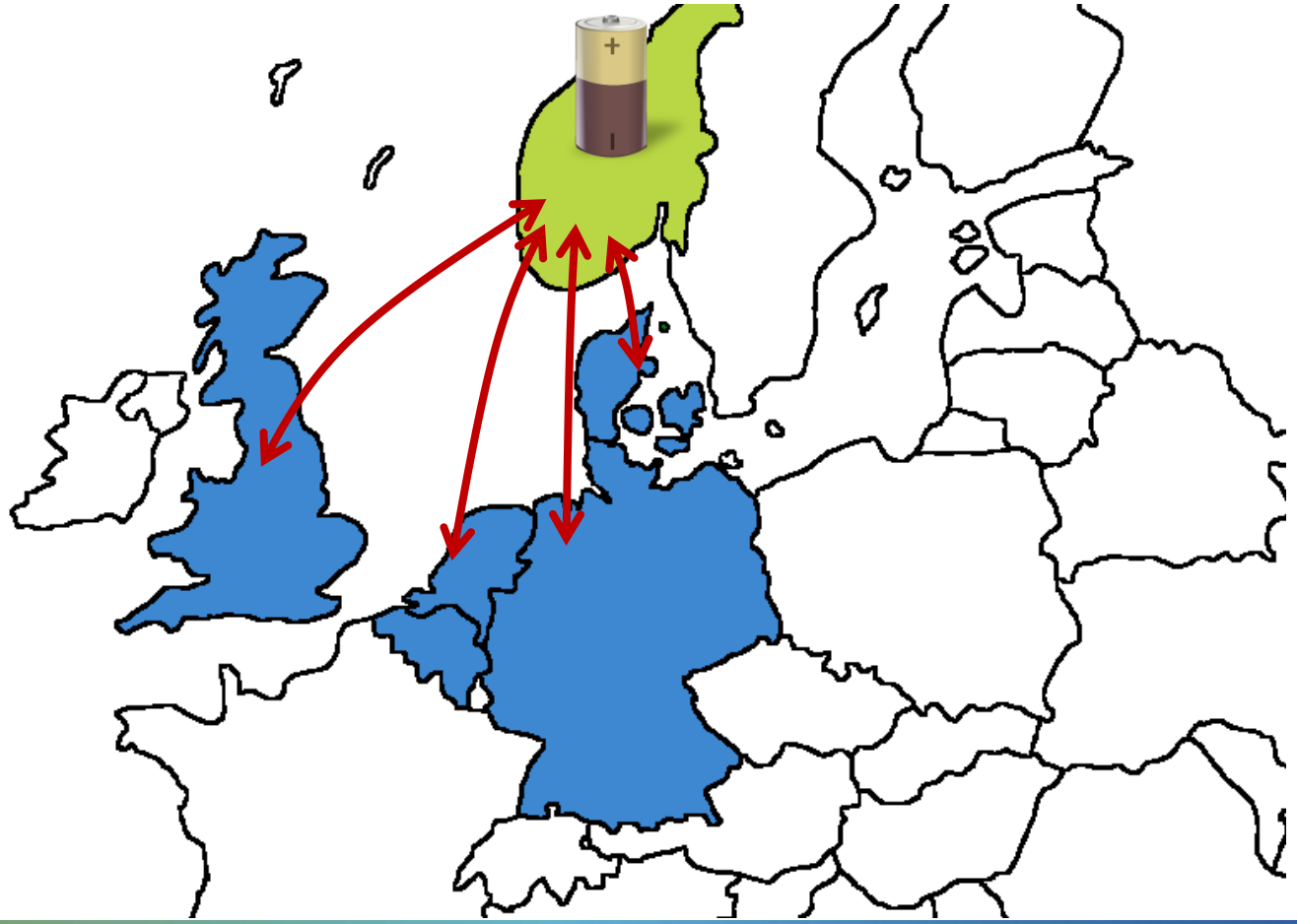
# Design of Future Pumped Storage Hydropower in Norway



