Large-scale balancing and storage from hydropower - trends for the future in Europe

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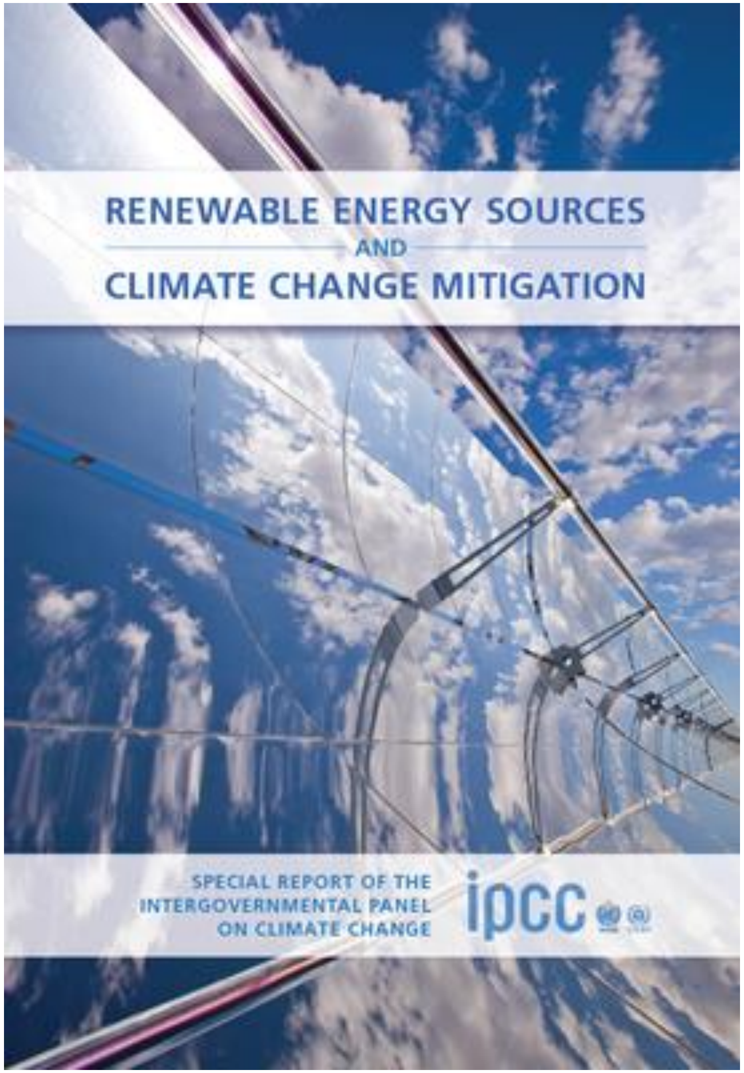
Norwegian University of Science and Technology (NTNU) and CEDREN
IEA-Hydro meeting 10 June 2014 in Rovaniemi, Finland

IPPC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN, 2012)



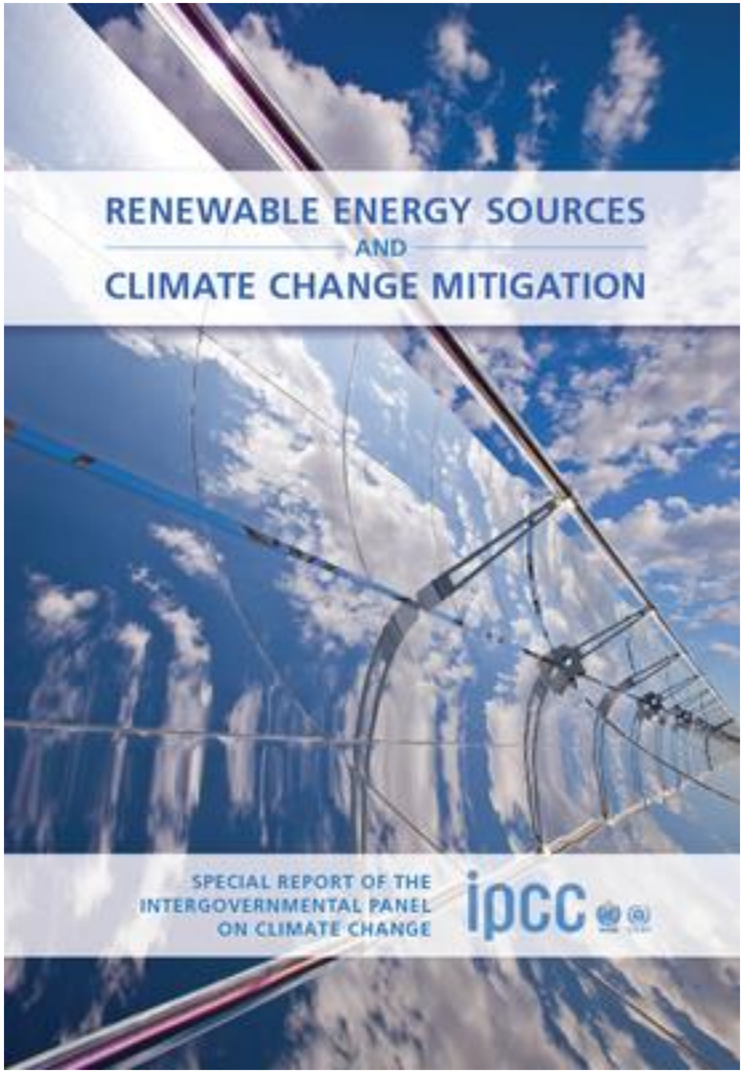
Up to 80% Renewable could be possible If backed by the right enabling policies

The global technical potential of RE sources will not limit continued growth in the use of RE

A wide range of estimates are provided in the literature, but studies have consistently found that the total global technical potential for RE is substantially higher than global energy demand

The technical potential for solar energy is the highest among the RE sources, but substantial technical potential exists for all six RE sources

IPPC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN, 2012)



Some main challenges:

- Transmission and distribution infrastructure
- Energy storage technologies
- Demand side management
- Improved forecasting of resource availability

Climate-friendly 100% renewable electricity supply for Europe by 2050 (SRU, 2010)

SRU German Advisory Council on the Environment

Climate-friendly, reliable, affordable: 100% renewable electricity supply by 2050

Statement

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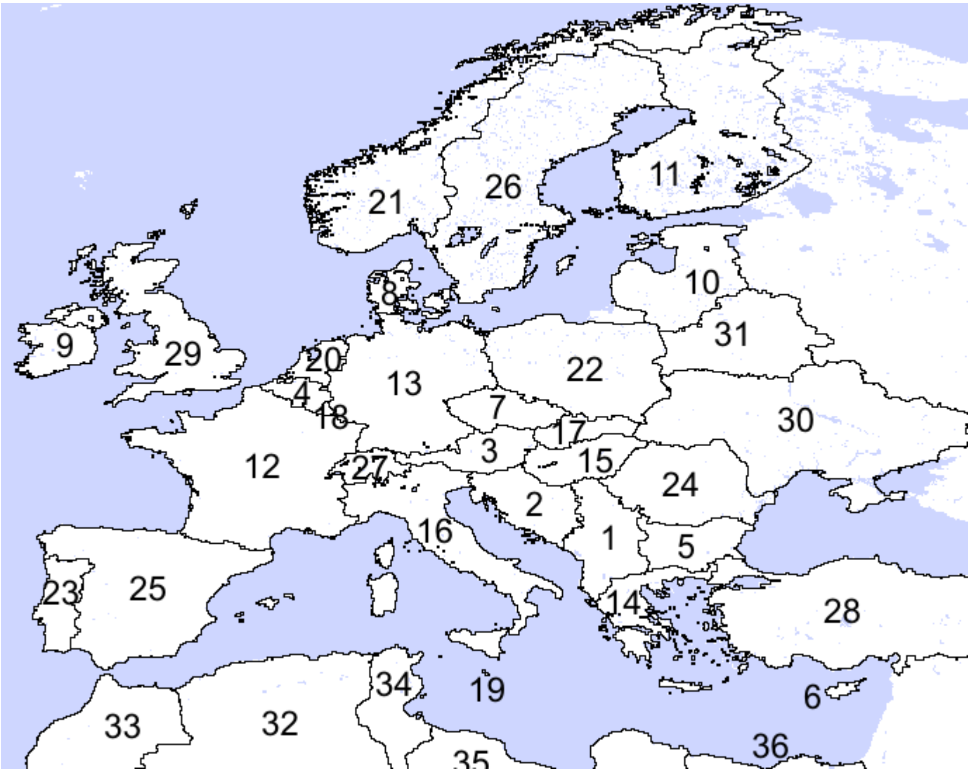


SRU German Advisory Council on the Environment

- 100% renewable electricity supply for Germany and Europe is possible by 2050 (2030 if needed)
- The system will mainly be based on wind and solar
- Storage and transmission will be crucial
- Pumped storage hydro will be in great demand
- Norway will become a unique swing provider for the European system due to its hydro resource
- We can start with bilateral cooperation

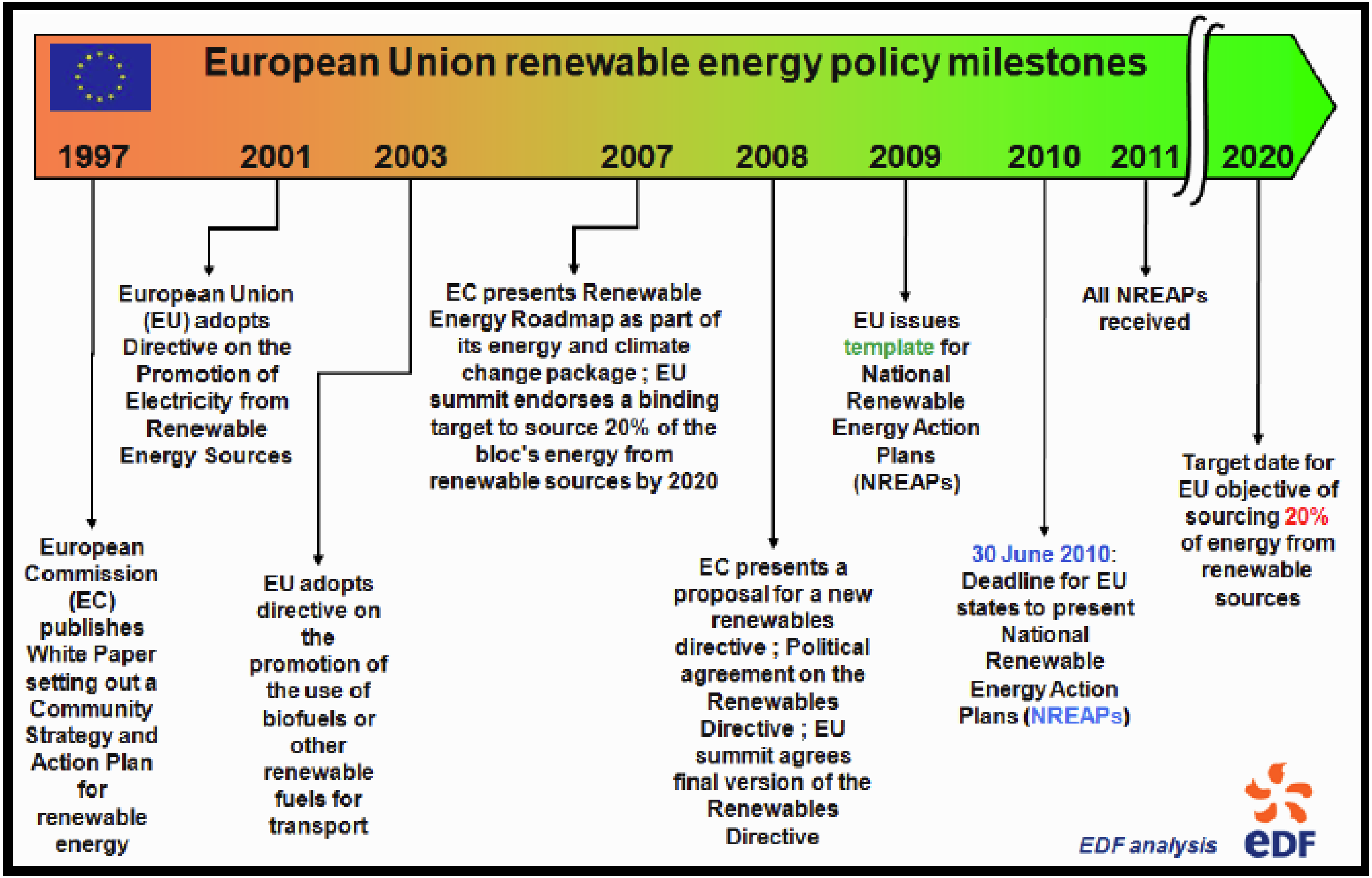
Conclusions in these and other studies agree well:

Large scale RE development is possible with known technology

Three main sources will be dominating: Wind, Solar and Hydro

Few, if any, fundamental technical limits exist to the integration of a majority share of RE, but advancements in several areas are needed:

- **Transmission and distribution infrastructure**
- **Energy storage technologies**
- **Demand side management**
- **Improved forecasting of resource availability**



European Union renewable energy policy milestones
1997
2001
2003
2007
2008
2009
2010
2011
2020
European Commission (EC) publishes White Paper setting out a Community Strategy and Action Plan for renewable energy
European Union (EU) adopts Directive on the Promotion of Electricity from Renewable Energy Sources
EU adopts directive on the promotion of the use of biofuels or other renewable fuels for transport
EC presents Renewable Energy Roadmap as part of its energy and climate change package ; EU summit endorses a binding target to source 20% of the bloc's energy from renewable sources by 2020
EC presents a proposal for a new renewables directive ; Political agreement on the Renewables Directive ; EU summit agrees final version of the Renewables Directive
EU issues template for National Renewable Energy Action Plans (NREAPs)
30 June 2010: Deadline for EU states to present National Renewable Energy Action Plans (NREAPs)
All NREAPs received
Target date for EU objective of sourcing 20% of energy from renewable sources
EDF analysis
EDF

