     

Large scale balancing and storage from Norwegian hydro
HydroBalance project

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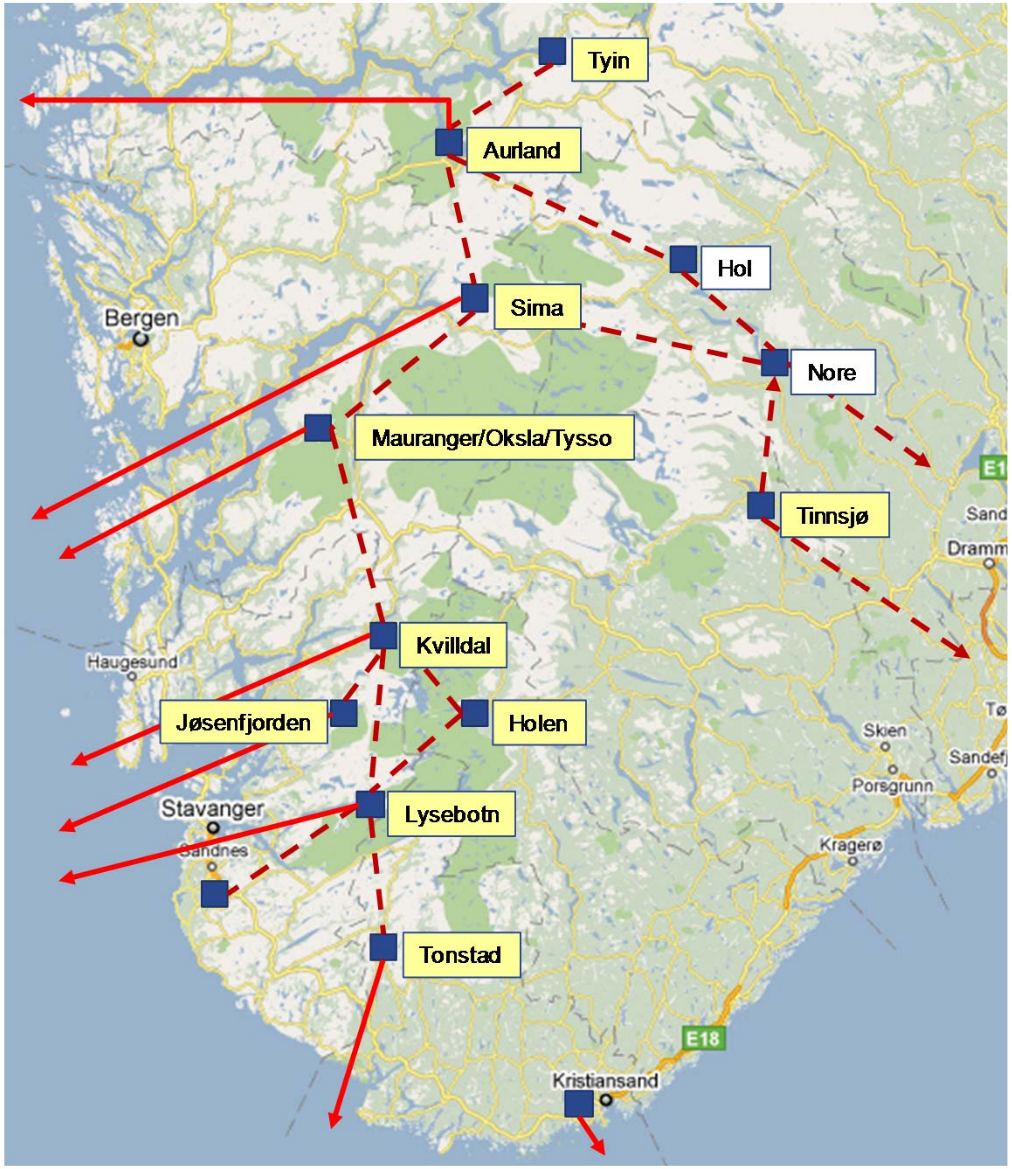
Centre for Environmental Design of Renewable Energy

FME

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH



2012, Eivind Solvang et al., Increasing balance power capacity in Norwegian hydroelectric power stations, SINTEF Report TR A7195

Case study 2030

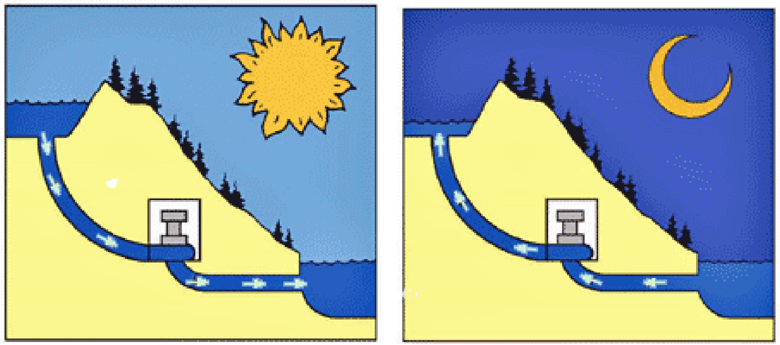
10-20 GW new pumping and generation capacity using existing reservoirs