Professor Ånund Killingtveit
Centre for Environmental Design of Renewable Energy

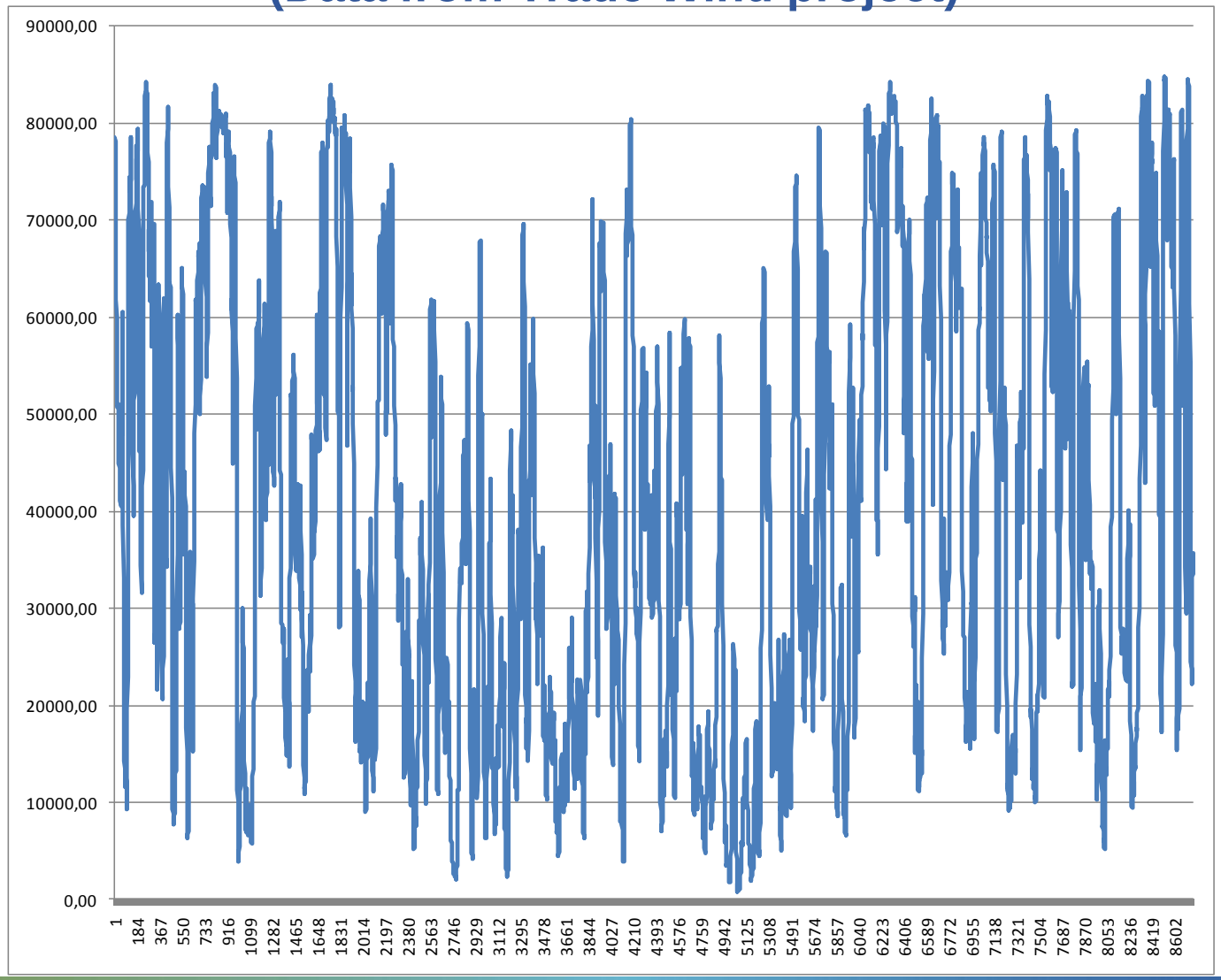
# Centre for environmental design of renewable energy – CEDREN