EU-Policy is very determined

“The energy challenge is one of the greatest tests faced by Europe today”

“Key decisions have to be taken to reduce drastically our emissions and fight climate change”

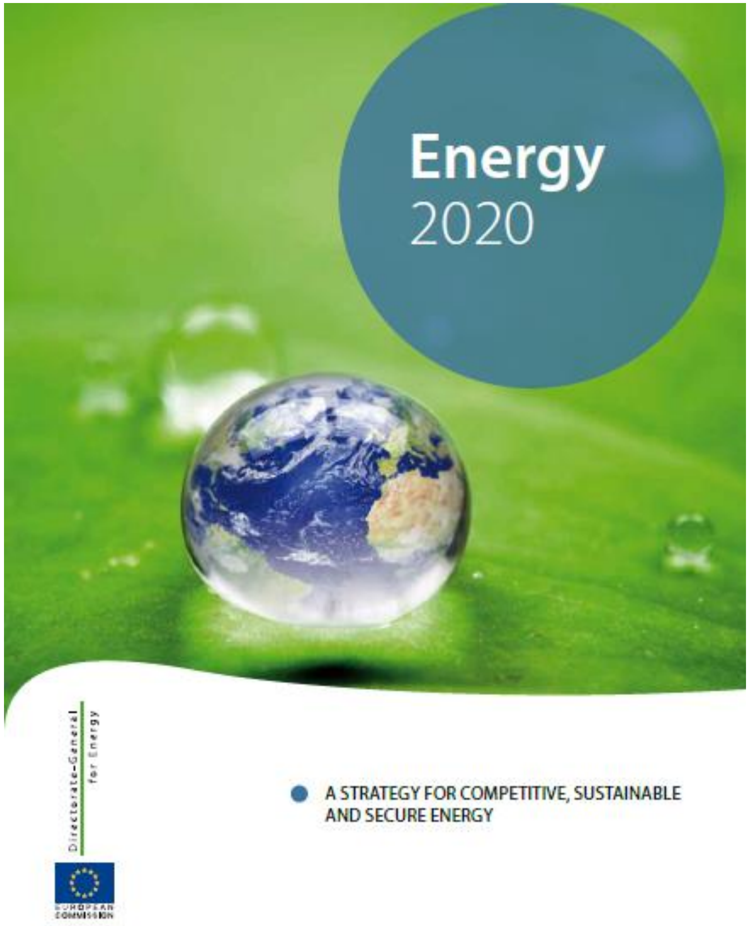
G. Oettinger (EU commisionar for energiy)
Energy 2020

The RES Directive (20/20/20 Goals)

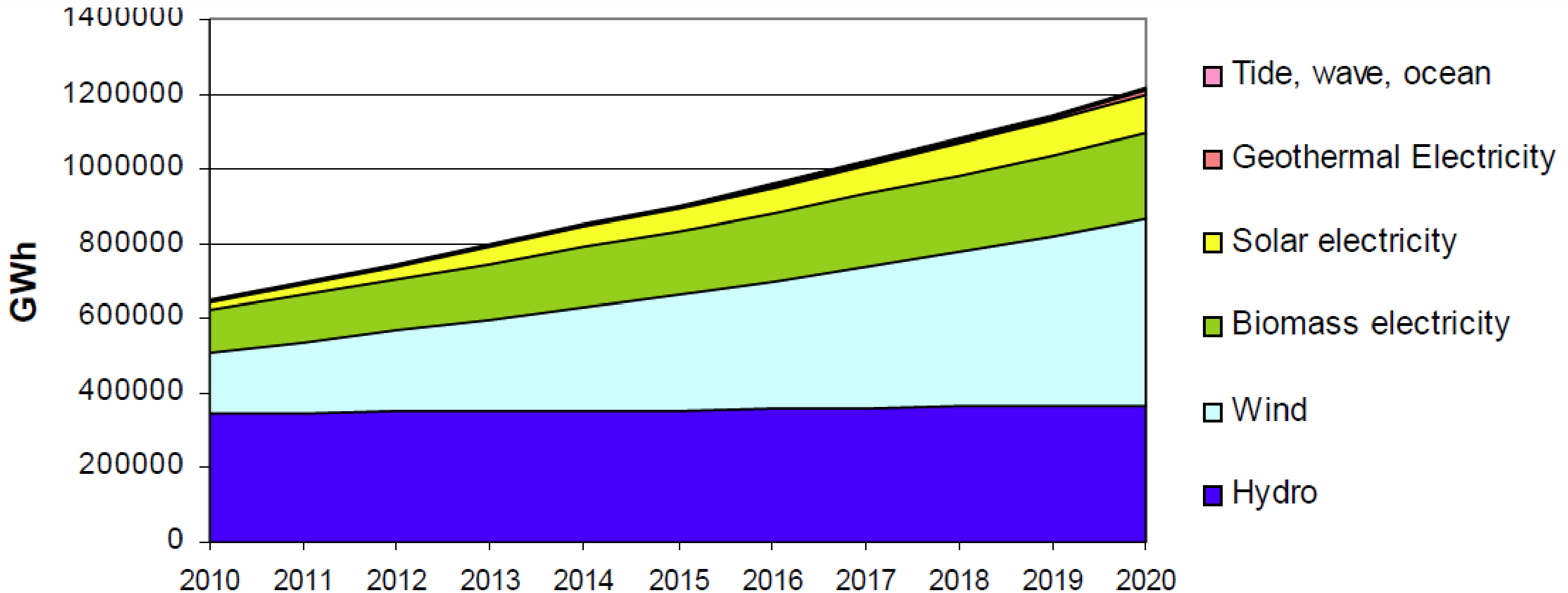
<u>1. Main targets</u>
- 20% reduction in GHG emissions
- 20% better energy efficiency
- 20% of energy from RES

For electricity 34% in 2020

Source: *Energy 2020 – A strategy for competetive, sustainable and secure energy*



Towards 2020 – Implementation of the RES-directive

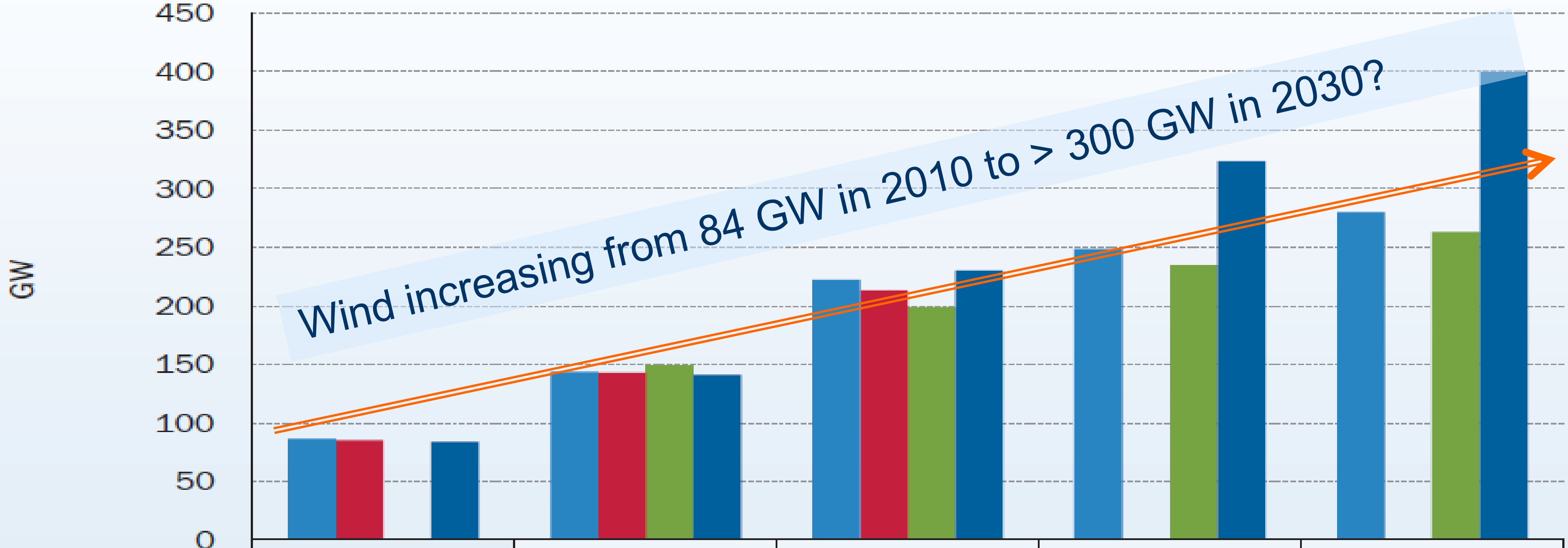


RES generation from **632** TWh in 2010 to **1152** TWh in 2020
Largest increase in Wind - ca 120 GW and 305 TWh
Also rapid increase in Solar PV - ca 65 GW og 100 TWh

➔ Increase of non-dispatchable power generation (wind, solar PV)

Wind Power Development in Europe

FIGURE 4.1 LATEST WIND ENERGY SCENARIOS FOR EU-27 FROM THE EUROPEAN COMMISSION, THE MEMBER STATES, THE IEA AND EWEA (GW TOTAL INSTALLED CAPACITY)



	2010	2015	2020	2025	2030
EC 2009	86	144	222	248	280
NREAPs	85	143	213	-	-
IEA 2010		149	199	235	263
EWEA 2011	84	141	230	324	400

Source: EWEA, European Commission, International Energy Agency, National Renewable Energy Action Plans.

EU - Energy Roadmap for 2050

- Decarbonization of Energy system by 2050 (80-95% reduced GHG)
- Energy saving / Energy Efficiency
- Switching to Renewable Energy Sources
- More market integration / European approach
- Storage technologies remains critical
- Gas plays a key role <u>in the transition</u>
- Need for flexible resources
- Transition in close partnership with neighbours (Norway, …)
- Further interconnection with Norway and Switzerland … critical
- Engaging the public is crucial (Social dimension)

Centre for environmental design of renewable energy – CEDREN

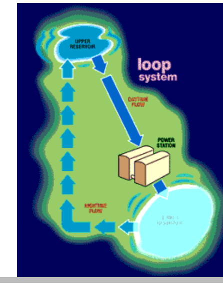
SINTEF

NTNU
100 skapende år

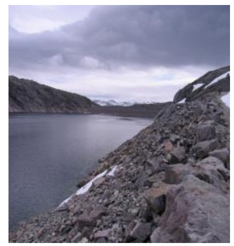
NINA
Norsk institutt for naturforskning

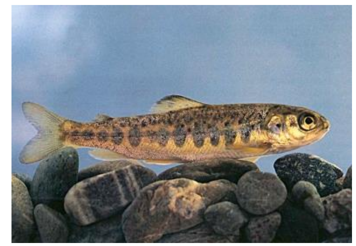
CEDREN – Four Main Focus Areas

Hydropower technology



Environmental impacts of hydropower





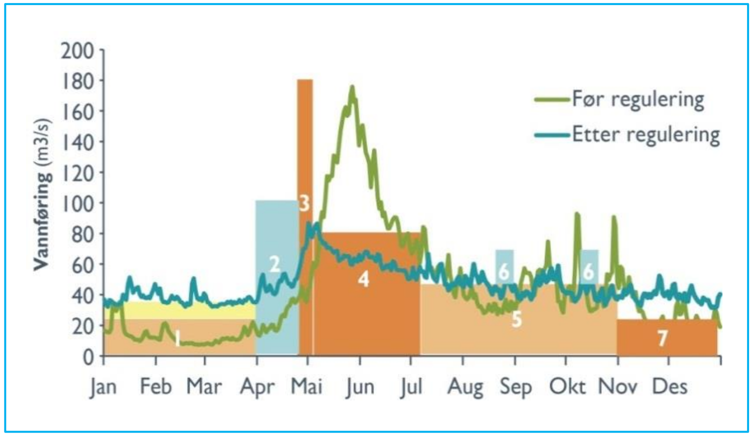
Environmental impacts of wind power and power transmisson

How to reconcile energy and environment policy?