Norwegian hydropower for balancing

- The reservoirs are **natural** lakes
  - Multi-year reservoirs
  - Total **84 TWh** reservoir capacity
  - Largest lake stores 8 TWh

- Balancing capacity estimates 2030
  - **29 GW installed at present**
  - **30 GW total new capacity** (+10 GW upgrading + 20 GW pump storage)

    Within todays environmental limits
  - Requires more transmission capacity



1. CEDREN HydroBalance: Facts

Feasibility of **large scale** development of energy **balancing and storage** from **Norwegian** hydropower in the **future European** electricity market with respect to the **power system**, **environmental** aspects, **economic** viability and **social acceptance**.

WP 2
Demand for energy balancing storage

WP4
Environmental impact of operation schemes for balancing

WP 1
Roadmaps for balancing from Norwegian hydropower

WP 3
Analyses to develop relevant business models

WP 5
Social acceptance and regulatory framework

WP1. Scenario building methodology

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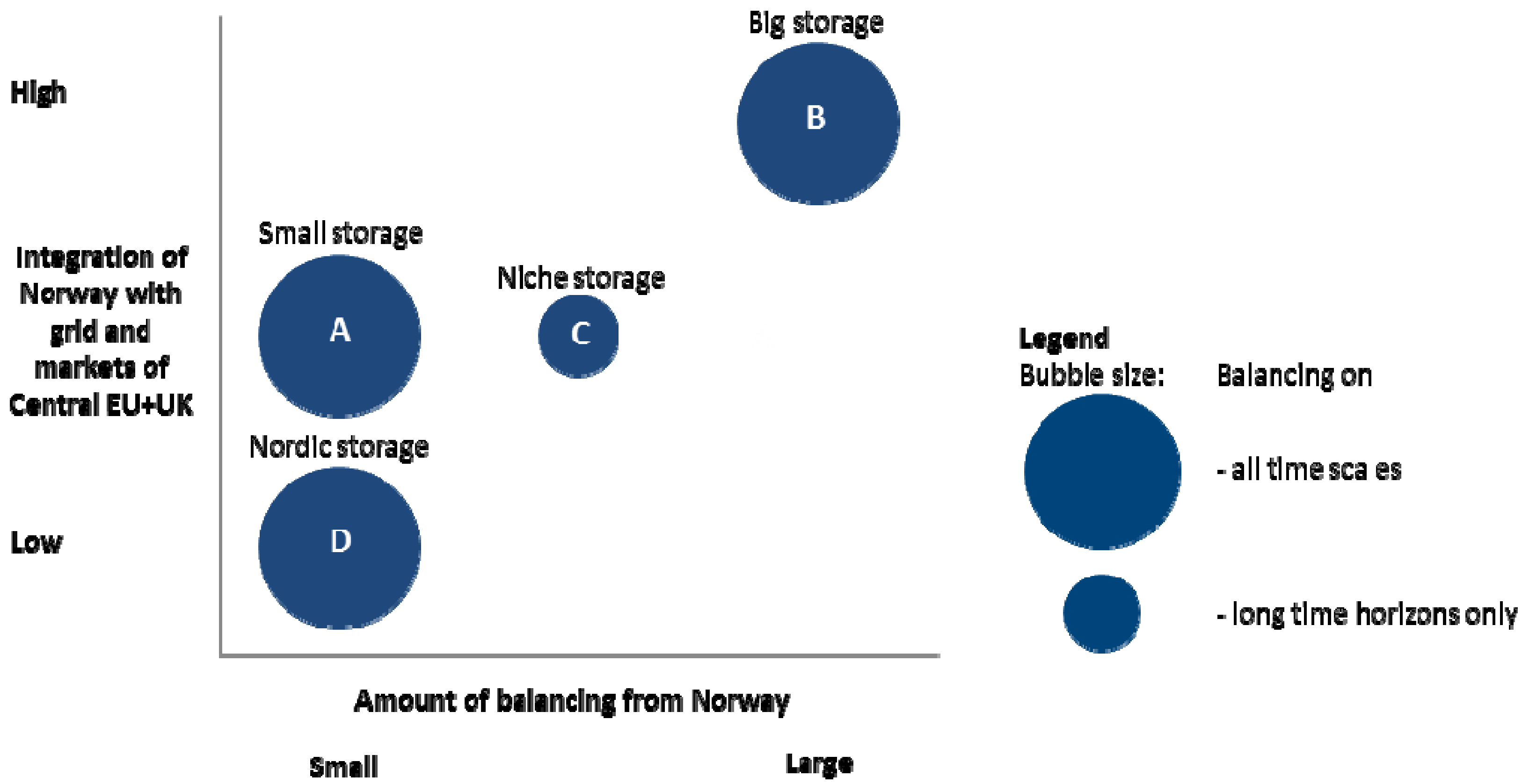
WP 1

