Oslo Centre of Research on Environmentally friendly Energy

True or not true: Carbon-free electricity generation is possible

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Towards the low-emisison society

- Radical GHG emissions reductions in the EU by 2050
  - 95% emissions reductions in electricity generation by 2050
  - Electrification necessary to reach the total 2050 emissions target
  - More electricity and much cleaner electricity is required

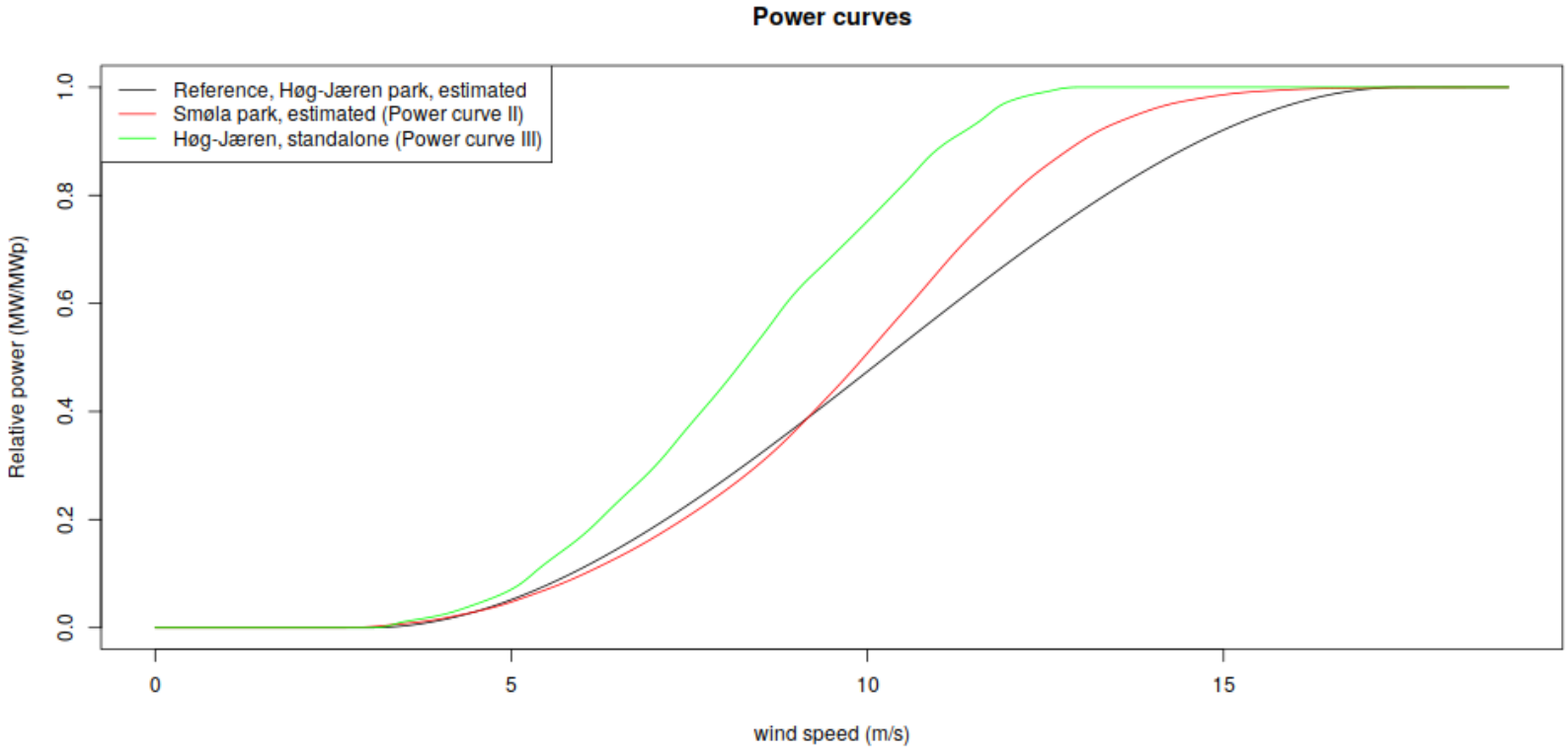
- Is carbon-free electricity generation possible in Europe?
  - Need more wind and solar, but what about problems due to intermittency?
  - Need electricity storage
  - Is it also necessary with a (carbon-based?) backup technology?
    - Biopower, CCS gas/coal power