International partners:

PhD and PostDoc Research have high priority

Environmental design



Water release

Habitat mitigation

Power system

Handbook for environmental design of regulated salmon rivers

HYDROPEAK - Main goals

To study how the hydropower system can support increasing amounts of non-regulated renewables (eg offshore wind power) for Peaking and large scale Power balancing

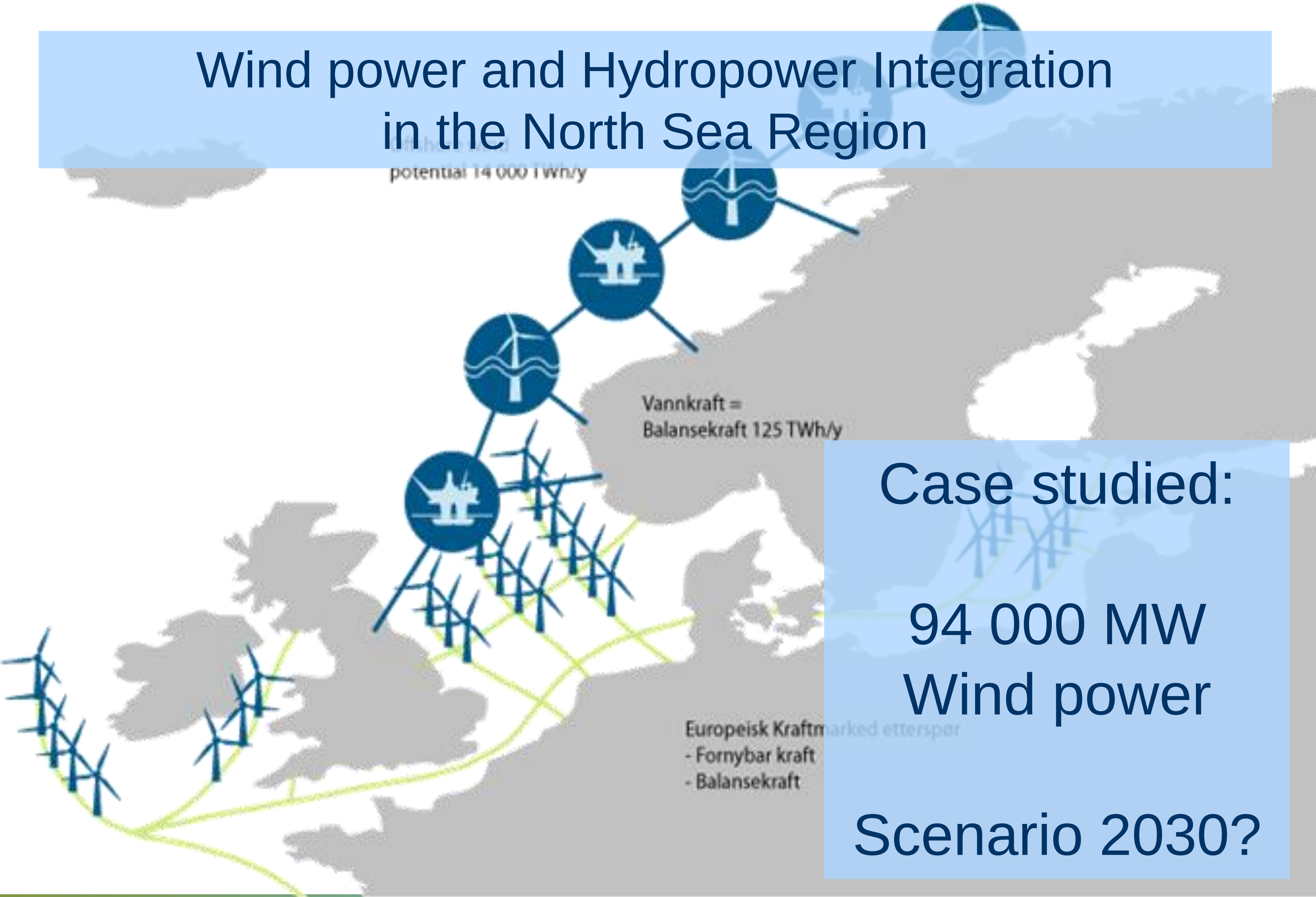
What type of adaption that are needed (and possible) in the existing hydropower system

Optimal design of the future hydropower system (including adaption to future Climate Change)

Technological evolution and innovation (e.g. for pumped storage, tunnels, …)

Design of environmentally friendly hydropower

Wind power and Hydropower Integration in the North Sea Region

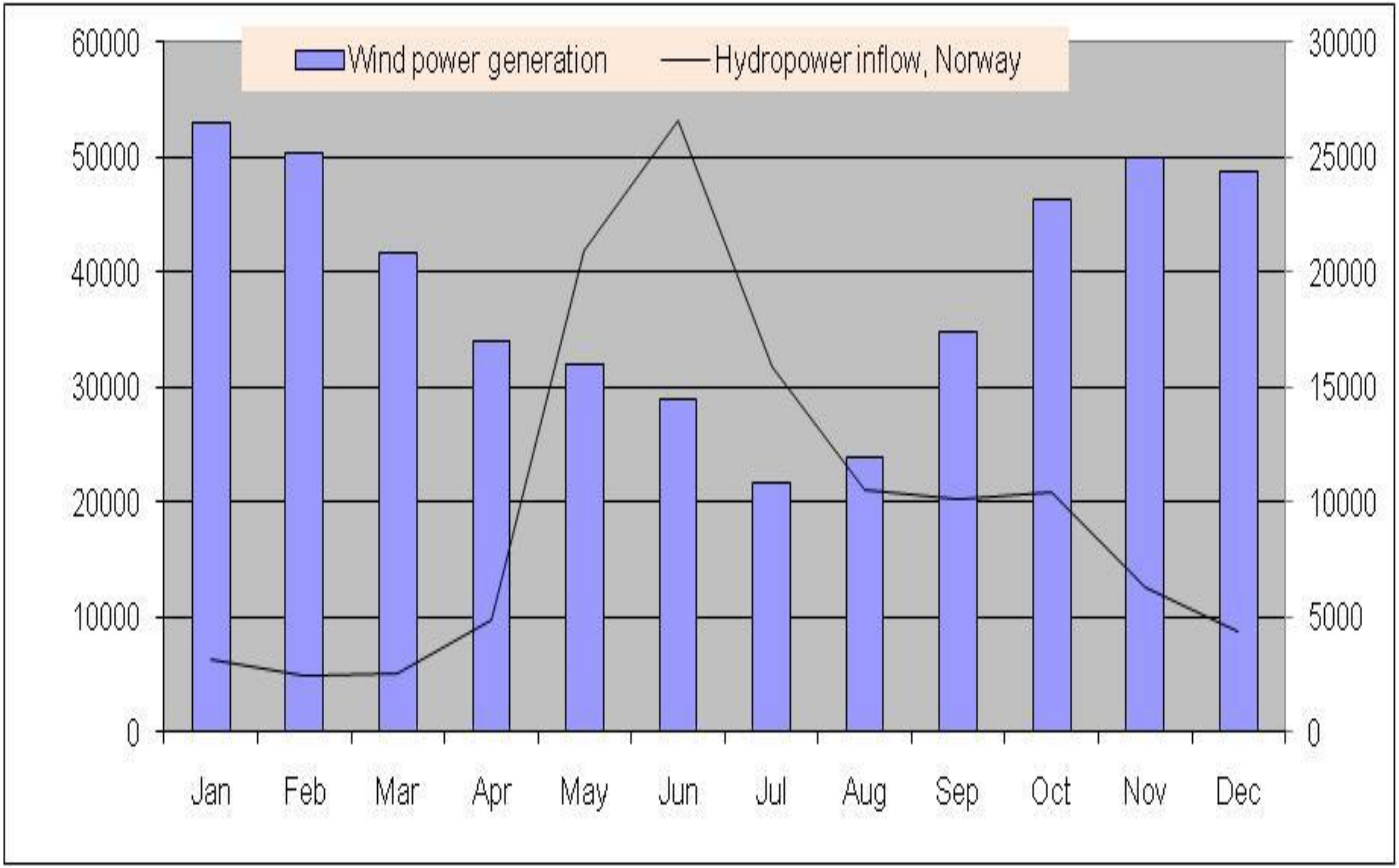


Case studied:

94 000 MW
Wind power

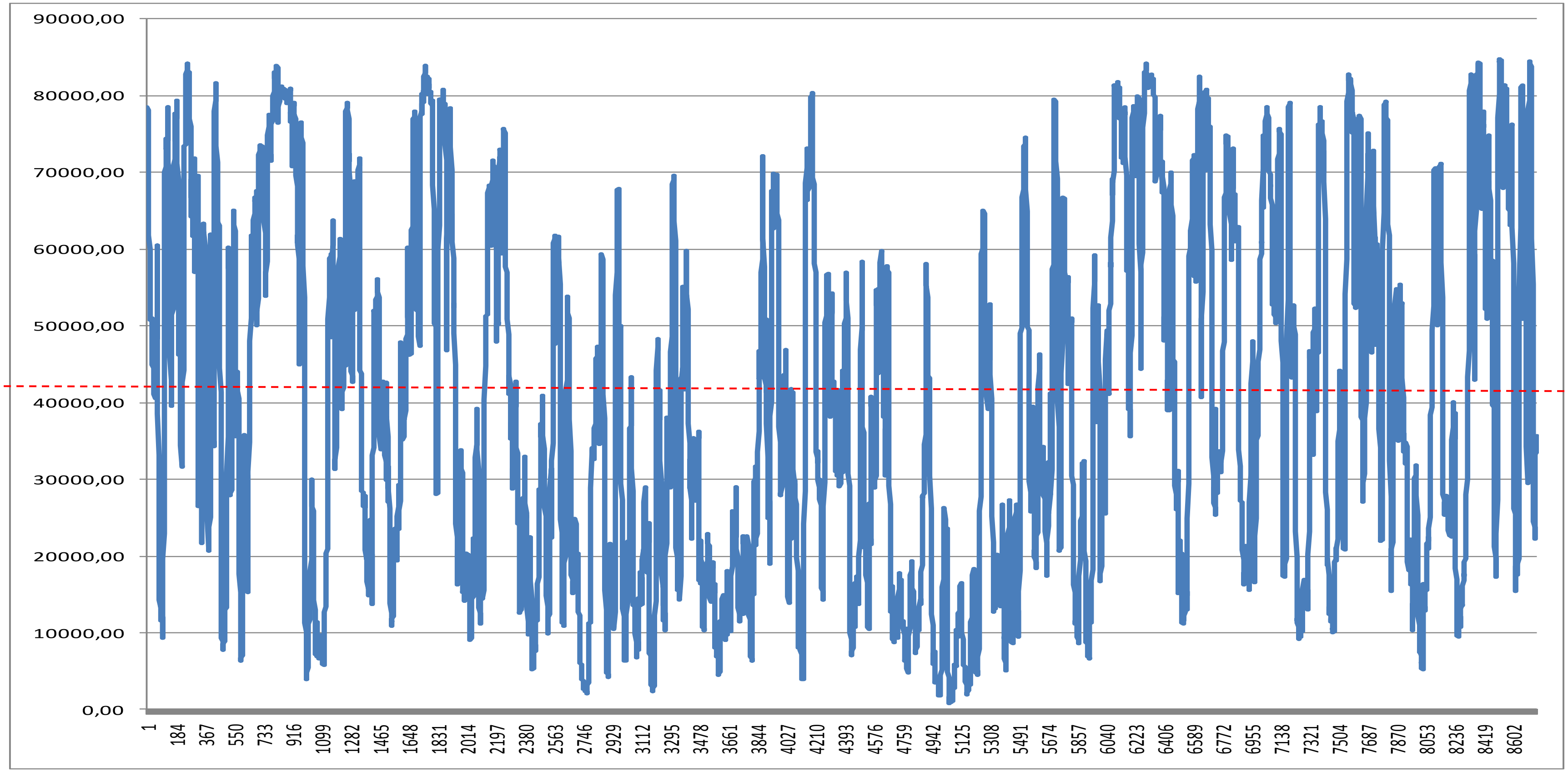
Scenario 2030?

Wind and hydro looks like a good match



However - Wind energy is highly variable

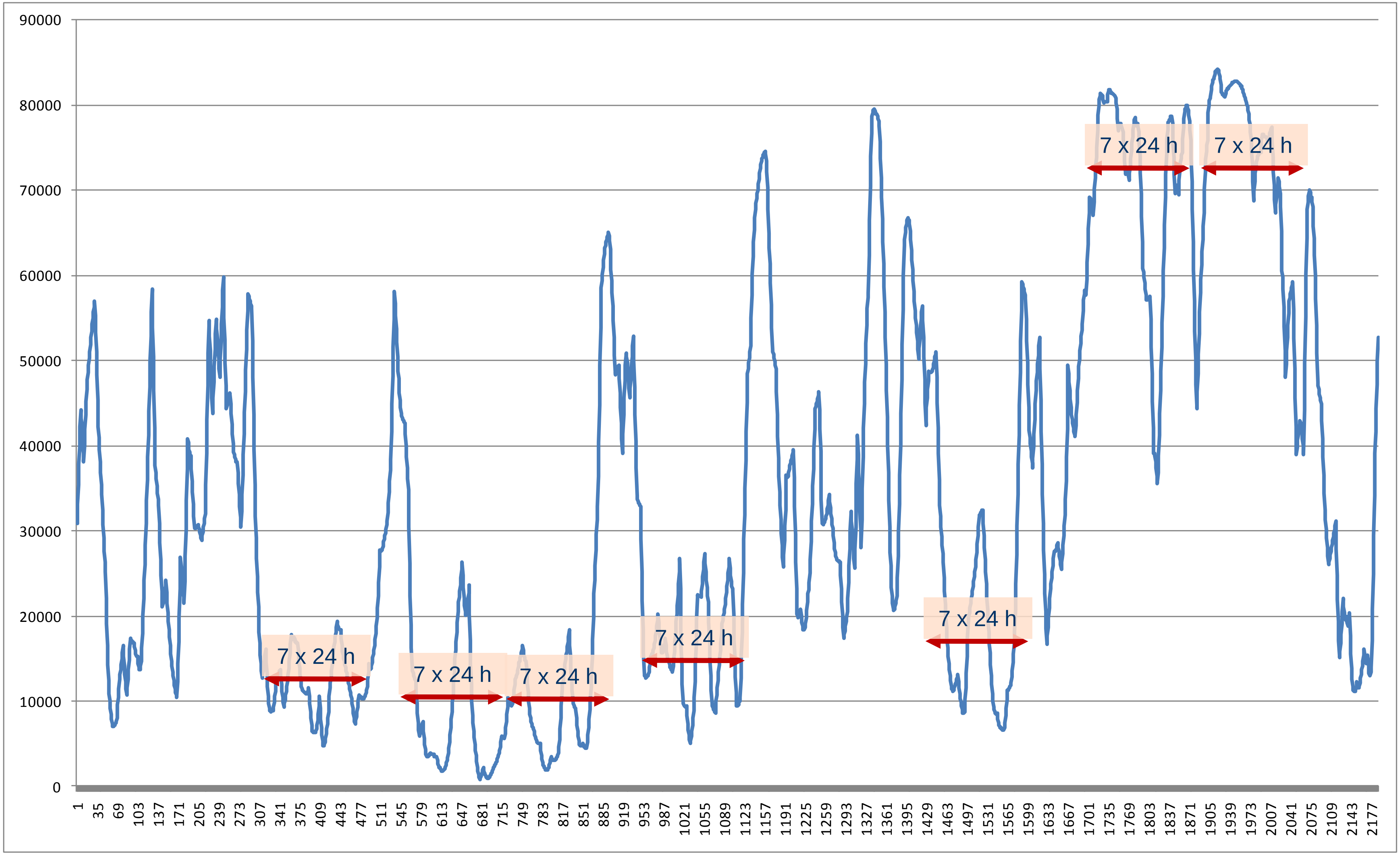
(Hourly simulated wind power for one year – data from TradeWind)