Roadmaps for balancing from Norwegian hydropower

Scenarios development

WP1. Scenario building methodology

Scenarios

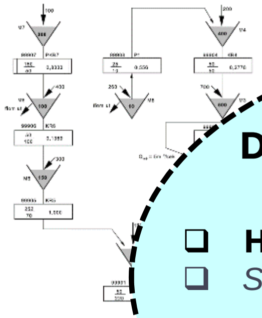


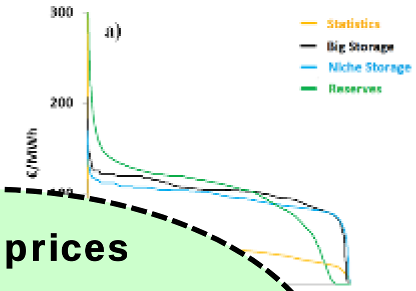
2015, Sauteuleute et al., Scenarios for large scale balancing and storage from Norwegian hydro

WP3. Central research questions

WP 3
Analyses to develop relevant business models

WP3. Overview of work





Develop methodology

- **Hydropower optimization**
- *SINTEF's optimization tools for hydropower*
- **With several markets**

Forecast prices

- **HydroBalance scenario**
- **2050**
- **Several markets**

Case-study

- Real river system
- Relevant **pumped-storage project**

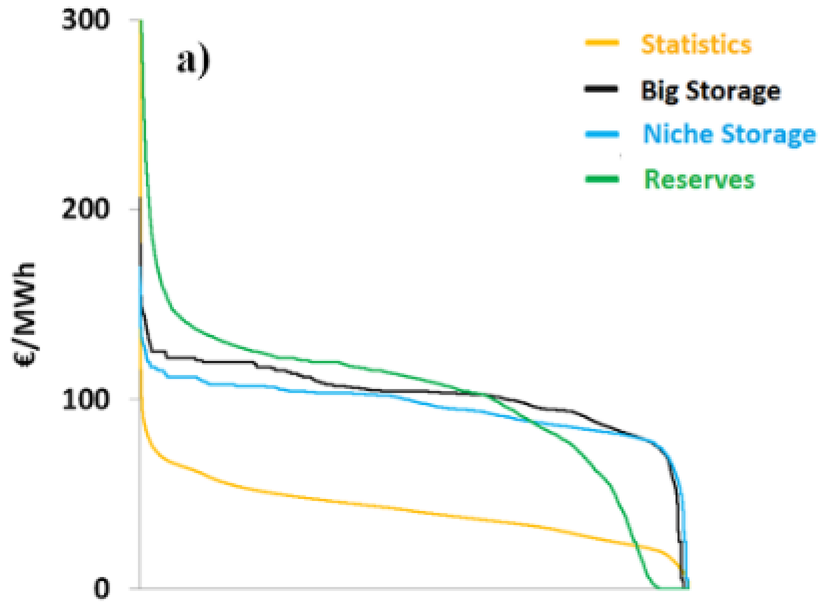
WP3. Overview of work

Scenario and prices simulation

- Statistics
- Big Storage
- Niche Storage