SINTEF

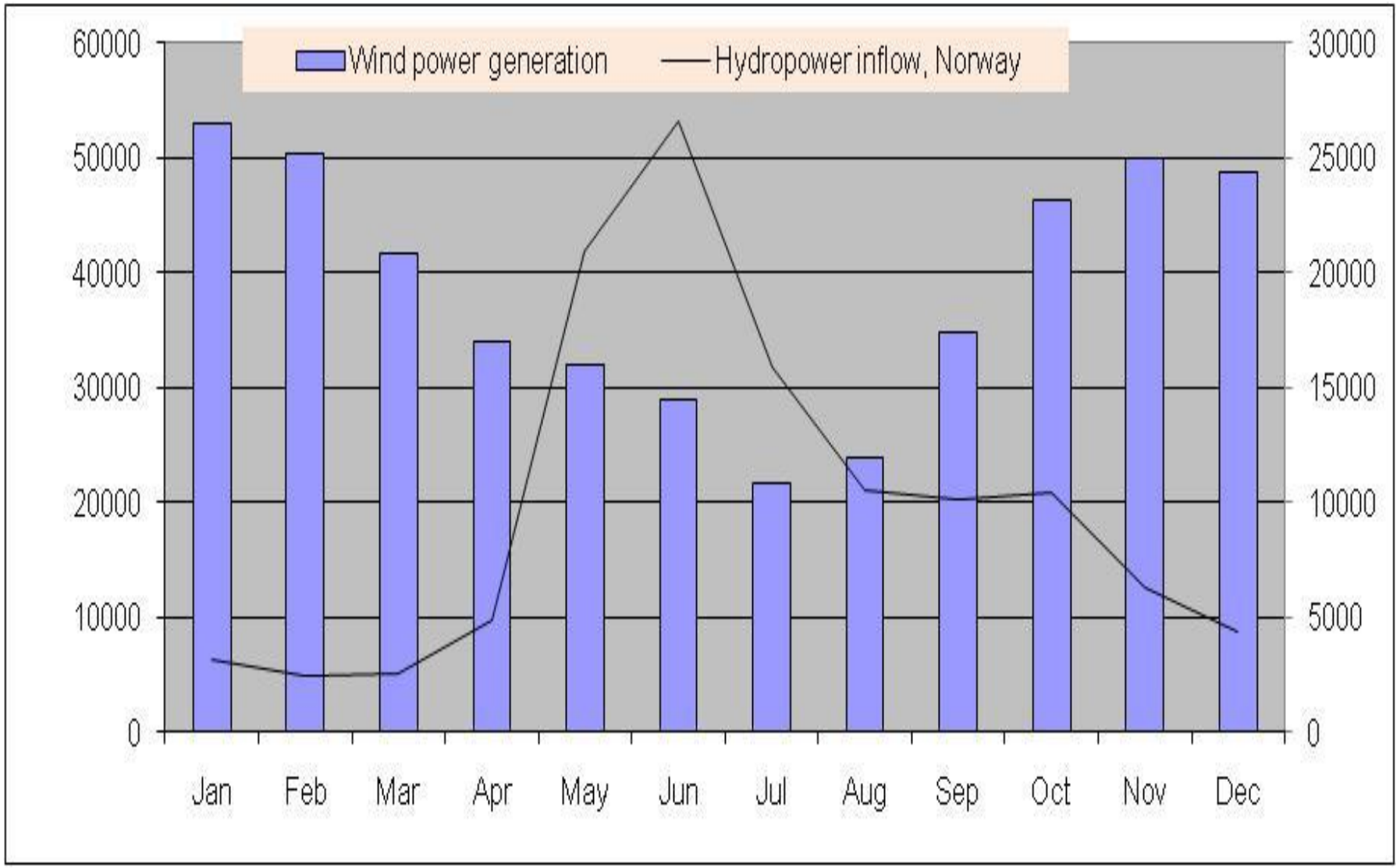
NTNU
100 skapende år

NINA
Norsk institutt for naturforskning

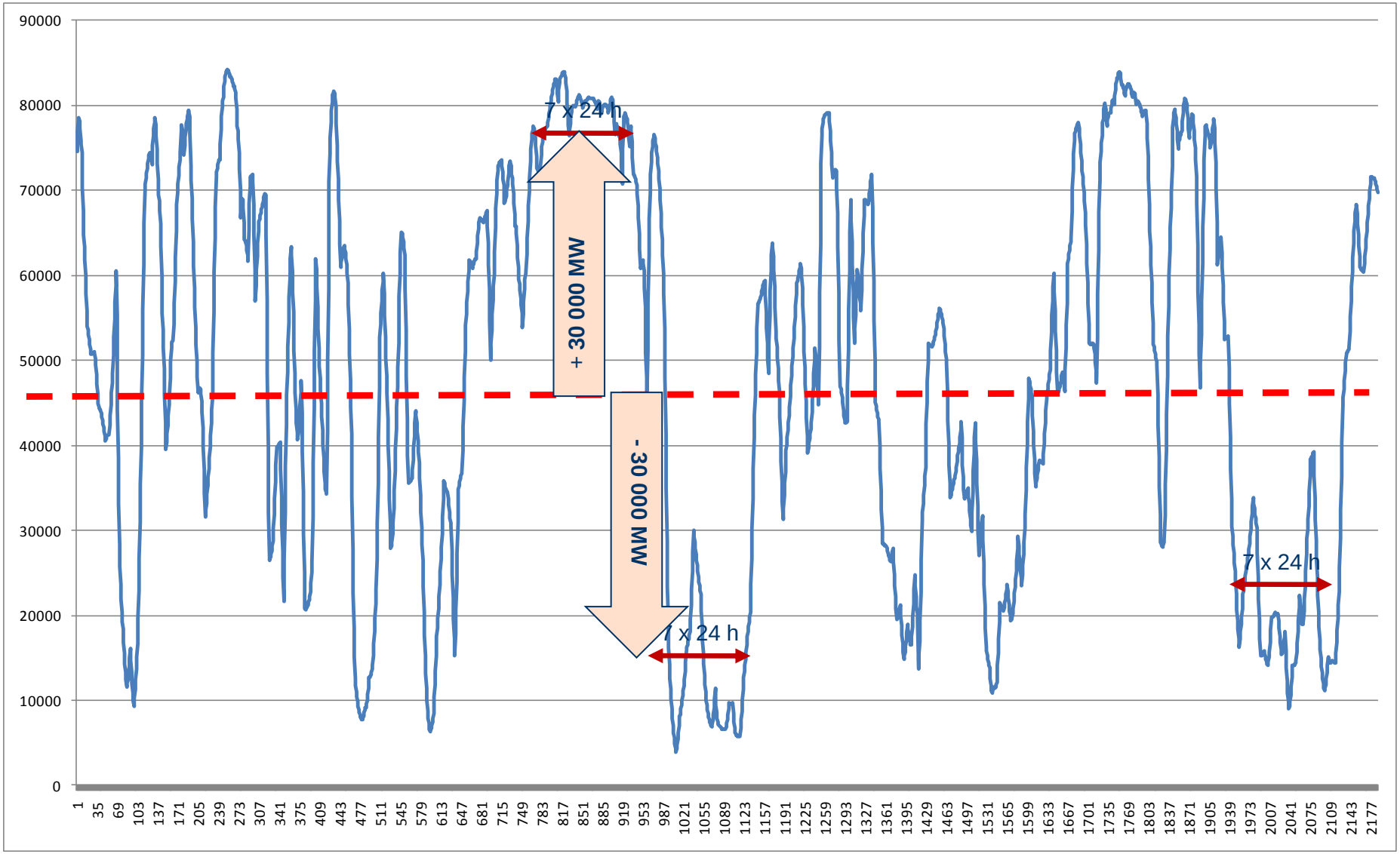
# Simulated Wind Power production in North-Sea Region
# Stadium 2030 – 94 000 MW installed capasity
# (Data from Trade Wind project)