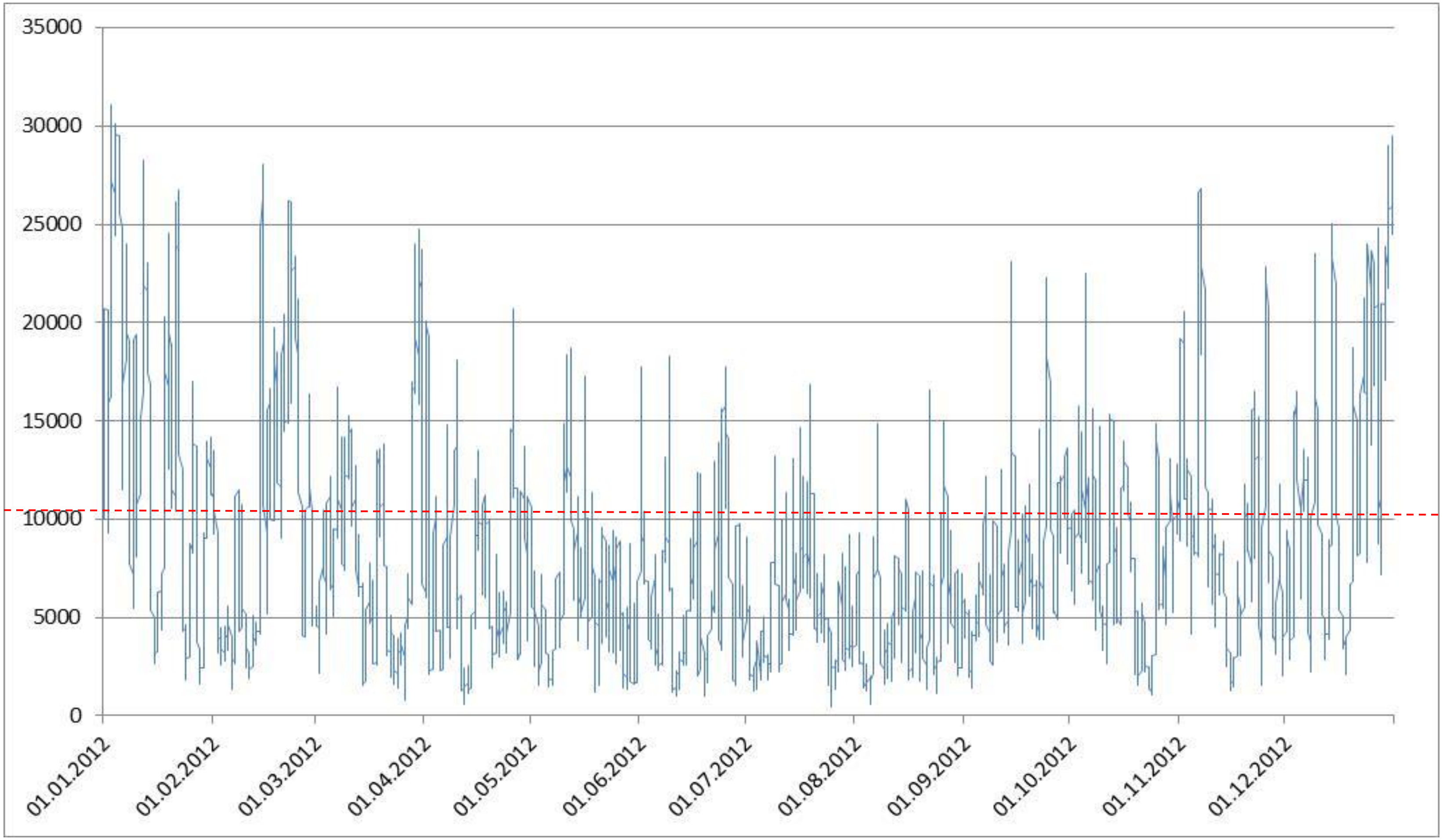
Simulated Wind energy production in a North-Sea system with 94000 MW installed capacity (Stadium 2030)

Maximum: 84 448 MW
Minimum: 2 774 MW
Typical: 40 000 MW

Sim. Wind Power North-Sea Region - July – Sep 2001



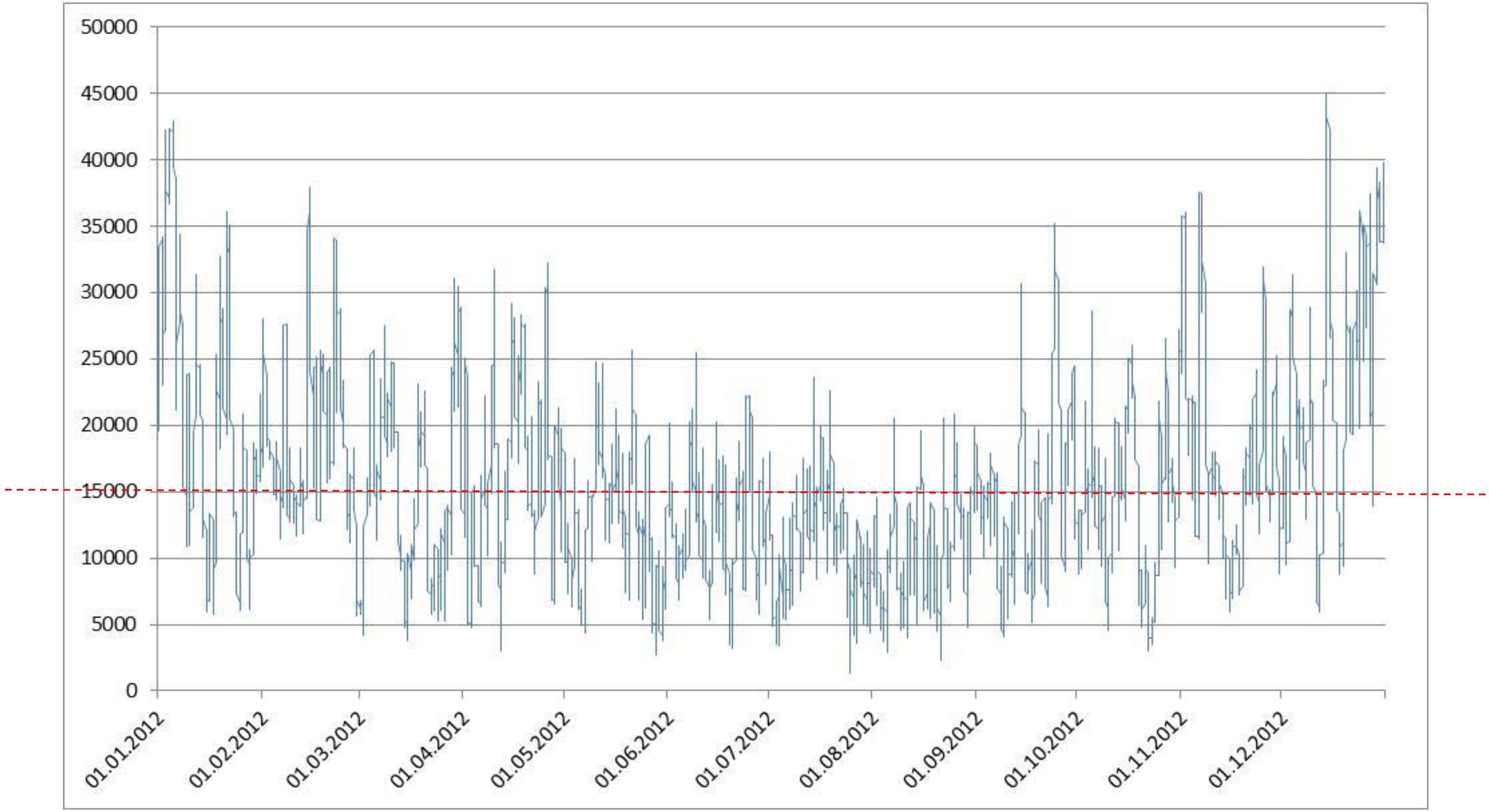
Wind Power in North-Sea Region (DE, DK, GB, IR) in 2012



Observed Wind energy production in a system with **45600 MW** installed capacity (Stadium 2012)

Maximum: 31062 MW
Minimum: 419 MW
Typical: 8300 MW
Capacity Factor: **0.18**

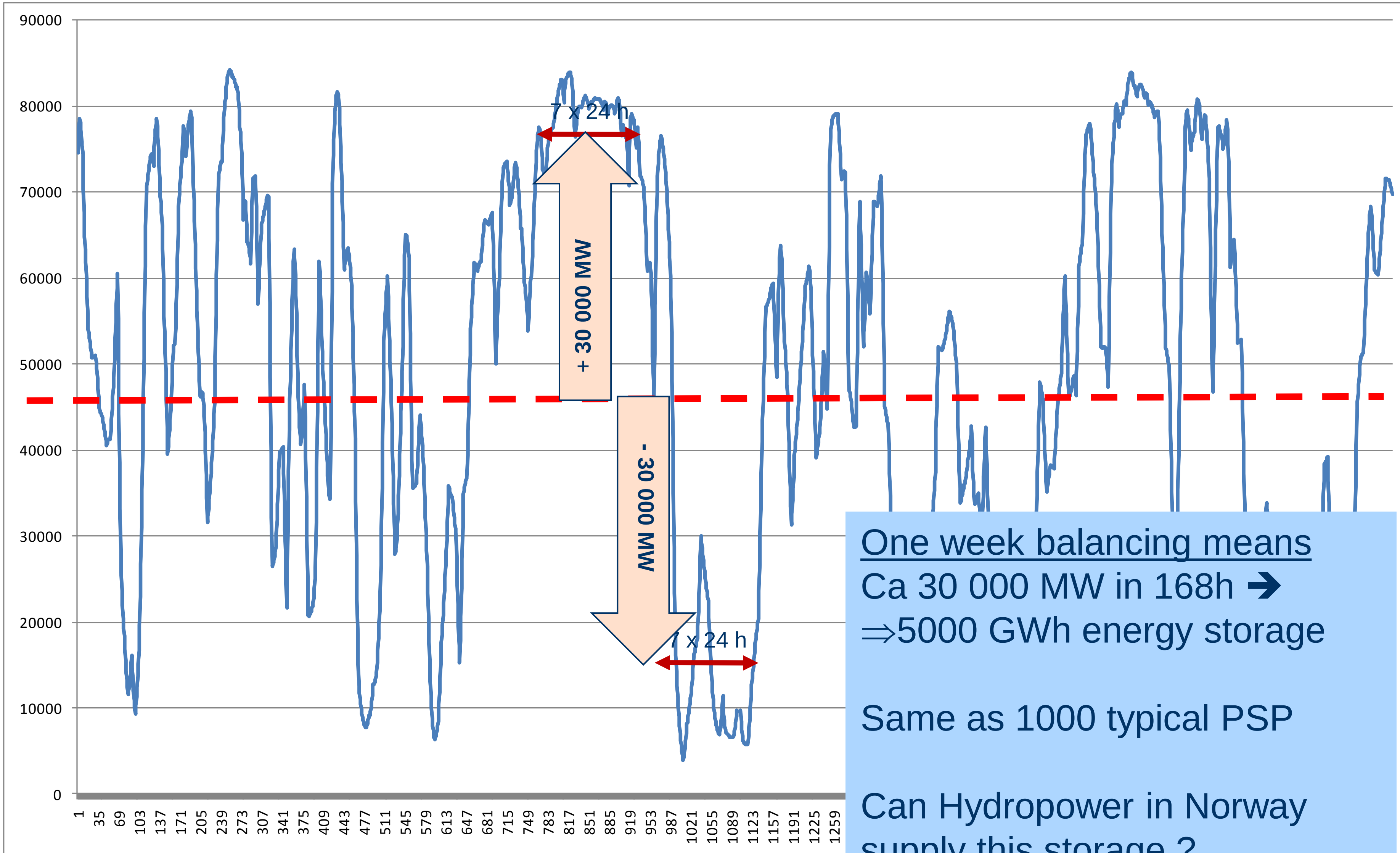
Wind Power in West Europe (ES, FR, DE, DK, GB, IR) 2012



Observed Wind energy production
In a system with **76013** MW
installed capacity (Stadium 2012)

