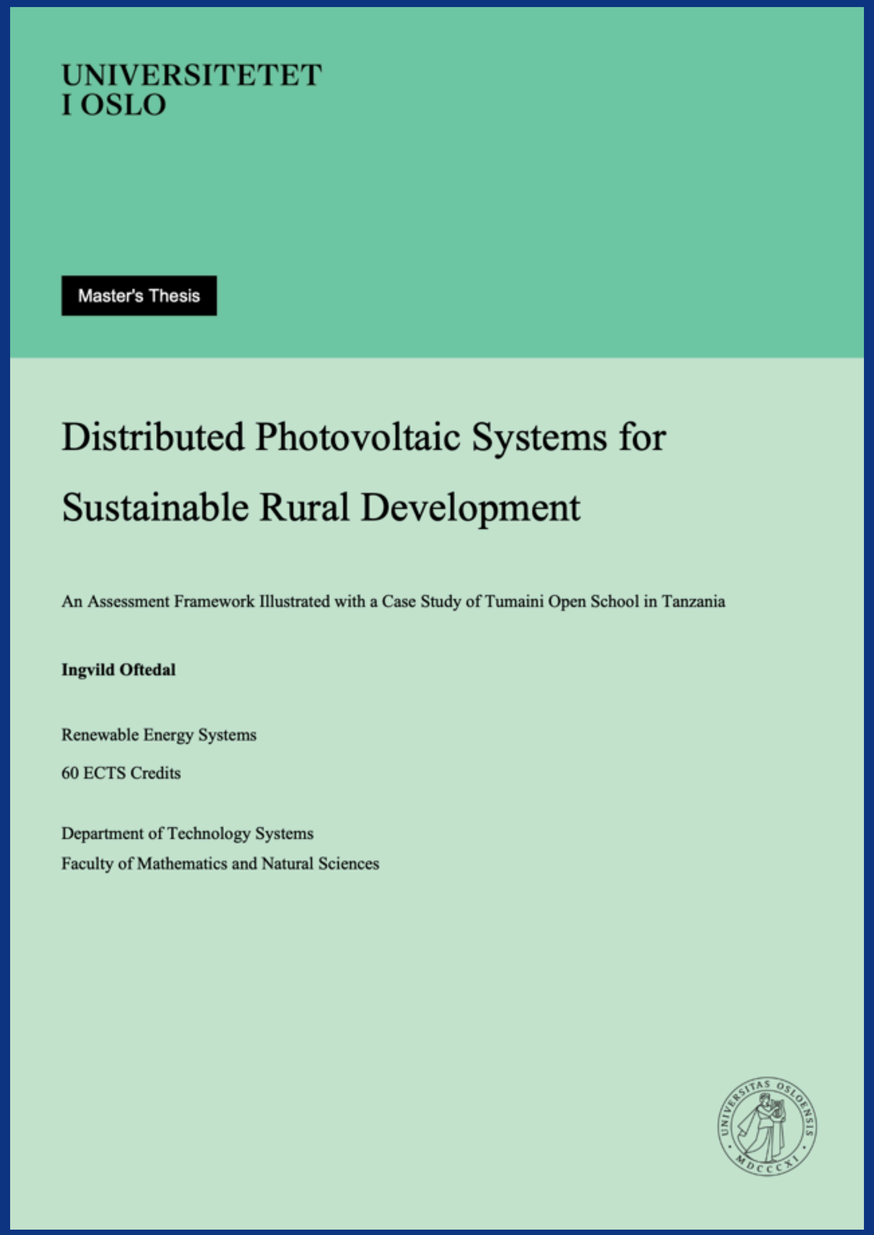
- Balcony Power Plants

[Source: TU Oct2024, Willy Kramer]

Master med Mening
by Ingvild Oftedal

“Stabil Energi til Tumaini Open School”

med støtte fra Ingeniører uten grenser (IUG), Traineé, Stiftelsen Basic Internet


UNIVERSITETET
I OSLO

Master's Thesis

Distributed Photovoltaic Systems for Sustainable Rural Development

An Assessment Framework Illustrated with a Case Study of Tumaini Open School in Tanzania