Data – metrological – MERRA2

- 23 European countries, grid cells (50 km by 50 km, 2703 cells onshore and offshore)
- 2006-15, with hourly time resolution
- Wind (speed)
- Solar (direct and indirect radiation, reflection, air temp)
- Load (national data)

Wind power

- Estimate a power curve
  - Transform wind speed to wind energy
- Want a power curve that mimics the German wind industry
  - 20% capacity factor for the last 10 years
  - Use data for a Norwegian wind park (Høg-Jæren)
  - Standalone mill vs. mill in a wind park (wake loss)


Power curves
Reference, Høg-Jæren park, estimated
Smøla park, estimated (Power curve II)
Høg-Jæren, standalone (Power curve III)
Relative power (MW/MWp)
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
wind speed (m/s)

Solar power parks

- Tradeoff between direct diffusion (radiation should hit panels at 90 degrees) and indirect diffusion (0 degree tilt) to max production
- Tradeoff within a designated area for solar power: Several rows of panels means many panels but big losses due to shadow effect

- Find optimal (fixed) tilt and distance between rows of PV cells that maximize profits when there is a given area available for solar parks (Solution vary by grid cell)

- Wind and solar data: 1.6 billion observations from MERRA2
- Select 10% best cells for each technology in each country
- Uniform development in cells (for each technology in each country)

Construction of an electricity system with low emissions

- Carbon-free technologies: Offshore wind, onshore wind, solar
- Additional electricity technology: Backup (e.g., bio power)
- Storage technology: battery

- Have hourly data for 2006-15
  - No reason to pick one particular year or construct a «representative» year
  - Will then lose information

- Construct a system for 2006-15 with five technlogies
  - No initial capacities (make the job as tough as possible)
  - Can later phase in other technologies (hydro, nuclear)

Battery strategy
Ensure that the load is covered in each hour

- If intermittent production is greater than load: charge battery
- If intermittent production is smaller than load: discharge battery
- If intermittent production is smaller than load and there is no stored electricity in battery: use bakcup technology to produce electricity
- Backup technology is plan B
- To ensure that backup technology is plan B: Impose that total renewable production 2006-15 is equal to total load 2006-15