Maximum: 44995 MW
Minimum: 1272 MW
Typical: 15400 MW
Capacity Factor: **0.20**

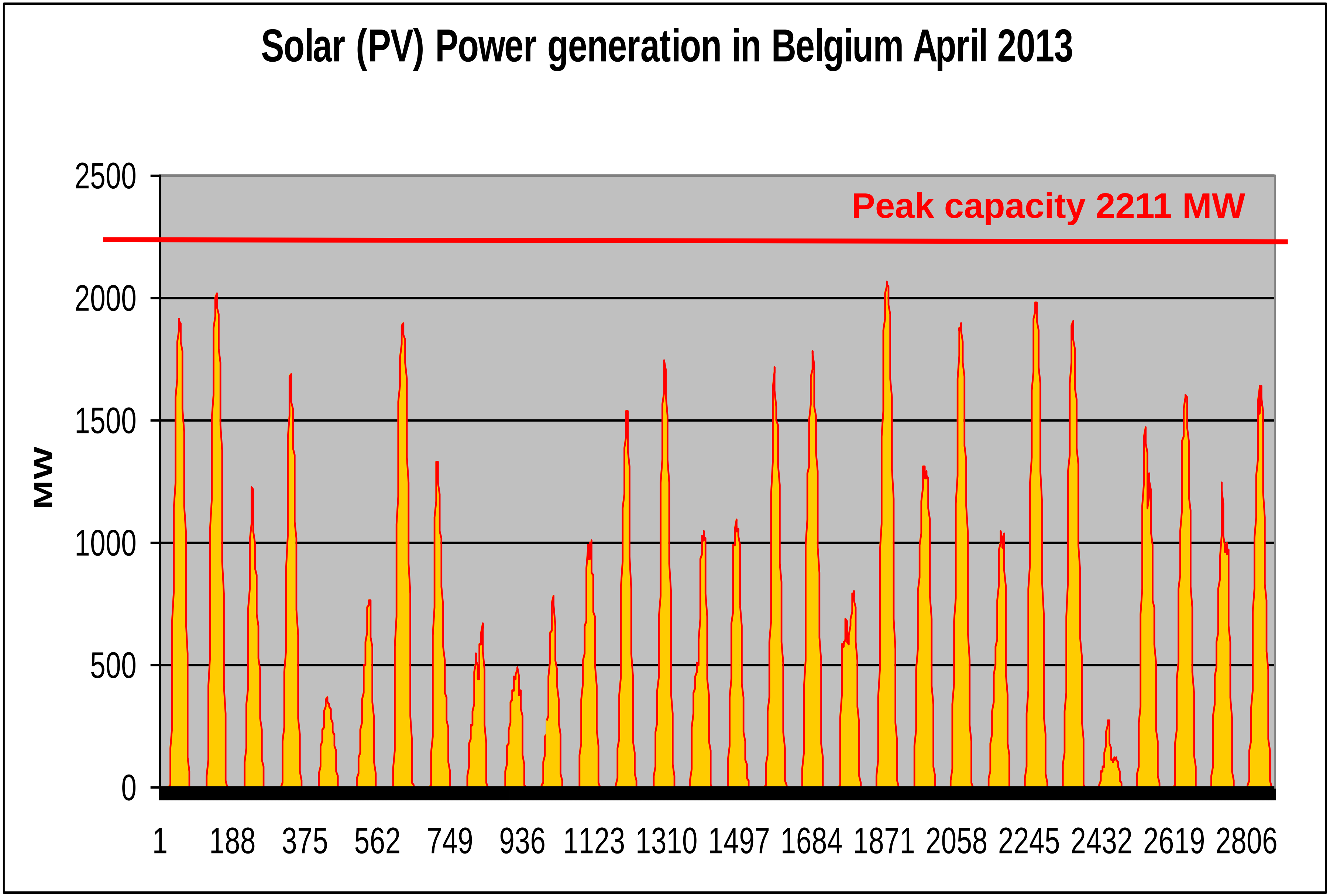
Simulated Wind Power North-Sea Region Jan–Mar 2001



<u>One week balancing means</u>
Ca 30 000 MW in 168h ➔
⇒5000 GWh energy storage

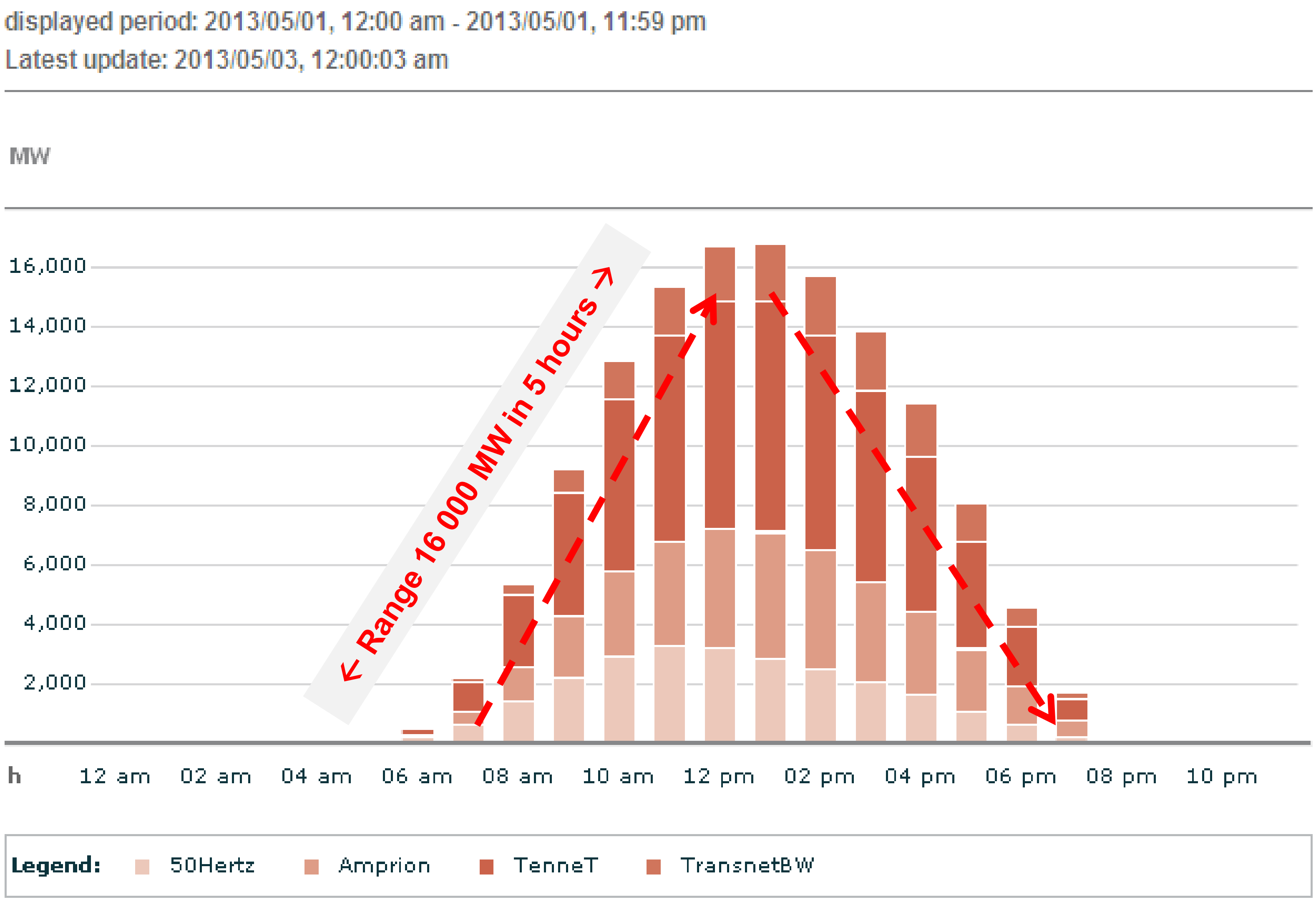
Same as 1000 typical PSP

Can Hydropower in Norway supply this storage ?

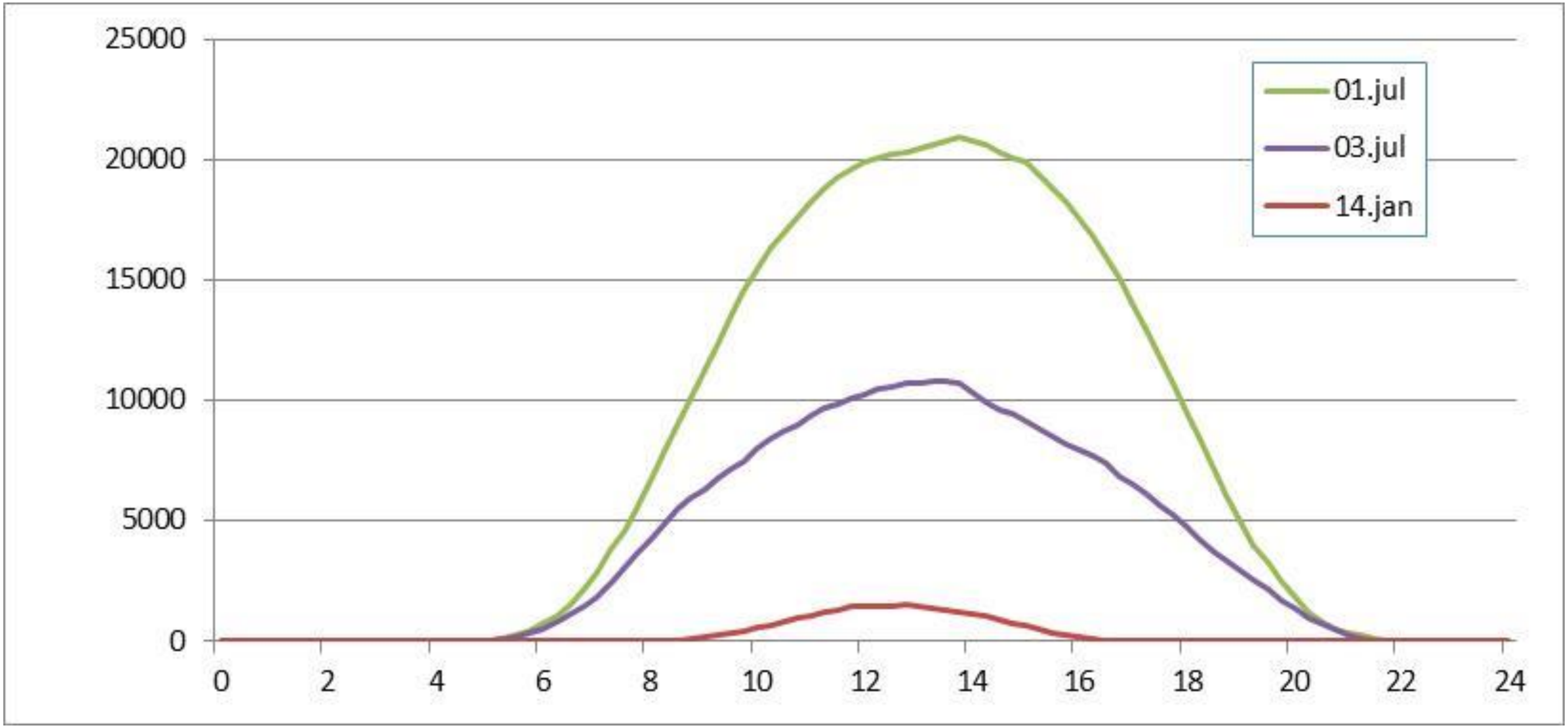


CEDREN Centre for Environmental Design of Renewable Energy

Solar energy output (MW) in Germany May 5th 2013



Solar power output (MW) in Germany in 2013
System capacity: 30 000 MW



VRE Integration – Highlights

Integration cost increases with increasing penetration of VRE

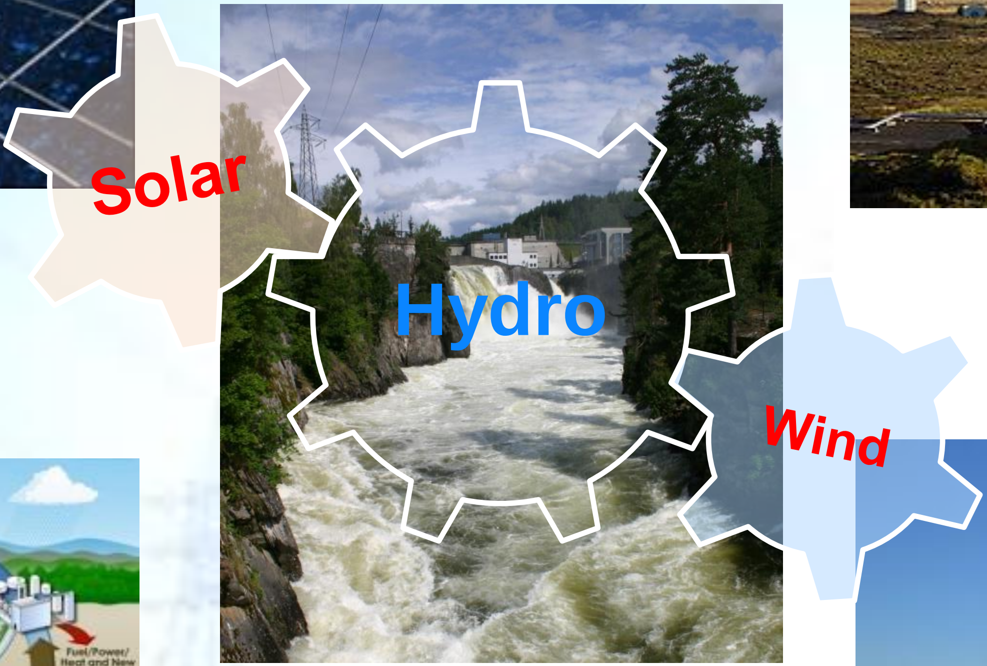
Integration costs of wind power can be in the same range as generation costs at moderate shares (~20%)

Integration costs can become an economic barrier to deploying VRE at high shares

A significant driver of integration costs is the reduced utilization of capital-intensive conventional plants

An economic evaluation of wind and solar power must not neglect integration costs!