Ingvild Oftedal

Renewable Energy Systems

60 ECTS Credits

Department of Technology Systems
Faculty of Mathematics and Natural Sciences

Performing the work

Item	Qty	Total cost (USD)
PV module	6	1109
AGM battery	8	2134
Hybrid inverter	1	2179
Battery enclosure	1	333
Racking system	1	222
Installation accessories and materials	1	780
Labor charge	1	370
Grand total (Investment costs)		7127

The InfoSpot at Tumaini

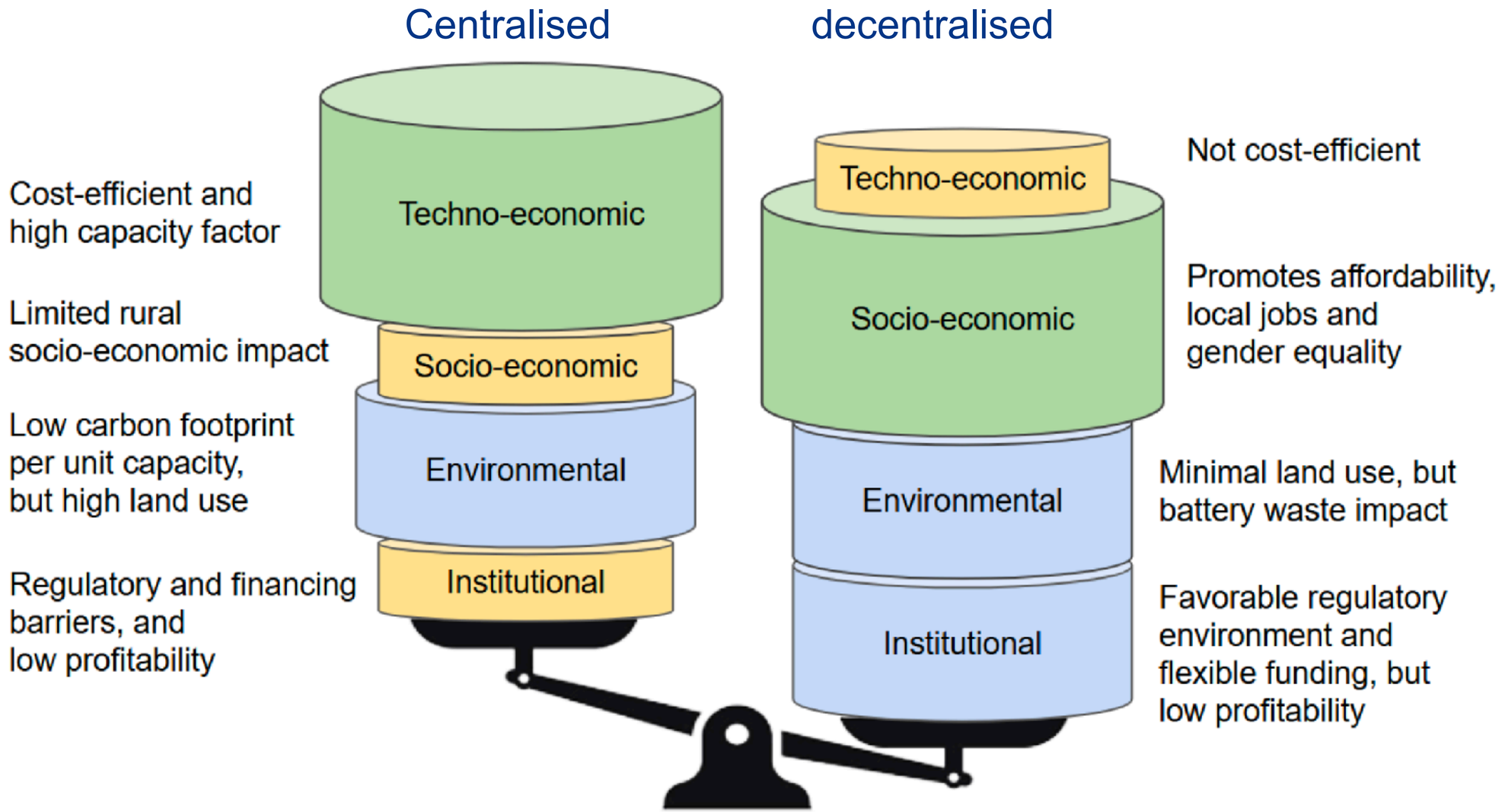

Mounting the directive antenna

Training on local cloud (Nextcloud


Ingvild Oftedal


Training with students

Food for thoughts (1/3)
PhotoVoltaic (PV) system costs and effects



Food for Thoughts (2/3)

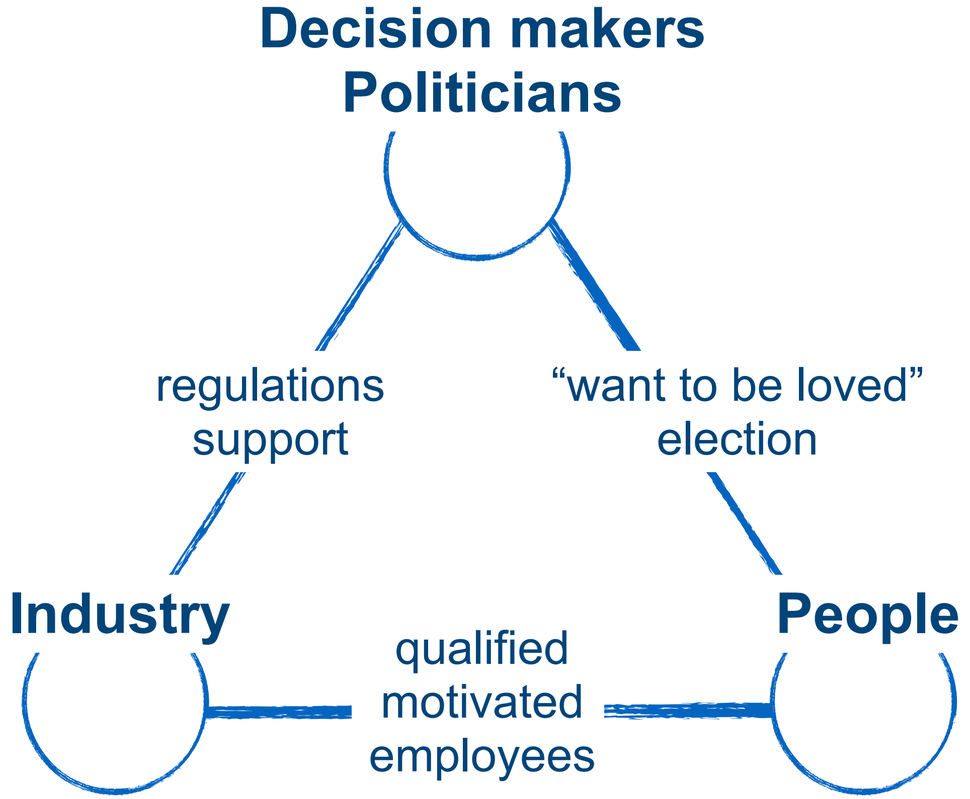
Energy Layers

Mission Planning	55% by 2030, 90-95% by 2050
	Reporting
Operation Planning	Sector specific goals & incentives: housing, …
	Control, AI, ..
Energy Management	Municipality buildings
twin layer interface	*energy distribution*
Energy-, Component-, Electrical Health	Component monitoring & control
Abstraction layers	*Municipality example*

Food for thoughts (3/3)

How to include people & decision makers?

- Include people
  - Neighbours
  - Fear
  - Incentives
  - ….
- Pilots & examples
  - Other cities



Summary and food for thoughts

- From centralised to decentralised energy
- Today:
  - shortage of electrical energy
  - cyber- and hybrid-attacks
  - “no work”
- Future
  - Participatory transition
  - increased Resilience
  - decentralised installations (work)
- How to “make it happen”?
  - centralised vs decentralised
  - handling the complexity
  - psychology of the transition