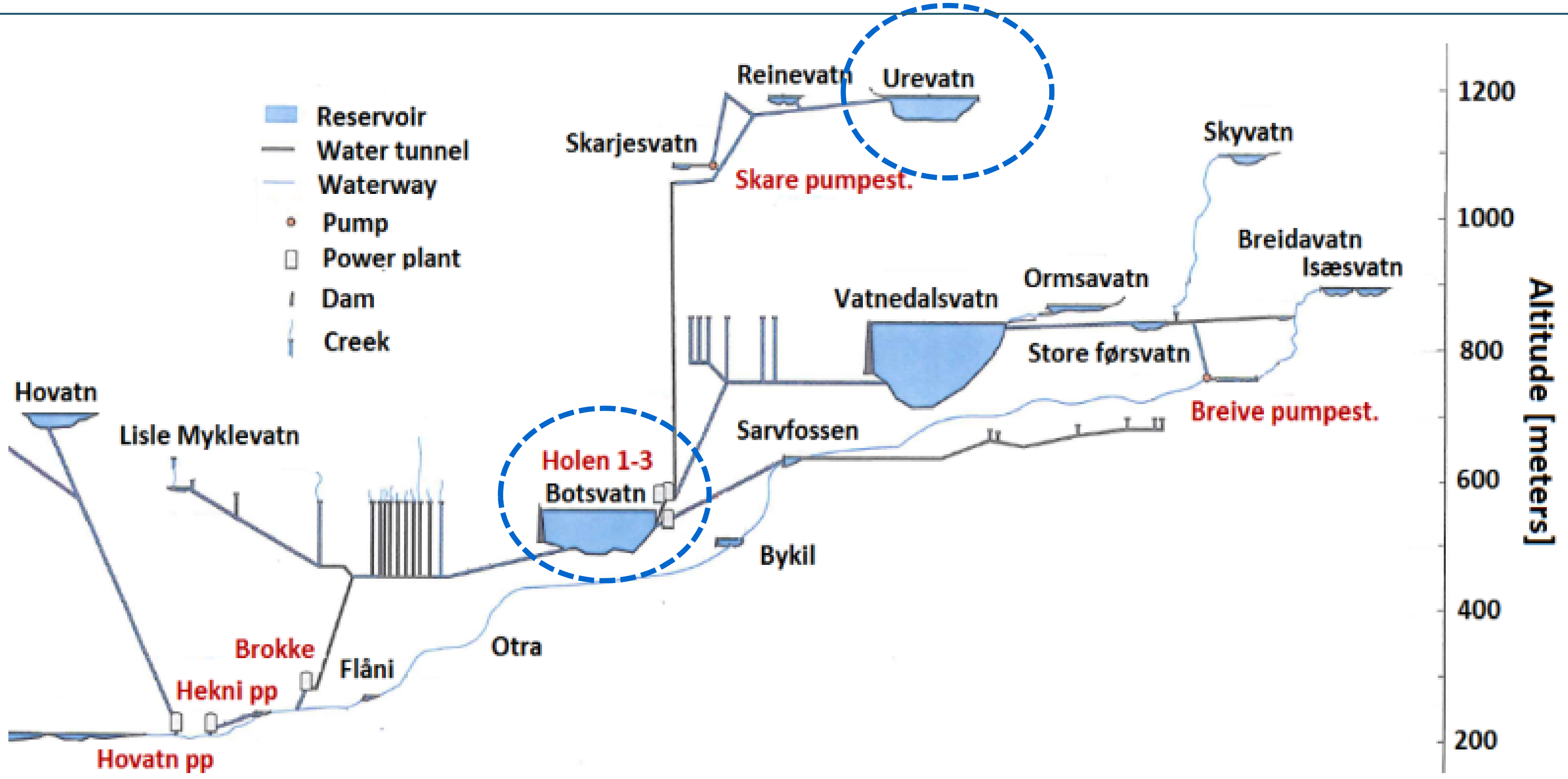
} Supply only for day-ahead market

- Multi-market — day-ahead + RR activation



→ **All scenarios: With and without investment in additional pump**

WP3. Case-study: Pumped storage investment



- 1000 MW: extra generation capacity and pump
- Reservoirs: 15 days to empty/fill
- Total efficiency (pump x generation): 72.2 % (conservative, cf. Ibrahim 2007)
- Estimated total costs: 416 M € (Henden, 2014)

WP3. Case-study: Economic results (in M € per year)

	Day-ahead only (Climate years 2007-2011)			German prices (Climate year 2008)	
	Statistics	Niche Storage	Big Storage	DA only	Multi-market
Average yearly income	205	474	517	654	669
Additional operating profits	9	23	30	133	161
Investment cost *)	-24	-24	-24	-24	-24
Investment profits *)	-15	-2	5	109	137
Break even interest rate	-0,5 %	4,5 %	6,6 %	31,1 %	38,8%