Hydropower – Supporting other Renewables



CEDREN studies in 2011 And 2012: How can Norway contribute?

Hydropower - supporting other Renewables

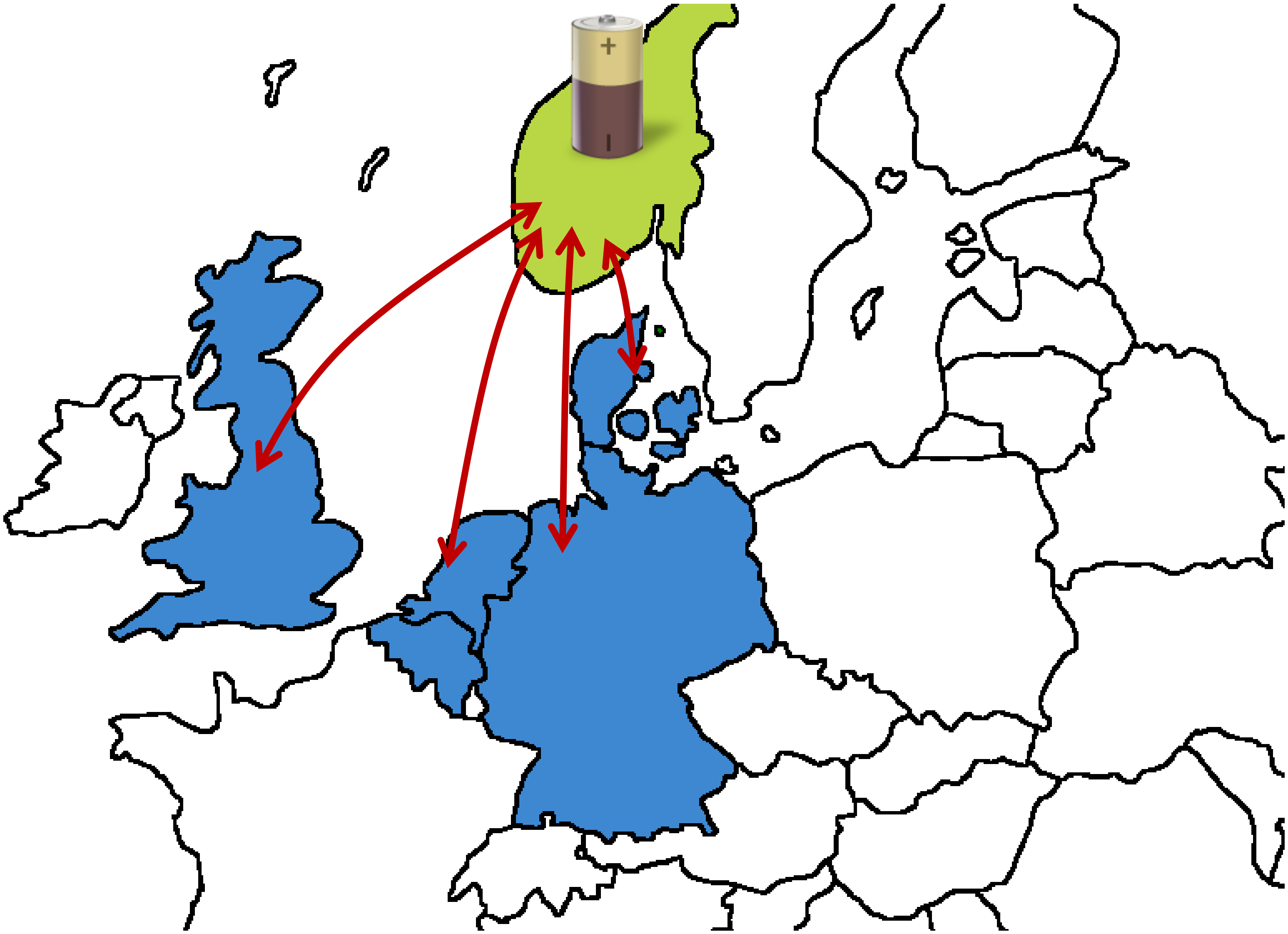
Storage of energy (as water)
- Seasonal
- Synoptic scale (7-10 days, PSH)
- Daily balancing (PSH)

Very fast response time
- Frequency regulation
- Spinning reserves
- Non-spinning reserves
- Voltage support
- Black-start capacity

Important for achieving
- Grid stabilization
- Load balancing
- Storage of intermittent energy (Solar and Wind)

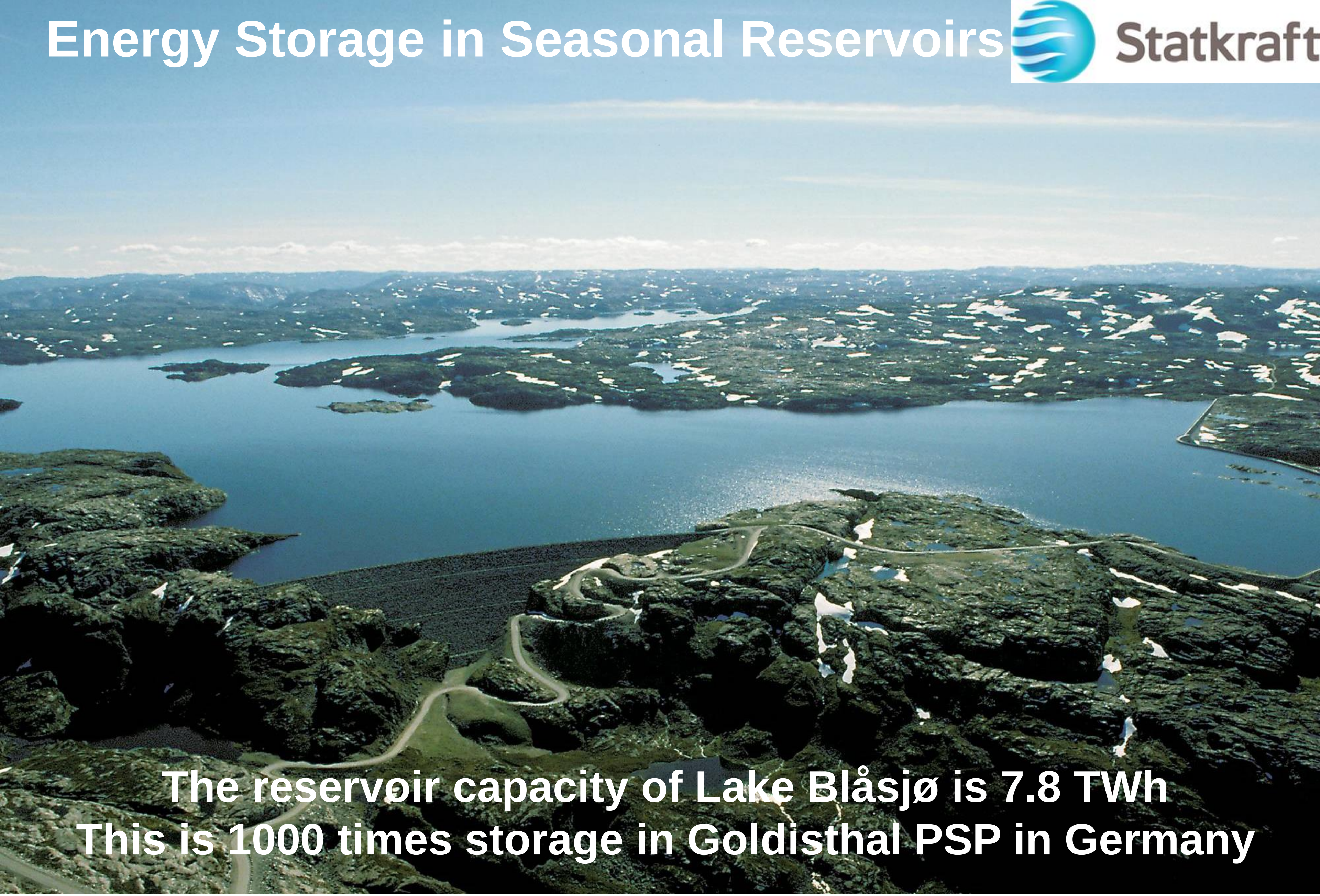
➔ Permitting higher penetration levels for RE in Europe

Hydropower storage in Norway – «The Green Battery of Europe»?

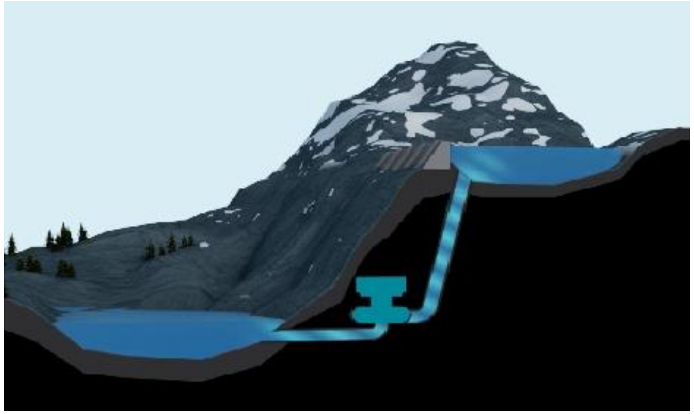


Energy Storage in Seasonal Reservoirs

Statkraft



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



(Source: Statkraft)

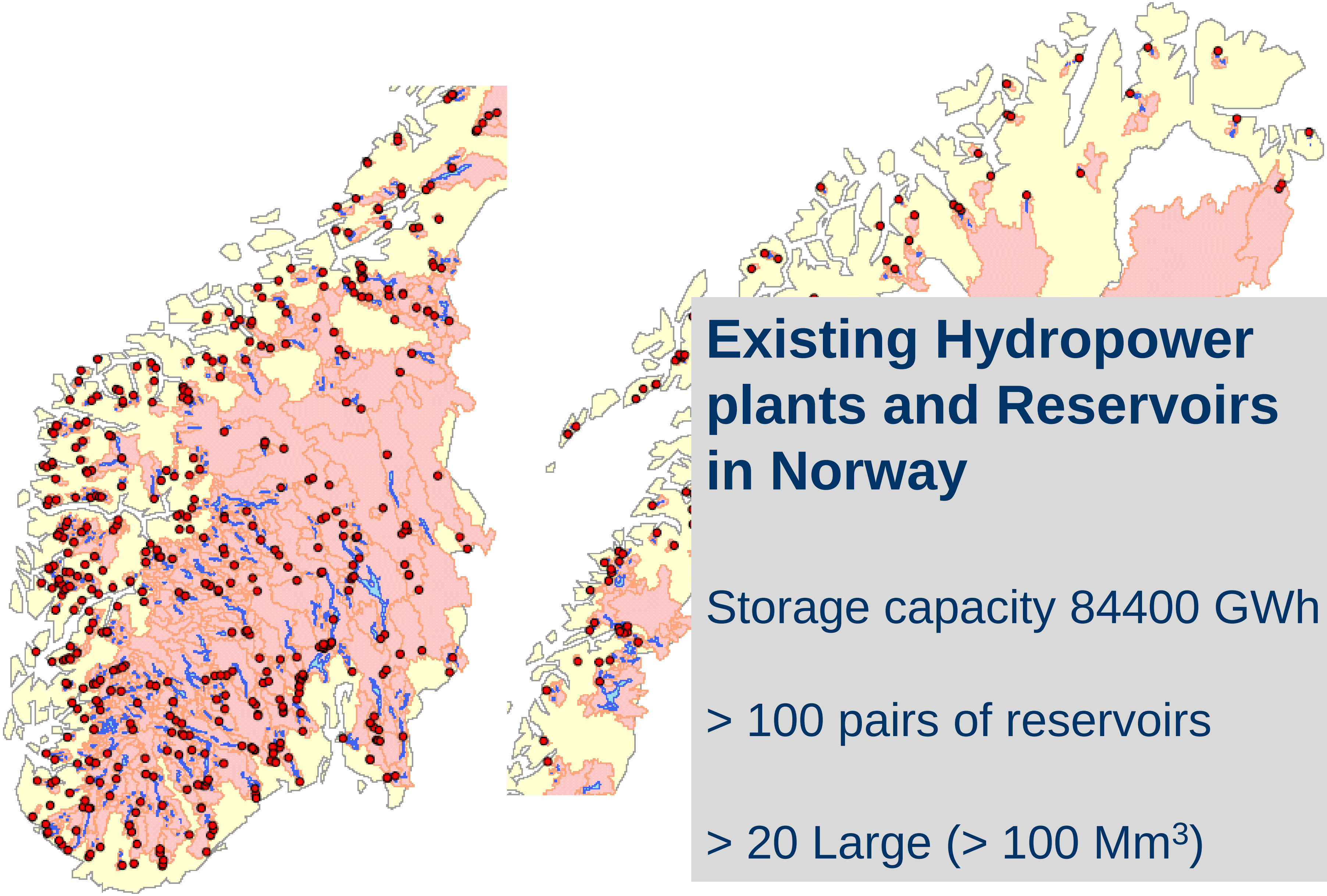
Pumped Storage hydroPower (PSP) seems the best option for balancing large volumes of wind energy