# Wind and hydropower is a good match



# Wind Power North-Sea Region - Jan – March 2001



Large volumes of energy needs to be stored – up to +/-5 TWh in each cycle

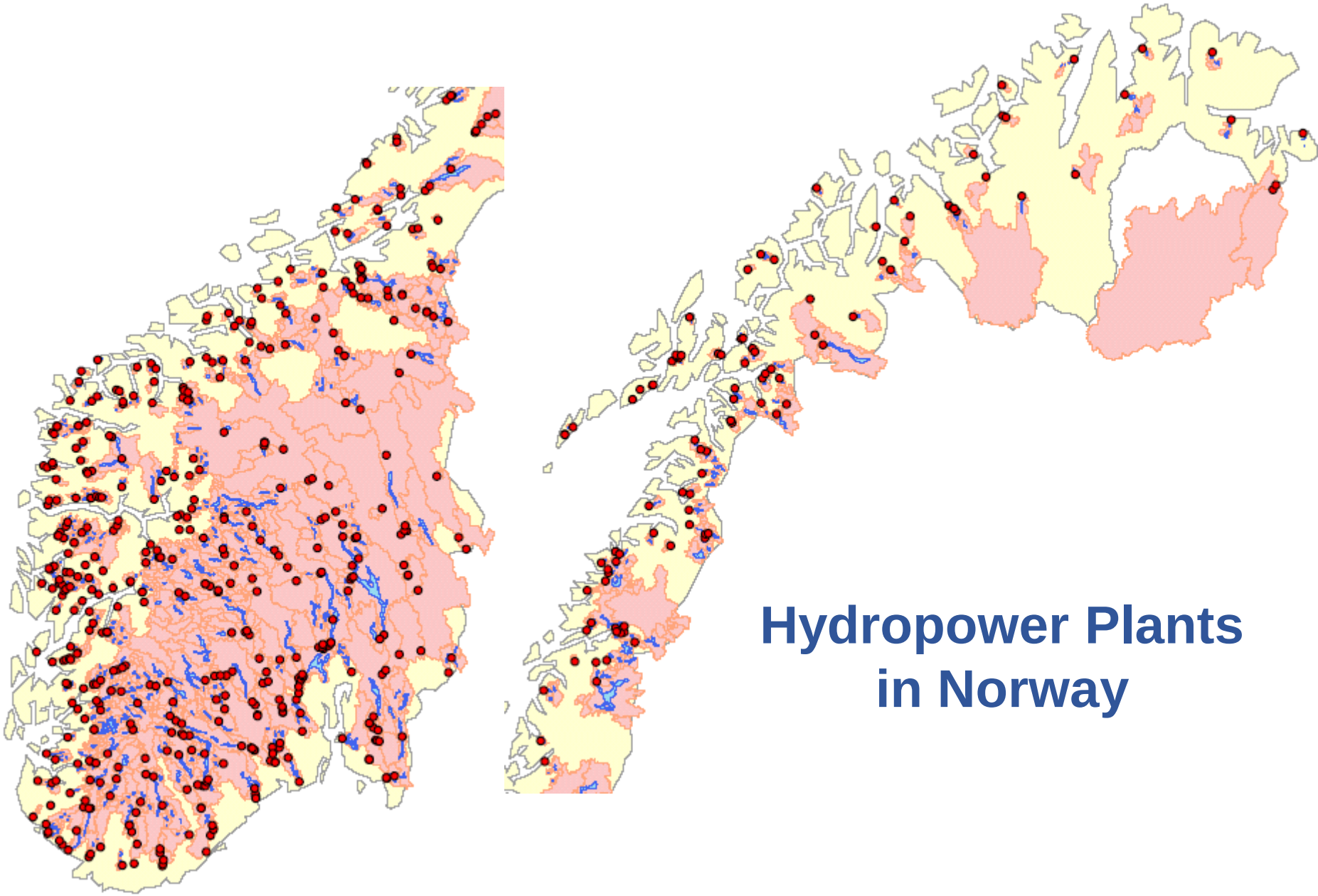
No existing storage technology in Europe can handle such volumes (Bulk storage)