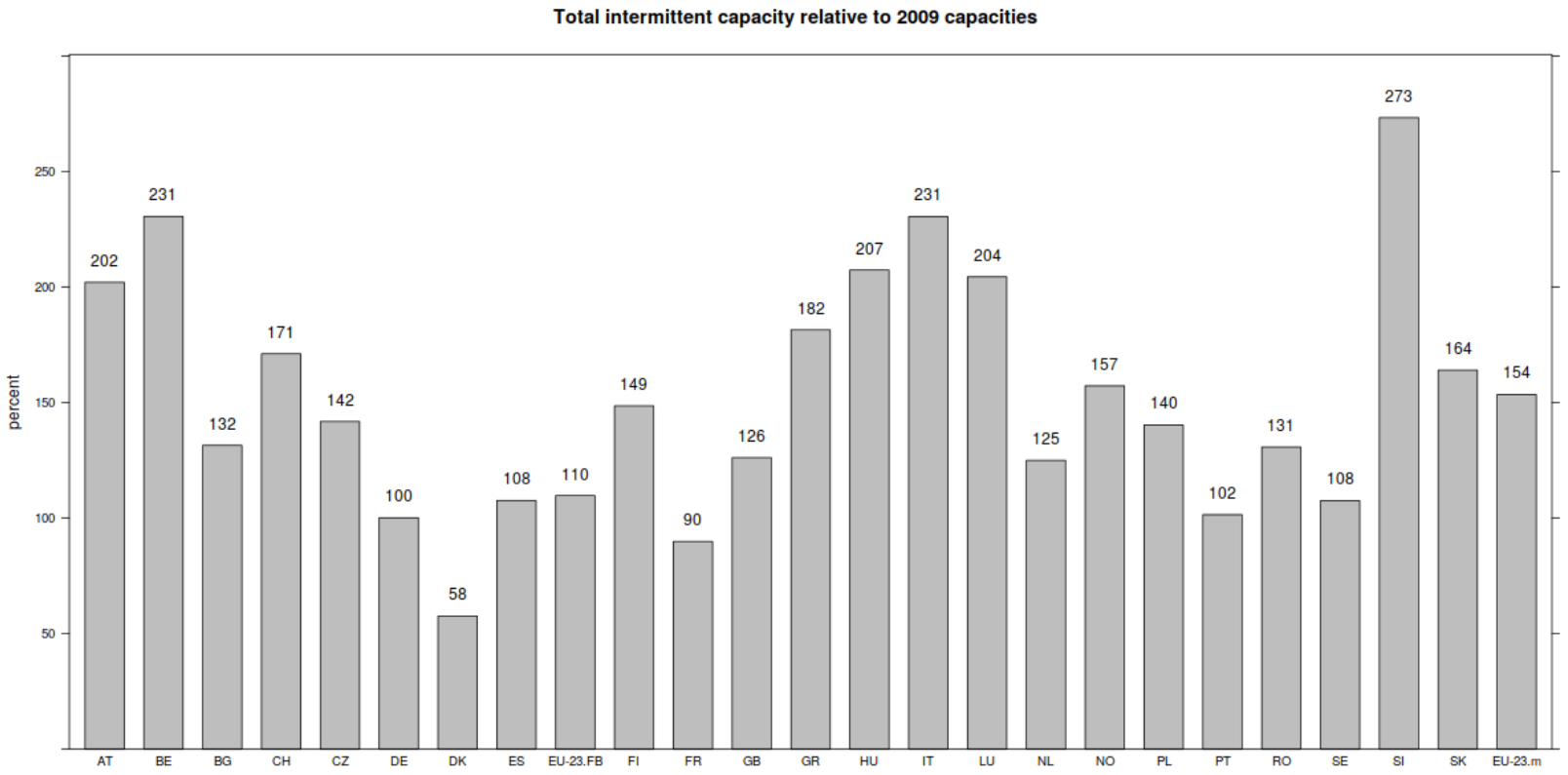
Batteries

- Match time path of renewable production and time path of load

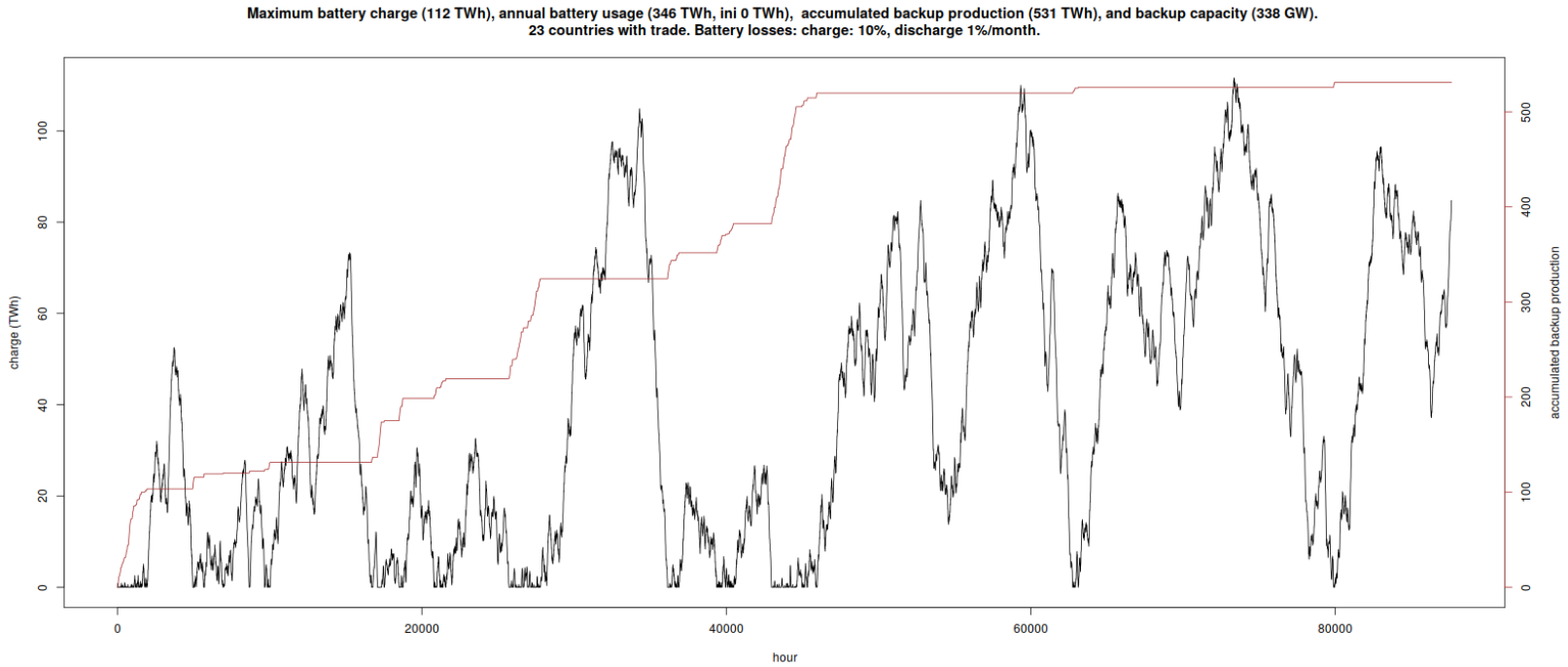
- RQ: How low can battery capacity be, provided that load is met in each hour?
- Minimize battery energy capacity wrt. renewable capacities, provided that total renewable production 2006-15 is equal to total load, and given the battery strategy