PSP can handle both surplus and deficit situations

Pair(s) of reservoirs needed

Large volume of storage

Large head difference

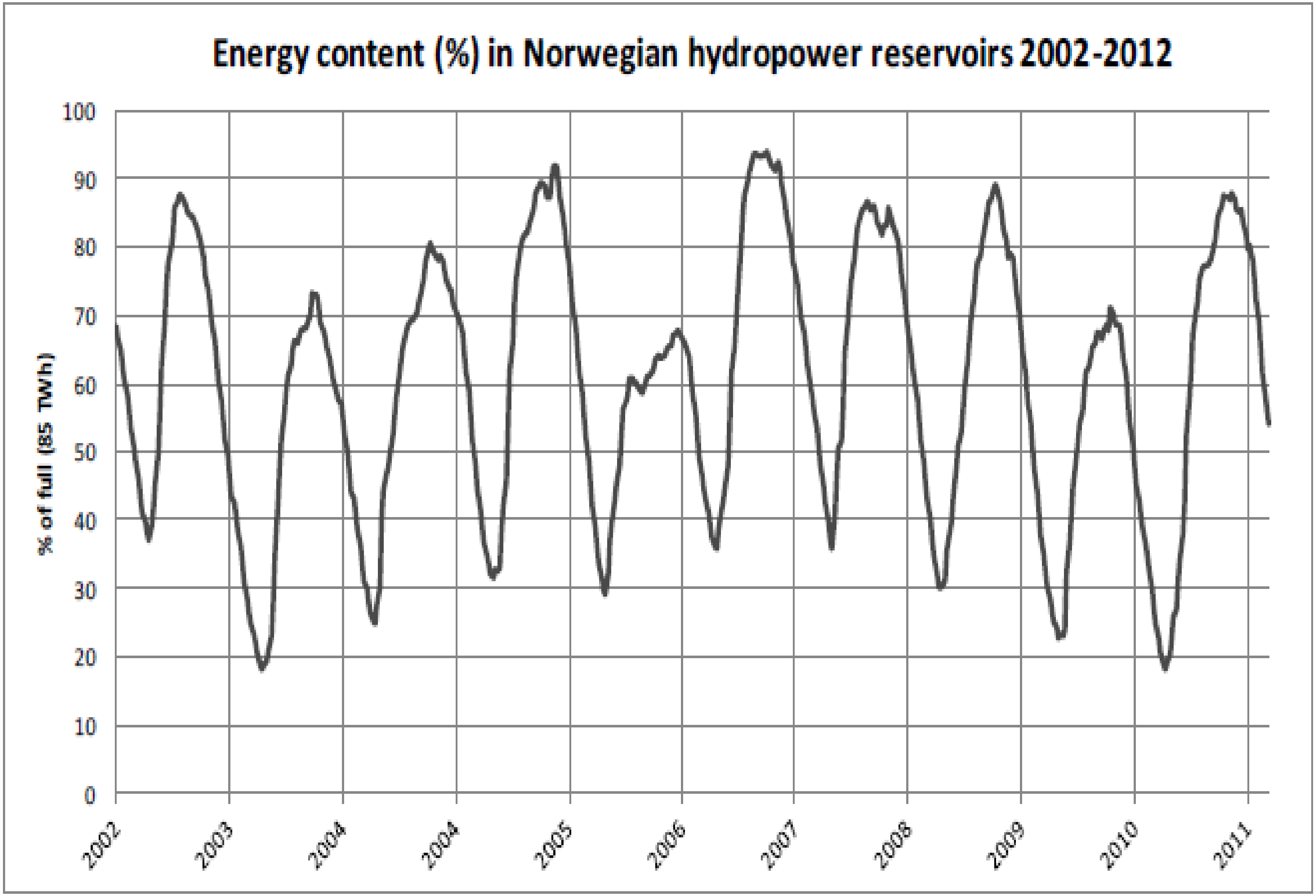


Existing Hydropower plants and Reservoirs in Norway

Storage capacity 84400 GWh

> 100 pairs of reservoirs

> 20 Large (> 100 Mm^3)


Energy content (%) in Norwegian hydropower reservoirs 2002-2012
% of full (85 TWh)
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2004
2005
2006
2007
2008
2009
2010
2011

TR A7227-Unrestricted

Report

Norwegian hydropower for large-scale electricity balancing needs

Technical, environmental and social challenges

Author(s)

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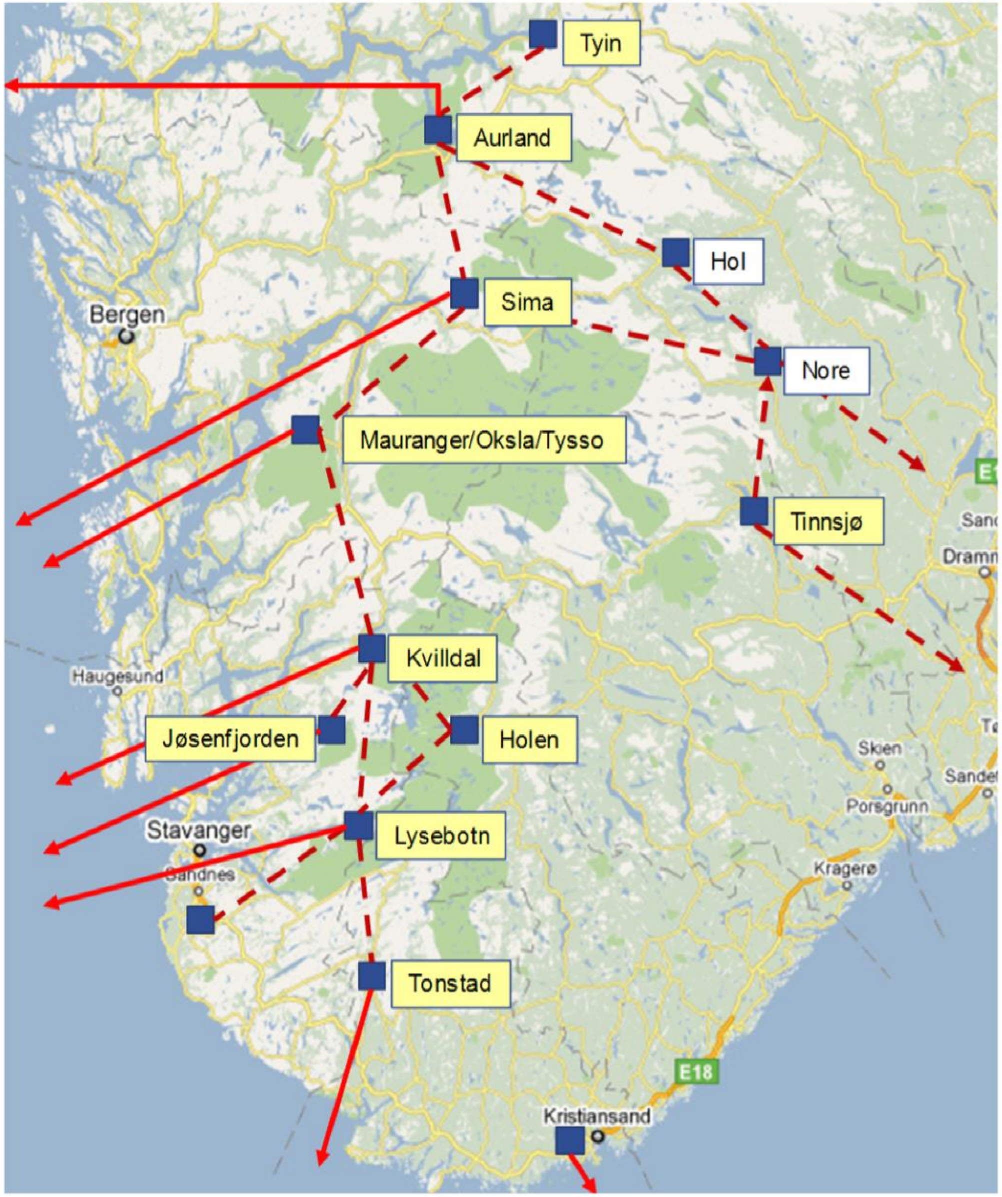
Julie Charmasson, Julian Sauterleute, Atle Harby, Ånund Killingtveit, Helene Egeland, Oddgeir Andersen, Audun Ruud, Øystein Aas

SINTEF Energy Research

Energy Systems

2013-06-30



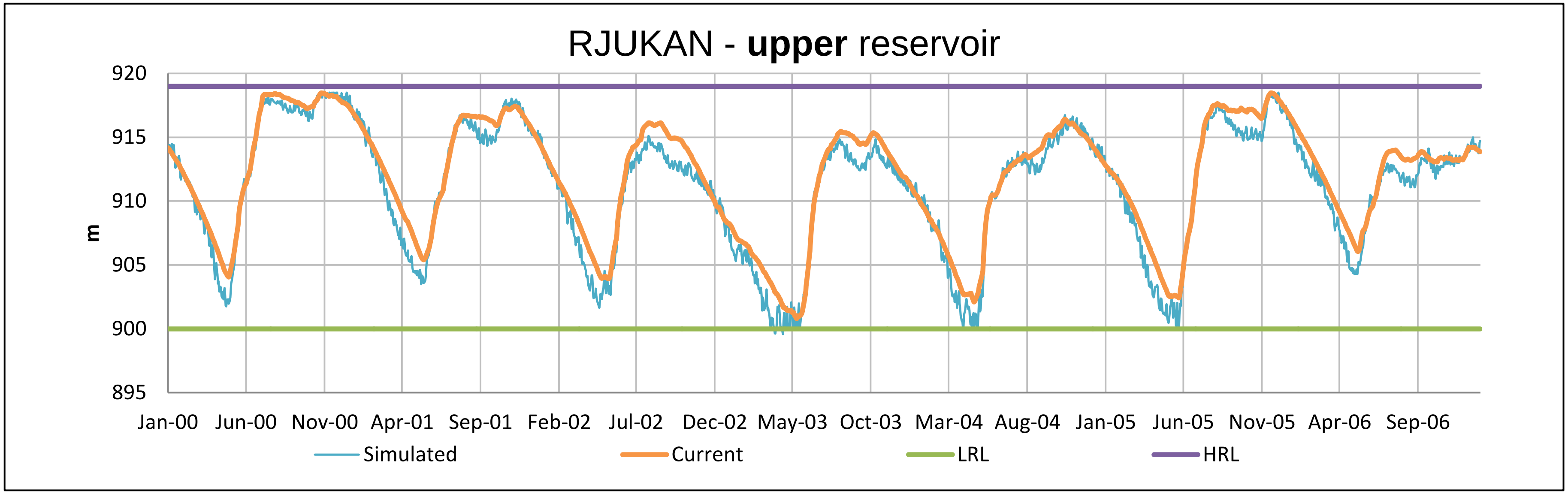
Case 1: Botsvatn - Vatnedalsvatn
Average Head 200 m
Max storage: 296 Mm3
Potential storage 150 GWh

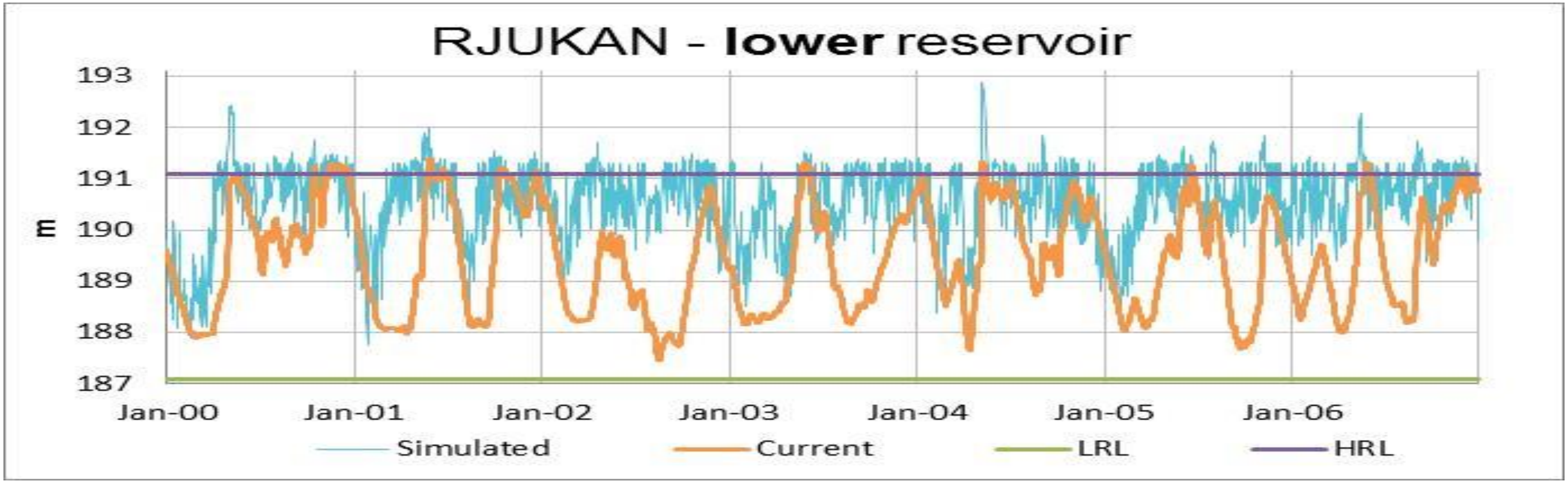
Upper reservoir:
Vatnedalsvatn
700 - 840 m.a.s.l
Volume: 1150 Mill m3

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

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

Simulating water level variations in existing hydro reservoirs





Environmental impacts in the reservoirs

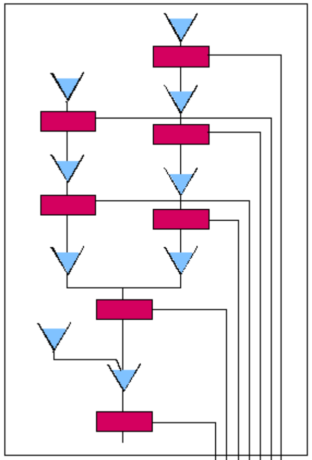
Ice on reservoirs – what about safety for wildlife and people?

Social and political acceptance?