Can Norway contribute?
How much?
Cost?


Studied in CEDREN projects HydroPEAK and HydroBALANCE

# Some facts about Hydropower in Norway

- Total installed hydro generation capacity in Norway:
  29 600 MW (2011)
- Total installed capacity in reservoir power stations 23 400 MW
- Total reservoir capacity: 84 TWh (or 62 bill. $m^3$) –
  70 % of the annual generation
- 50% of all hydropower storage in Europe (Energy)
- Average annual generation  ca124 TWh



# Hydropower Plants in Norway

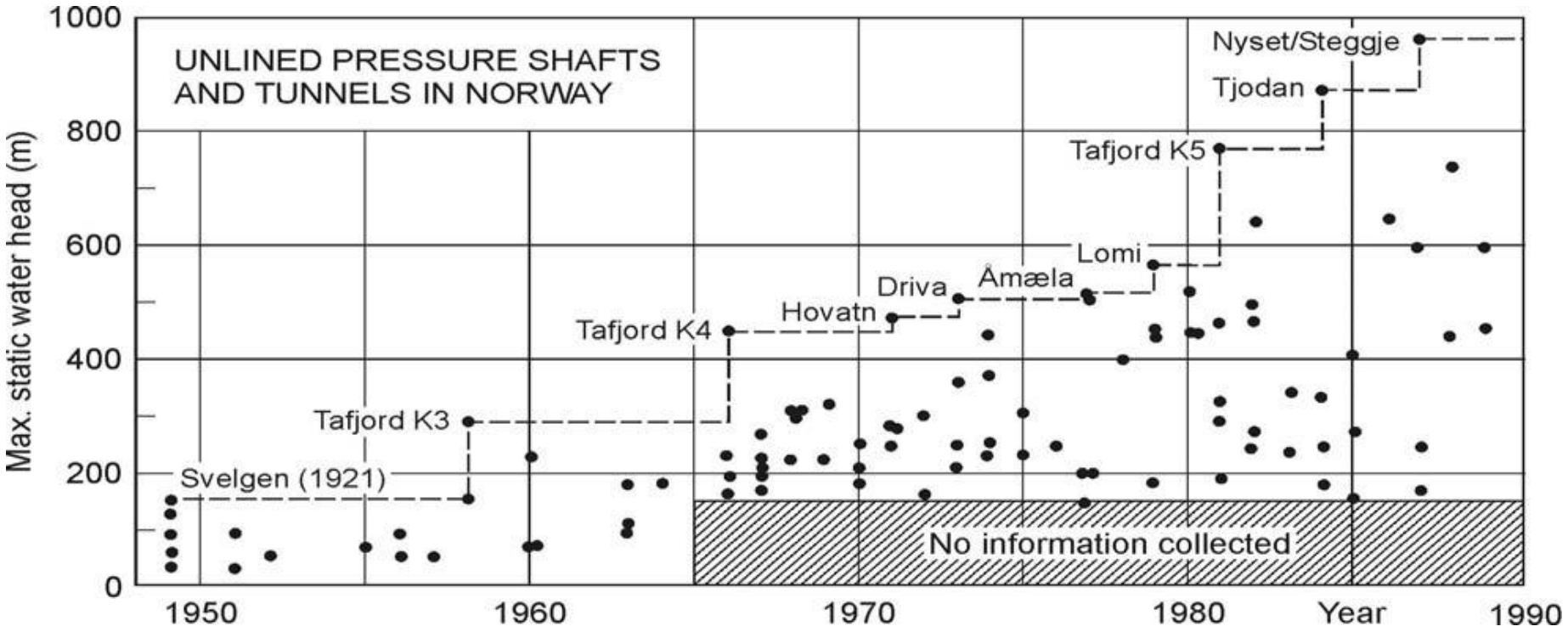
# Some characteristics for Hydropower in Norway