- If solution is characterized by an amount of stored electricity that has increased battery capacity but was not discharged, this production is curtailed
- Solve first for each of 23 countries. Then open up for trade. Can also find social optimal solution

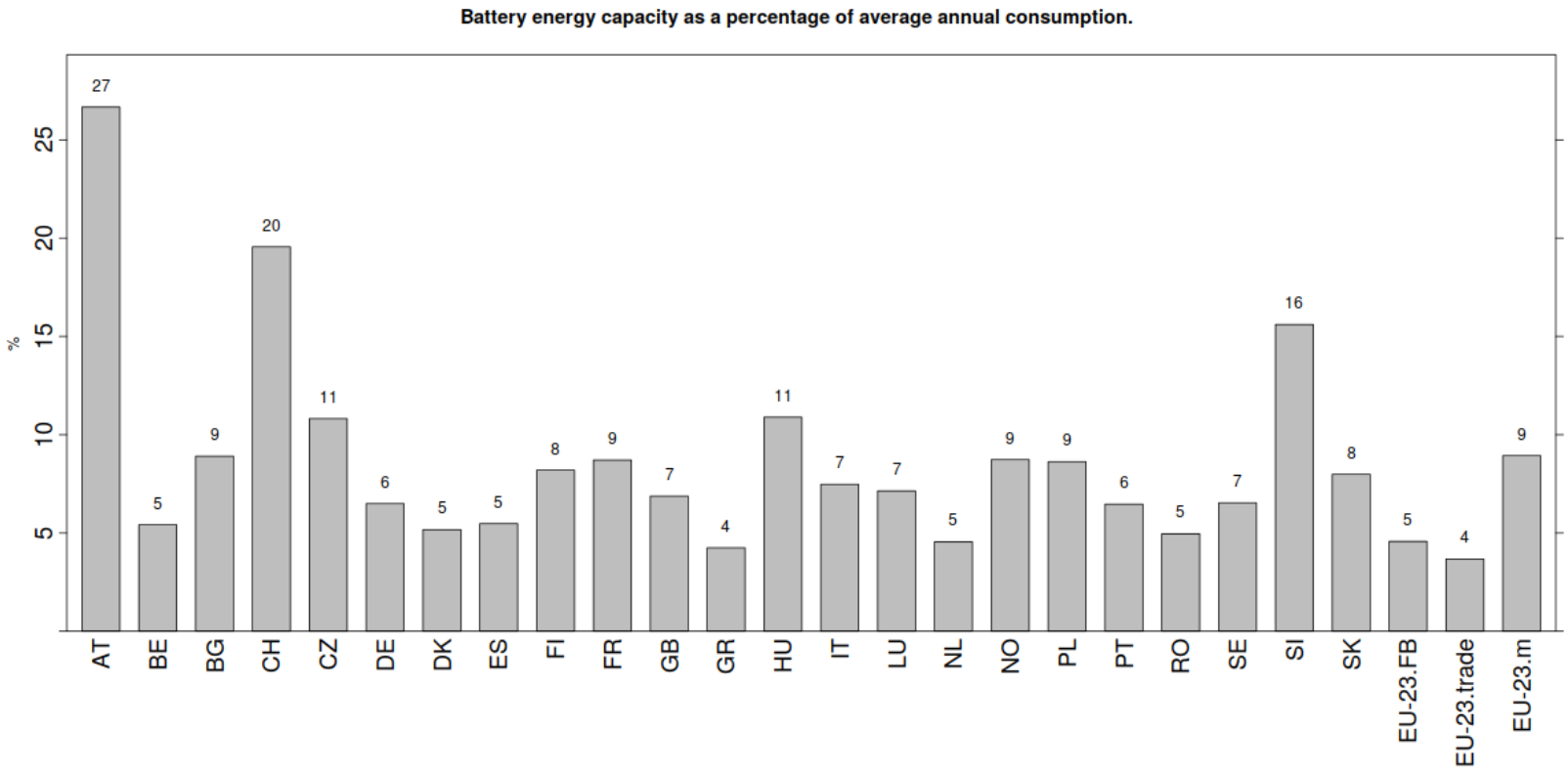
Total intermittent capacity relative to 2009 capacities