*) With 5 % annual interest rate

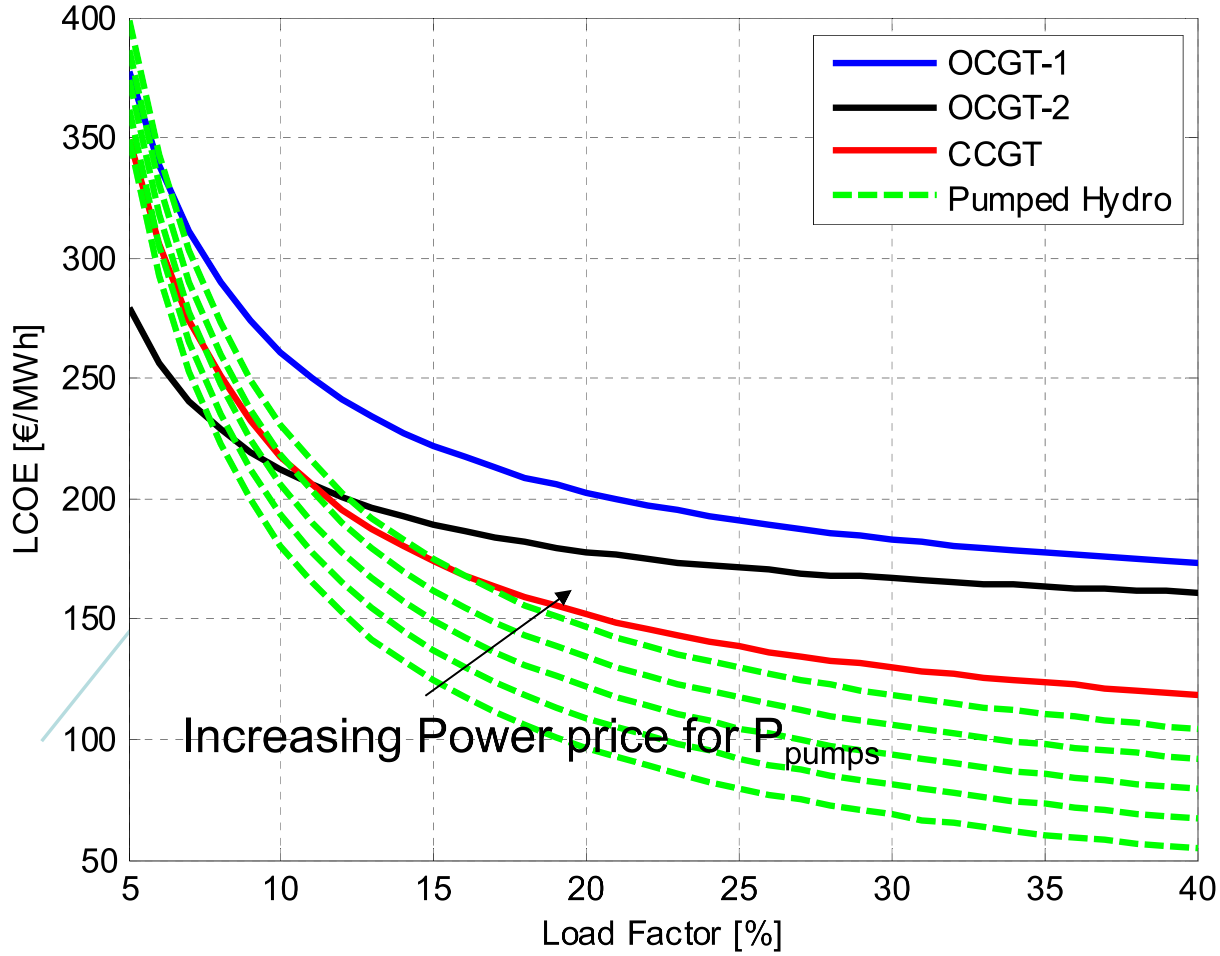
2. Levelised Cost of Electricity (LCOE)

WP 2
Demand for energy balancing storage

2. Levelised Cost of Electricity (LCOE)

Norwegian pumped hydro has a **relatively low LCOE** …

even when grid and cable costs are included



2. Levelised Cost of Electricity (LCOE)

Levelised Cost of Peak Generation (LCPG)

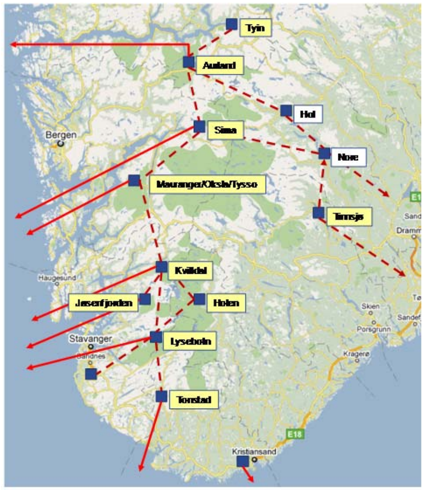
- New metric for **the cost of providing electricity when fluctuating renewables and inflexible thermal generation cannot meet the (fixed) demand**
  - Peak generation must cover the residual load
  - it's no longer the load itself that determines the need for peaking power but the residual load

Natural gas: $$LCPG_{ng} = \frac{i_{ng} \cdot (\delta_{n_{ng},r} + OM_{ng}) - p_{cap}}{\alpha_{ng} \cdot T_{ng}} + \frac{\left(p_{ng} + p_{CO_2} \cdot e_{ng}\right)}{\eta_{ng}}$$

2. Levelised Cost of Electricity (LCOE)

Conclusion so far..

Interconnectors *must be given full access to all markets, including capacity markets, for utilization of the most economical viable sources of storage and flexible power in Europe*