- Typical Norwegian hydropower system layout

  - Underground power stations
  - Reservoirs and power plants interconnected by tunnels
  - Many natural lakes used for storage
  - High head
  - Relatively low water flow
  - Tunnels usually unlined
  - Even pressure shafts unlined up to > 800m
  - Tunnel size up to 140 $m^2$

# Unlined pressure shafts and tunnels in Norway

## Some pilot projects



# Hydropower Storage in Norway

- Often using existing natural lakes in combination with:
  - Dams for raising storage above natural level
  - Underwater lake piercing for lowering reservoir below natural level
    (> 600 such lake taps since 1890)

- Relatively inexpensive storage (when it was constructed)
- But today building new storage is always controversial
- Difficult to build new reservoirs

- Need to use existing reservoirs
- Need to find pairs of reservoirs with high head difference and large storage volumes within small distance

Lake Totak in Telemark

”Natural” reservoir

Regulated 680-687.3 masl
Reservoir volume 258 Mill.$m^3$
Reservoir area 37.3 $km^2$

Reservoir created by a small dam and lake tap at 15 m depth

Connected both to reservoirs at higher (970 masl) and lower levels (460 masl)


The reservoir capacity of Lake Blåsjø is 7.8 TWh
This is 1000 times storage in Goldisthal PSP in Germany

# Status for Pumped Storage in Norway

- Few existing pumped storage plants today
- Mostly (Only?)  for seasonal storage
- No need for daily pumped storage plants today (98% hydro)
- But what about the future?
- Pumped storage used for balancing unregulated renewables
  - Wind
  - Solar
  - Small hydro
- Potential for development in Norway?
- Some design challenges

# Potential for new Pumped-Storage Hydropower in Norway

- Many (> 100) systems with existing large Upper and Lower reservoir
- Many (>20) with both Upper and Lower reservoirs > 100 Mill.m3
- Good rock quality makes tunnelling possible and cost-effective
- Many projects could be increased 1000 - 2500 MW (or more)
- Low environmental impact – using only existing reservoirs
- Preliminary studies have identified that probably at least 20 000 MW new capacity could be developed
- 12 Projects have been studied in more detail

# Characteristics for future Pumped Storage Hydropower in Norway

- Will probably be using only existing reservoirs
- This will often give very long tunnel systems (5-50 km)
- Costs for Tunnels and Rock caverns will usually be dominating (> 50%)
- Using mainly unlined tunnels and pressure shafts
- Low water velocity and low friction losses
- Large volumes of rock excavation and deposition
- ➔ Peaking power or pumped storage can be built at relatively low cost 3000-6000 NKO/KW (500-1000 USD/KW)

Case 1: Botsvatn - Vatnedalsvatn
Average Head 200 m
Max storage: 296 Mm3
Potential storage 150 GWh