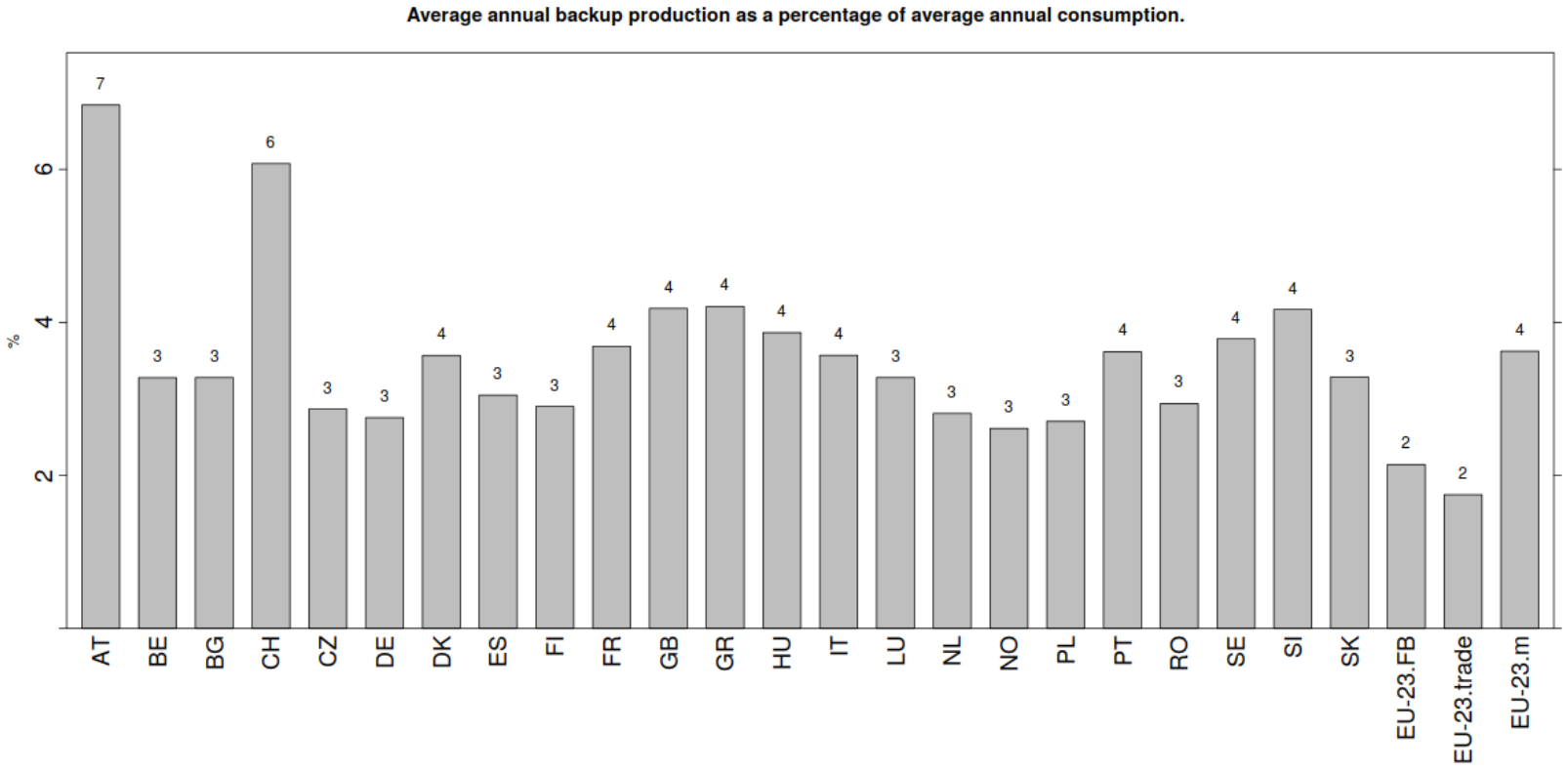
Stored electricity in battery and accumulated backup production. EU-23.trade