2. Levelised Cost of Electricity (LCOE)

Analysis of Cost of flexibility

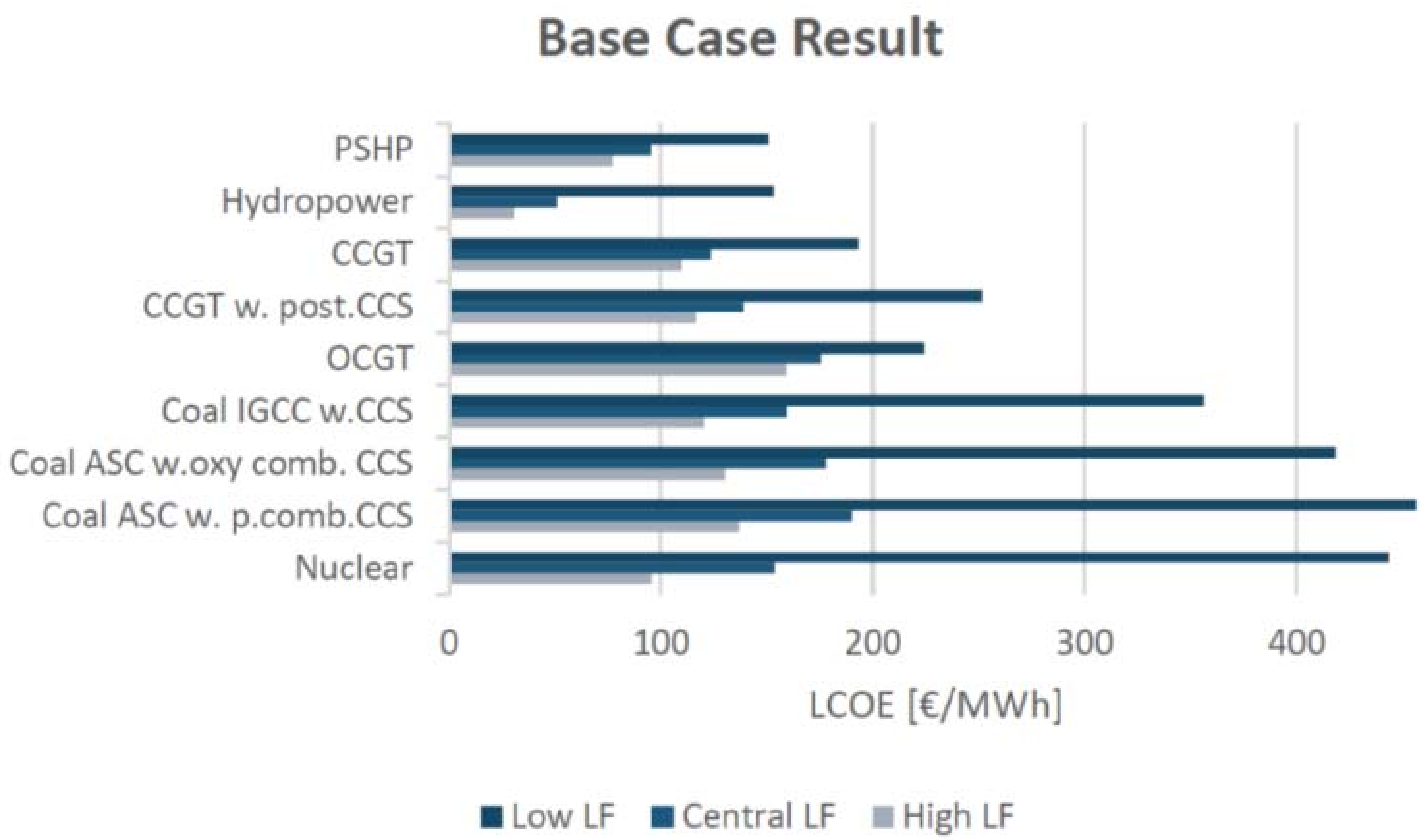
- Levelized cost of electricity (**LCOE**) study
  - Comparison of **competiveness** of several different generating technologies (cost, performance and ability for flexibility)
  - Development of a **method for general use** with simple clear metrics based on up-to-date information and future scenarios from reliable sources.

- **Technologies:**
  - PHS,
  - Conventional hydro,
  - CCGT, OCGT with/without CCS
  - Coal power plants with/without CCS
  - Nuclear

- Main sources: IEA, DECC, EIA, NVE

2. Levelised Cost of Electricity (LCOE)

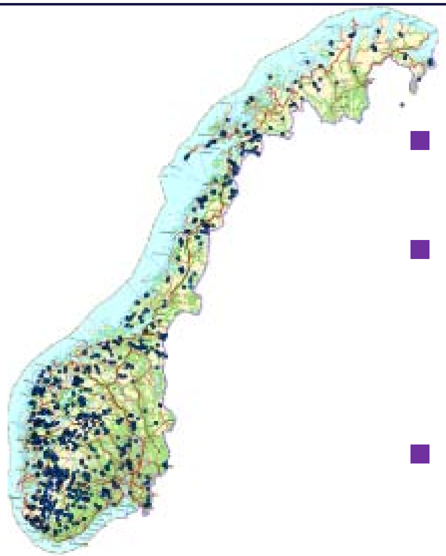
Analysis of Cost of flexibility



WP4. Future energy demand and water level fluctuations

WP4
Environmental impact of operation schemes for balancing

WP4 focuses on HP reservoirs



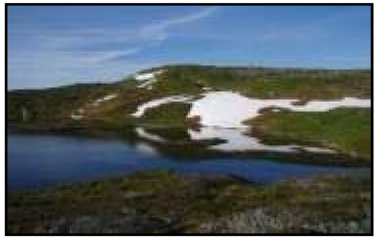
- Most of studies in rivers
- > 900 reservoirs (lakes) in Norway