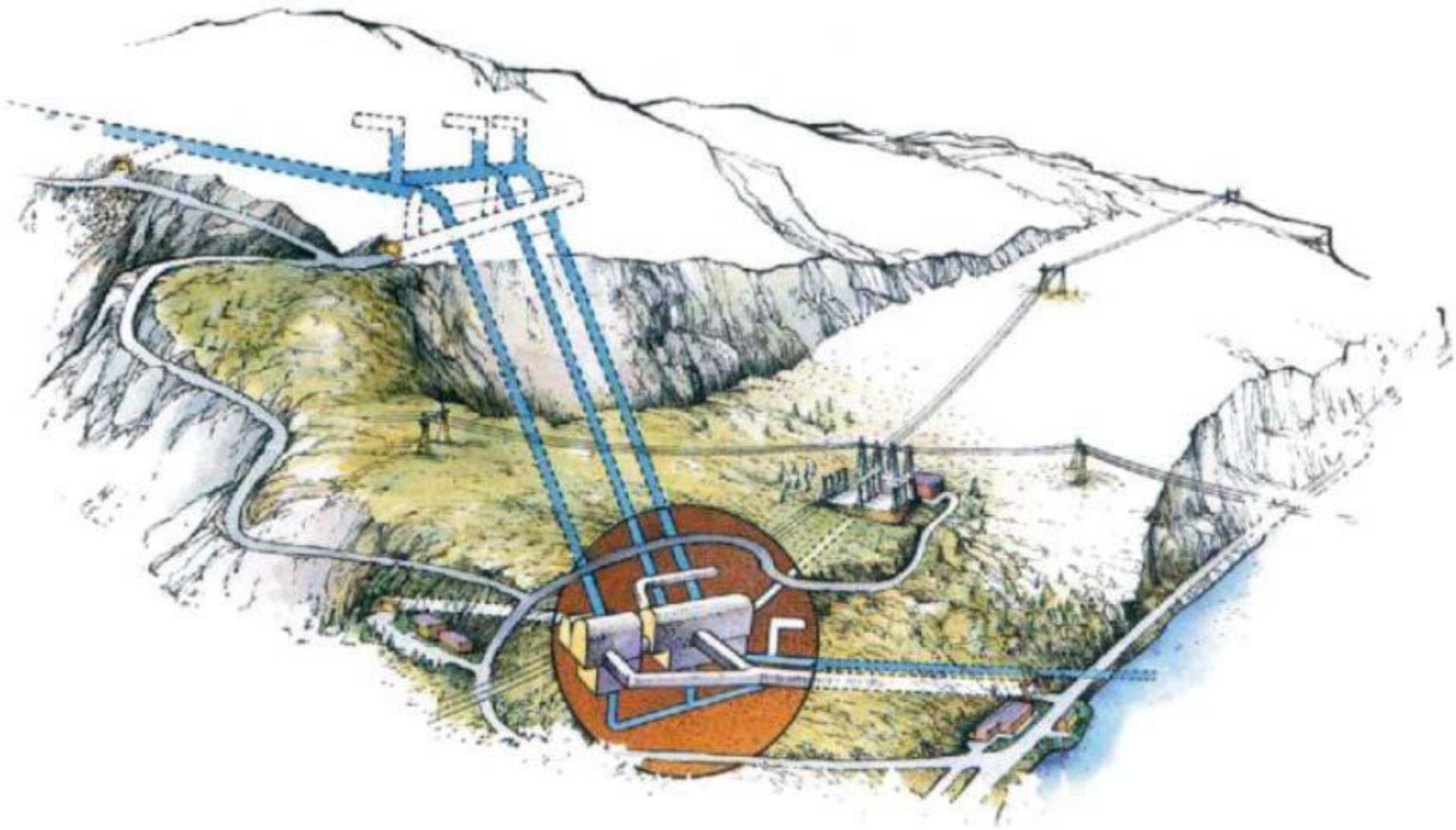
Upper reservoir:
Vatnedalsvatn
700 - 840 m.a.s.l
Volume: 1150 Mill m3

Distance: 13 km
dH/dL = 15.4 m/km

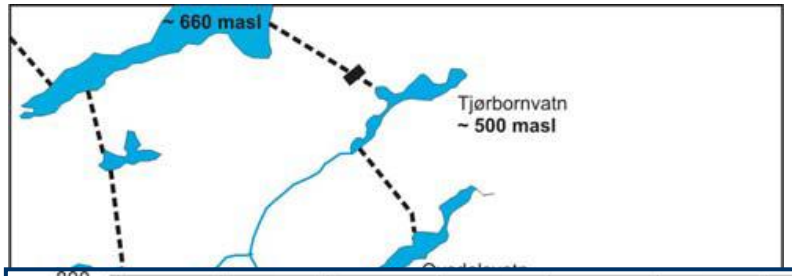
Lower reservoir:
Botsvatn
495 - 551 m.a.s.l
Volume: 296 Mill m3