Yes – Norway could become a “Green battery” for Europe

- **Norwegion hydropower reservoirs have enough unused storage capacity to give a significant contribution**
- **But - new peaking and PSP needs to be constructed – Exising capacity is not enough**
- **Balancing capacity > 20 000 MW is possible**
- **But many challenges remains:**
  - ✓ **Environmental/Social acceptance (NIMBY)**
  - ✓ **Market design (who will pay?)**
  - ✓ **Grid development is needed (lots of …)**

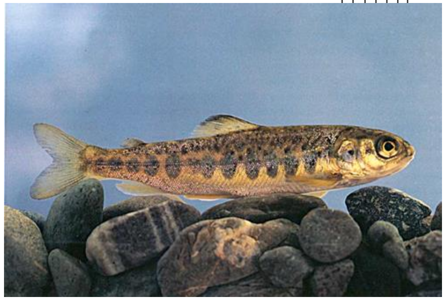
New project in CEDREN (2014): HydroBalance



WP 1:Roadmaps for balancing from Norwegian hydropower

WP 2:Demand for energy balancing storage

WP 3: Analyses to develop relevant business models



WP4: Environmental impact of operation schemes for balancing

WP 5: Social acceptance and regulatory framework

Finally – a few words about hydropower education

Hydropower has a bright future – Worldwide and also in Europe

Important also for supporting other renewables

We need people to build, operate, maintain and redesign the system

Existing and new knowledge needs to be transferred to next generation

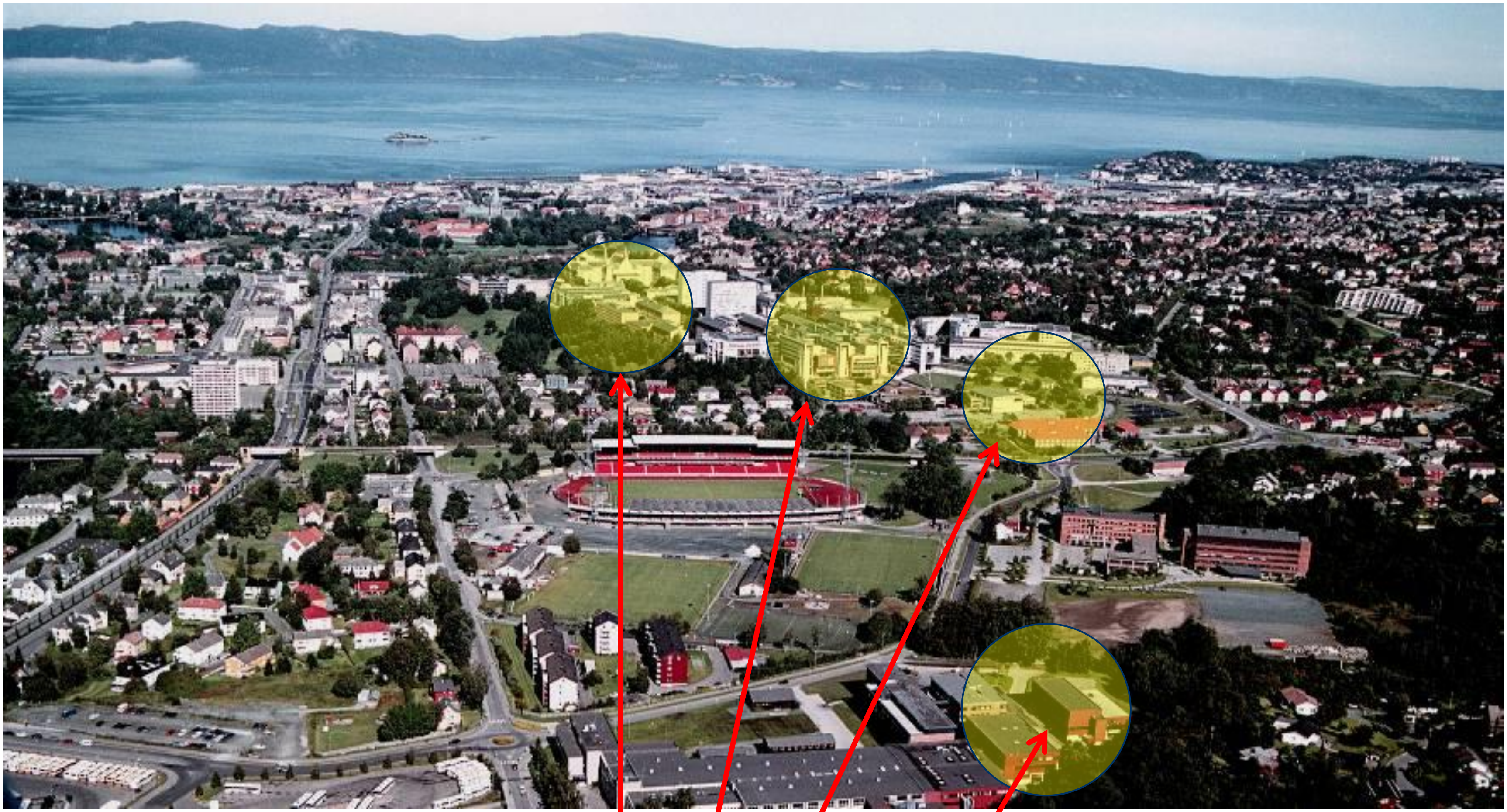
Do not forget education and training during periods of outsourcing

Research based education is very important in order to meet

New market demands,
new environmental regulations,
climate change …

A few slides about Hydropower education in Norway follows

Hydropower education at NTNU



Electrical Engineering
Mechanical Engineering

Civil/Hydraulic Engineering
Geology/geotechnology

MASTER OF SCIENCE IN HYDROPOWER DEVELOPMENT

WATER - ENVIRONMENT - ENERGY

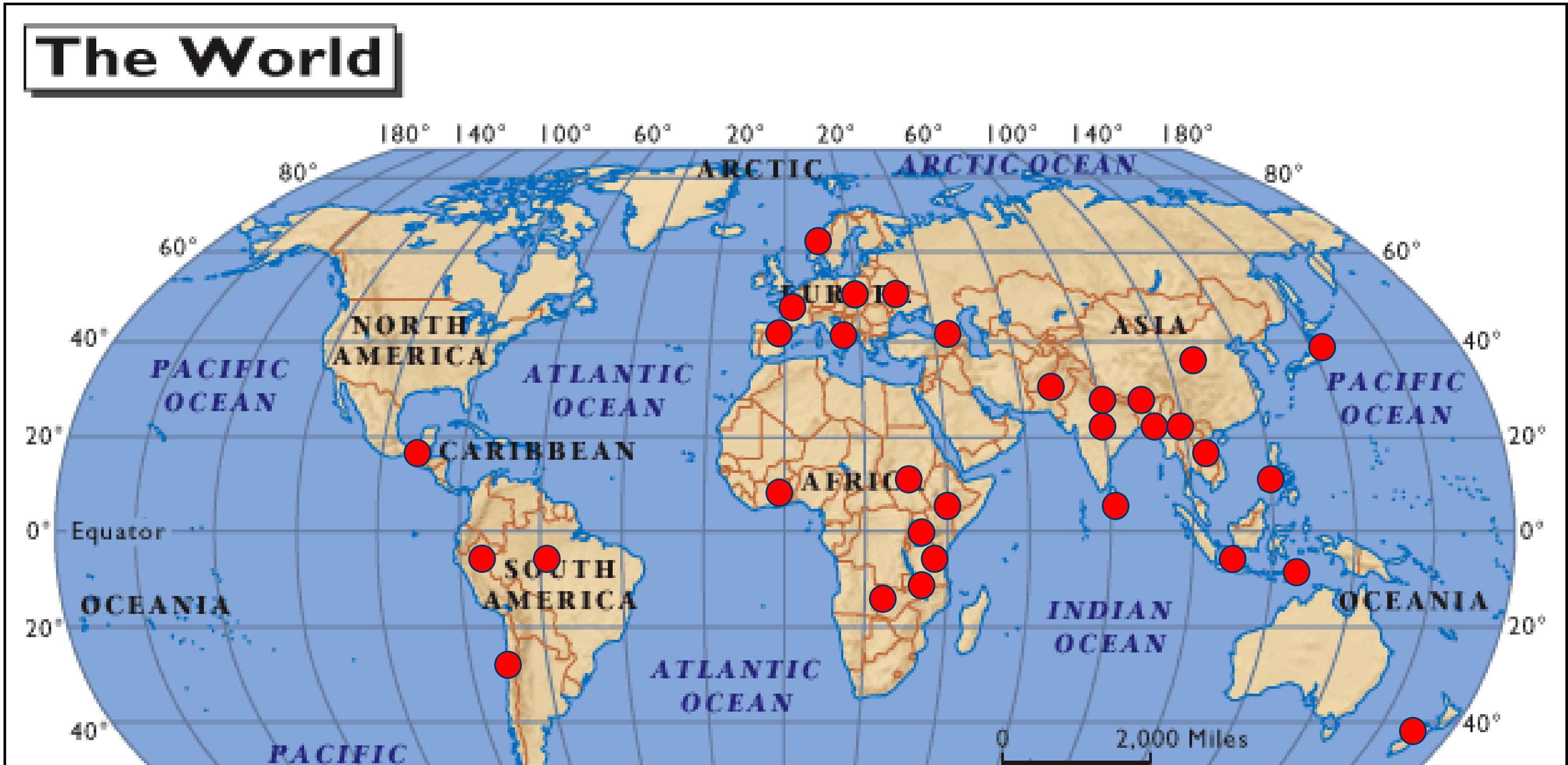
PROFESSOR ÅNUND KILLINGTVEIT

DEPARTMENT OF HYDRAULIC AND ENVIRONMENTAL ENGINEERING

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

NTNU

Where do the Hydropower Development MSc students come from?



In the 20 years from 1994 to 2014, over 300 students from 28 different countries have finished their 2 years MSc in the HPD program. Some of the countries are: Bangladesh, Bhutan, China, Costa Rica, Ethiopia, Ghana, India, Japan, Nepal, Pakistan, Phillipines, Sri Lanka, Sudan, Tanzania, Uganda, Vietnam, Zambia, Timor Leste, Malawi, Chile, Brazil, Italy, Armenia, Ukraine, New Zealand, Norway.

NTNU

The 17 volume book-series
HYDROPOWER DEVELOPMENT

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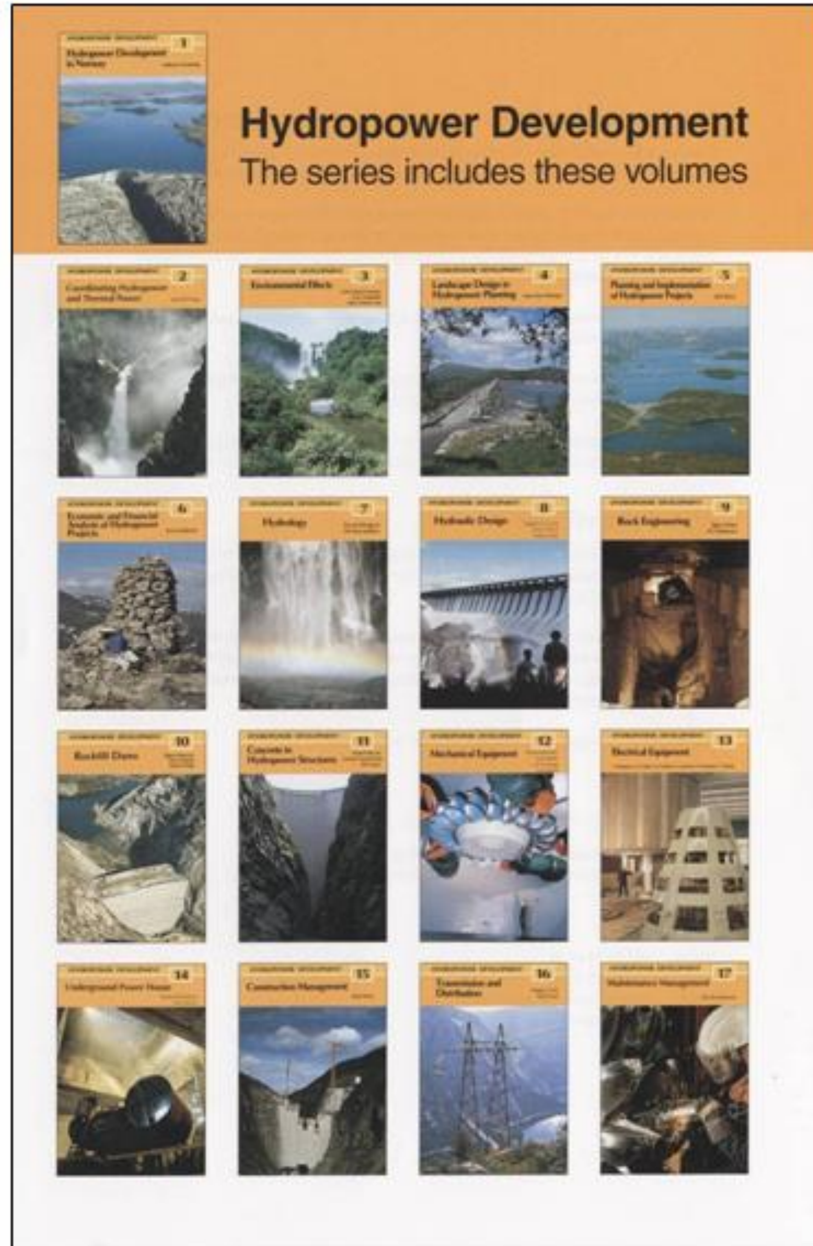
More than 10 years to complete

Basis for teaching hydropower planning and development

Published by Department of Hydraulic and Environmental Engineering at NTNU



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visit CEDREN at or our web-site

http://www.cedren.no/