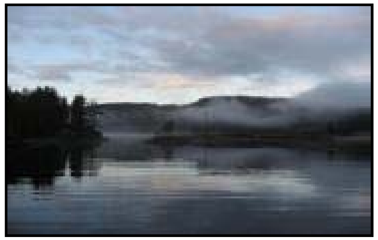
  Also used as recreational area

- **Environmental impacts of new operational regimes in reservoirs**

- **Abiotic consequences**
  - Water temperature
  - Stratification period/duration/intensity
  - Ice cover thickness/period/duration…
  - Water quality

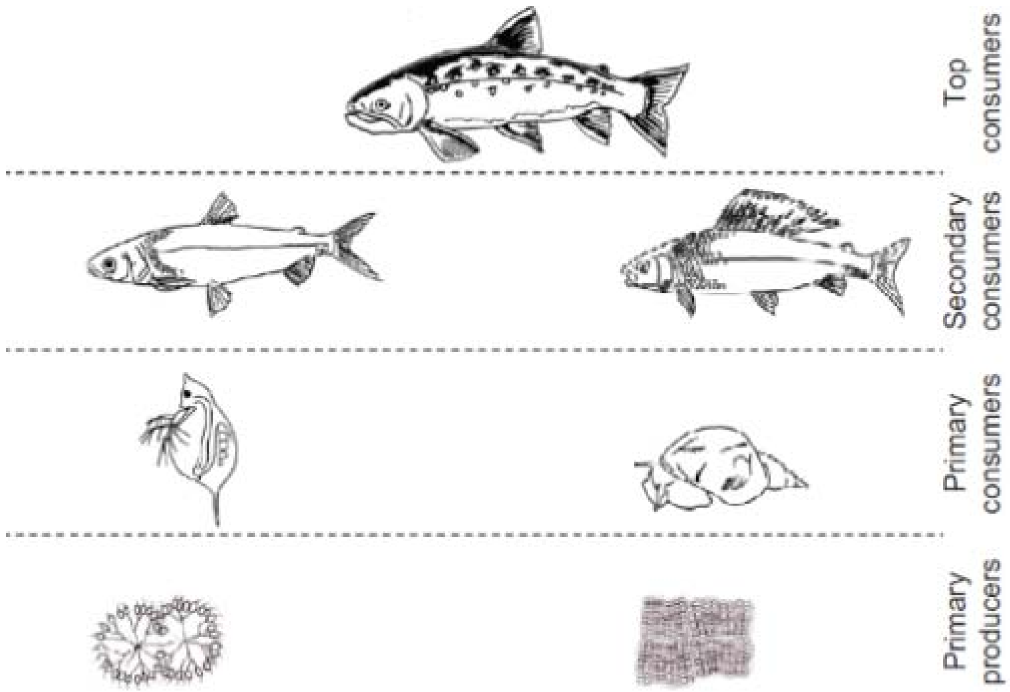
- **Biotic consequences**
  - Biological productivity
  - Species composition
  - Fish diet
  - Growth and reproduction…





WP4. Focus on fish

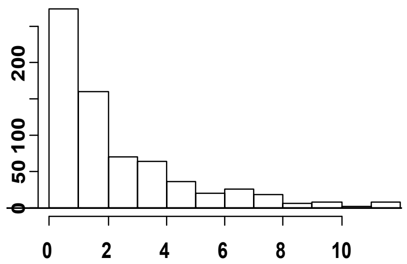
Fish as **top predator** : bio-indicator for **ecological status**



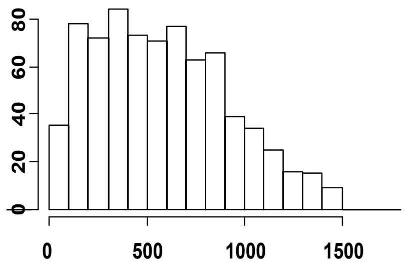
WP4. How to separate effects from **hydropower** from **natural** variation?