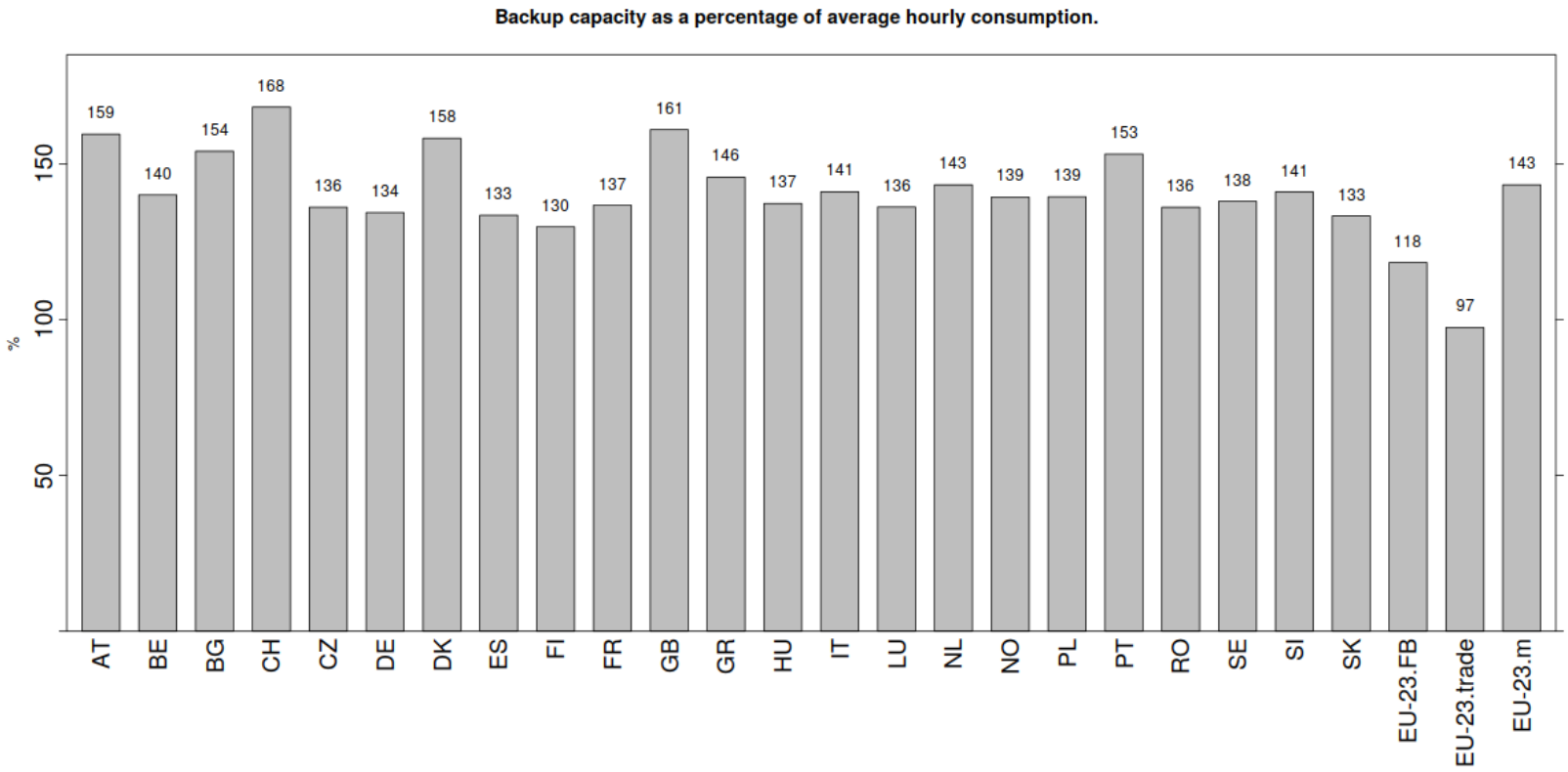
Battery energy capacity (max stored energy in an hour) as a percentage of average annual consumption