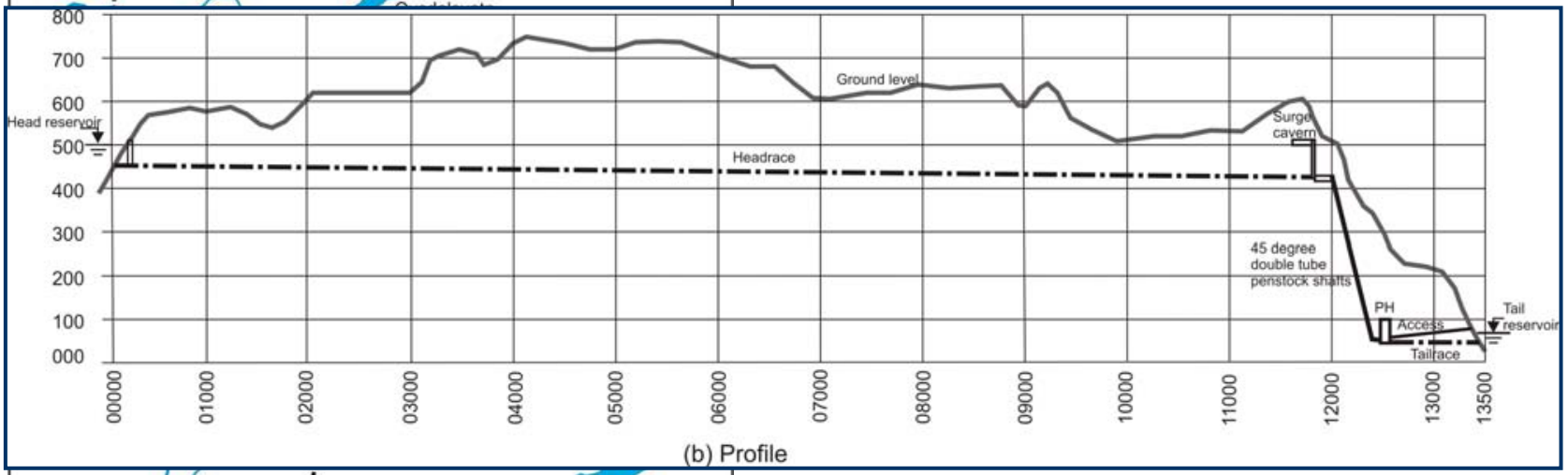
Google earth

# Existing Tonstad power station
# 960 MW and 3600 GWh/year

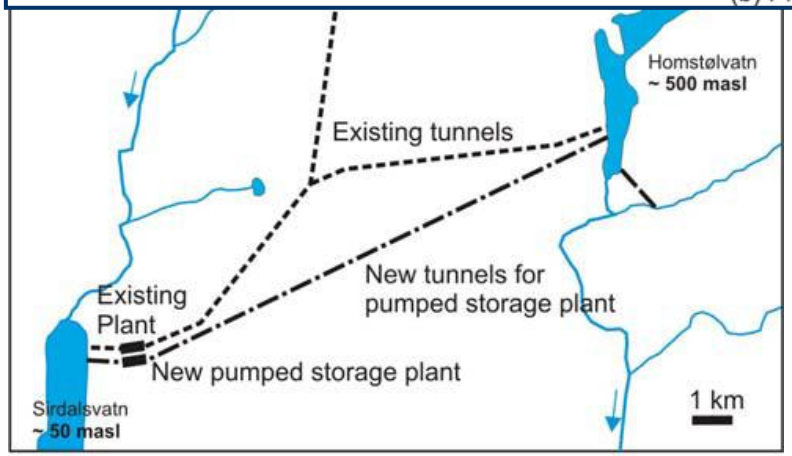


# Case new Tonstad Pumped Storage Plant (1000MW)




(b) Profile




(a) Plan

Tonstad pumped storage plant:

Two new turbines each 480 MW
14 000 meters of new tunnels
Two steel lined shafts of 600 m each
125 $m^3/s$ each unit in turbineing mode
100 $m^3/s$ each unit in pumping mode

# Design challenges

Market – What is the need?

Selecting the best location (Cost, Environment, Transmission)

Grid connection in Norway

Grid connection to Europe

Optimal layout of Hydraulic system – minimizing losses

Reversible turbines or separate pump and turbine?

Environmental effects in reservoirs

# Environmental impacts in the reservoirs

?

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# Summary - Pumped Storage Hydropower in Norway

Many possible sites – capacity from 250 to 2500 MW

Using only existing reservoirs

Capacity for bulk storage – Up to 5000 GWh per cycle

Potential for 20 000 MW (or more)

Very long tunnel systems – from 5 to 50 km

Large volumes of water in movement – what about stability during operation ?

Main challenges: Market, Environment, Transmission

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