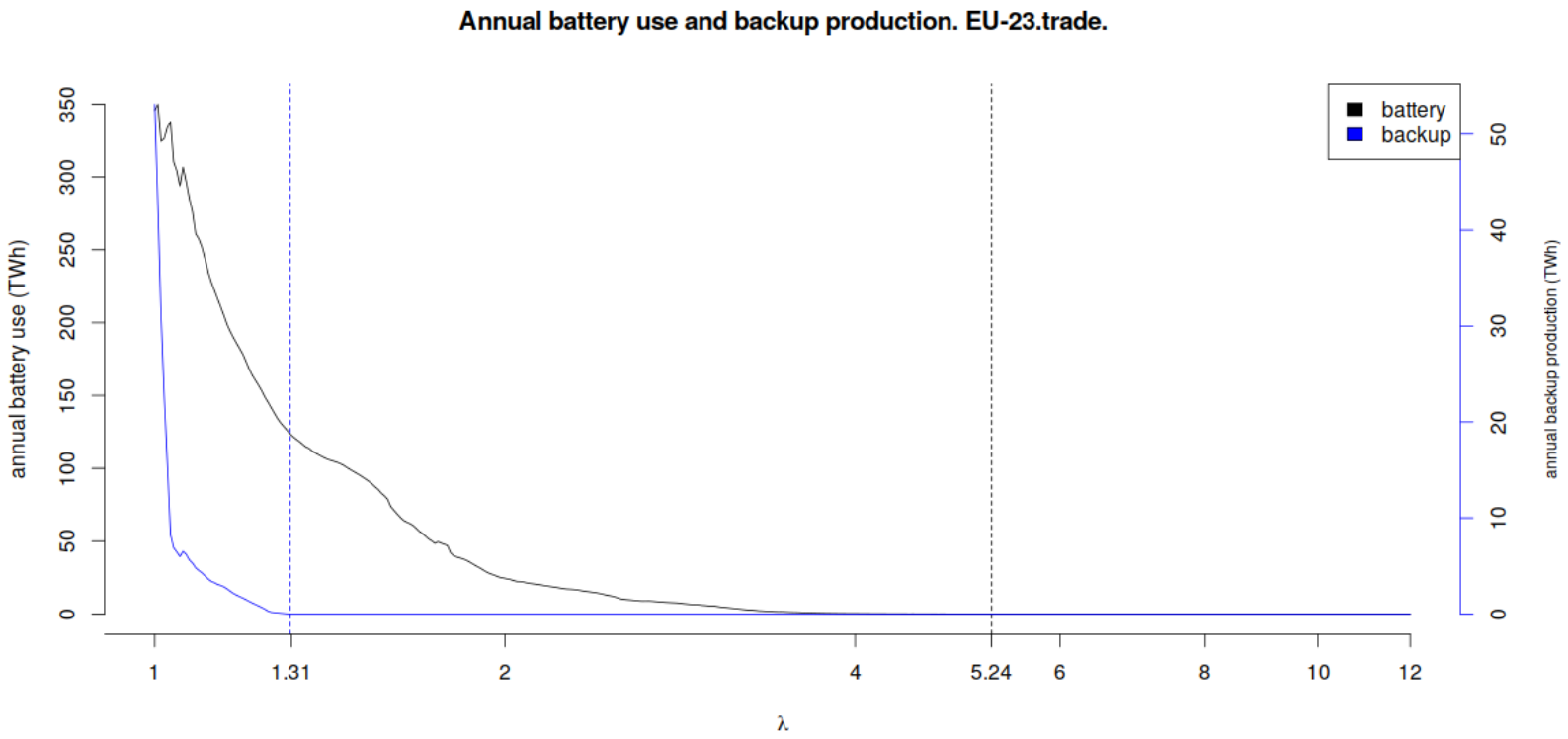
Average annual production from the back-up technology relative to average annual consumption



Backup capacity relative to average hourly consumption



Impose no backup production
EU-23.trade



Main findings

- An almost carbon-free electricity system (98%) is feasible
- Need a lot of batteries; costly
- A completely carbon-free electricity system (no backup technology) is also feasible, but even more costly
- Costs depend on objective function
- Minimize costs and 0.1% backup production: 3% of GDP

- Extensions
  - Alternative objective functions
  - Land restrictions
  - Impose current electricty production capacities