Lake morphology

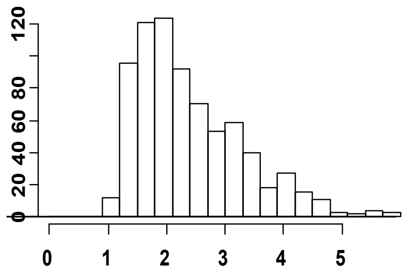
Area



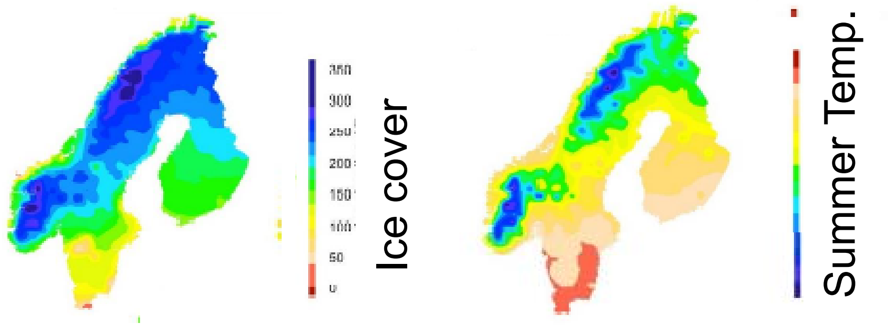
Altitude



Shape

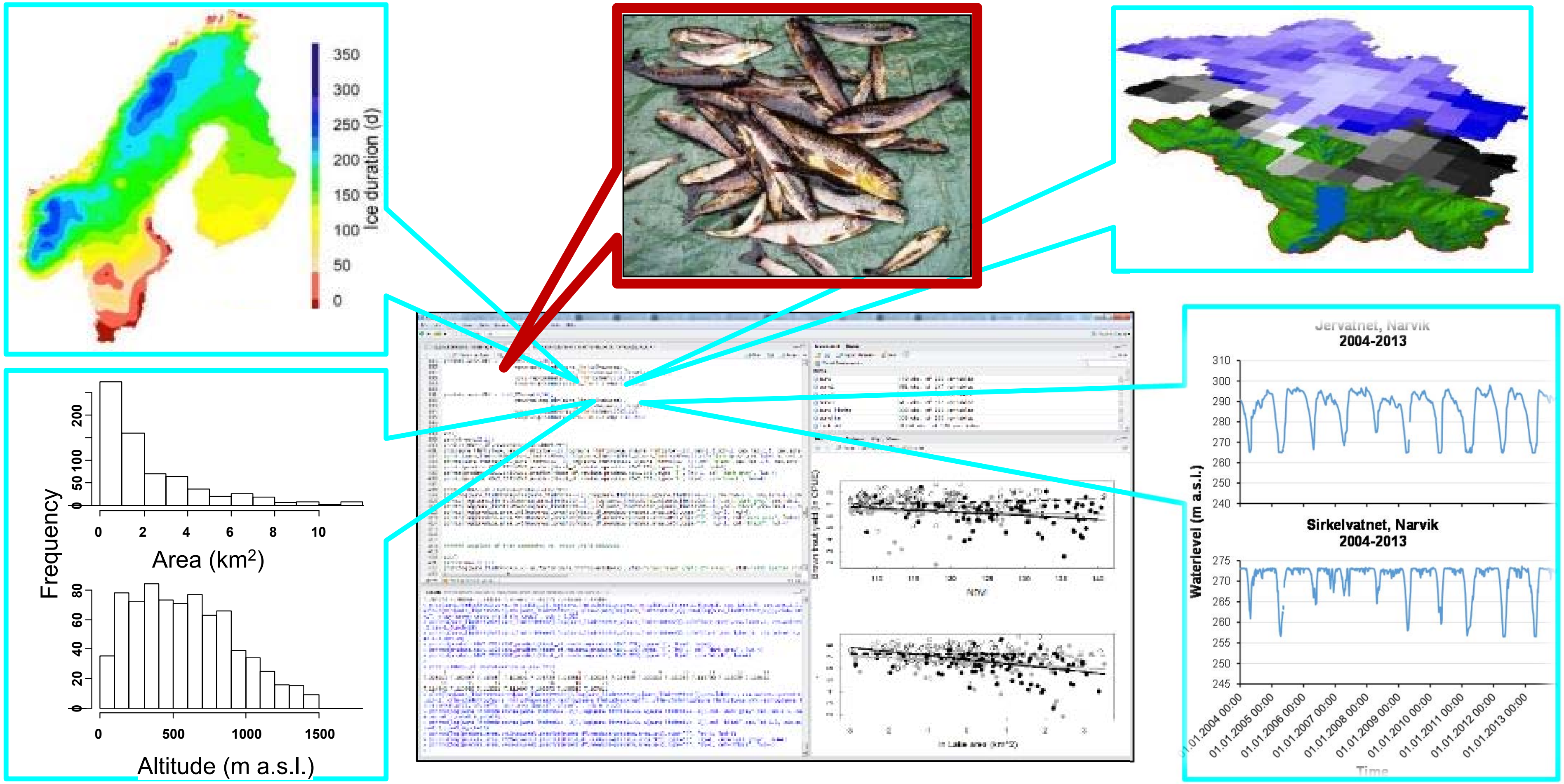


Climate



Fish growth

WP4. Data collection and Statistical analysis and modelling of interactions

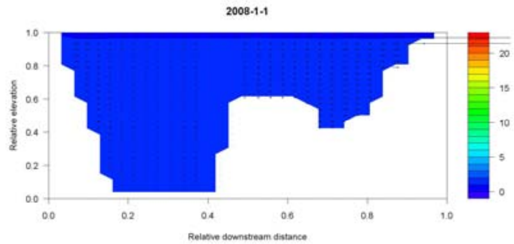


3. Modelling hydro-dynamics consequences from new operational regimes

1. 2D **hydrodynamic modelling** reservoir

   → water temperature and stratification characteristics

   → Ice cover period-thickness-duration



2. For a large range of synthetic cases
   - Regulated amplitude
   - Area
   - Mean depth
   - Climate region

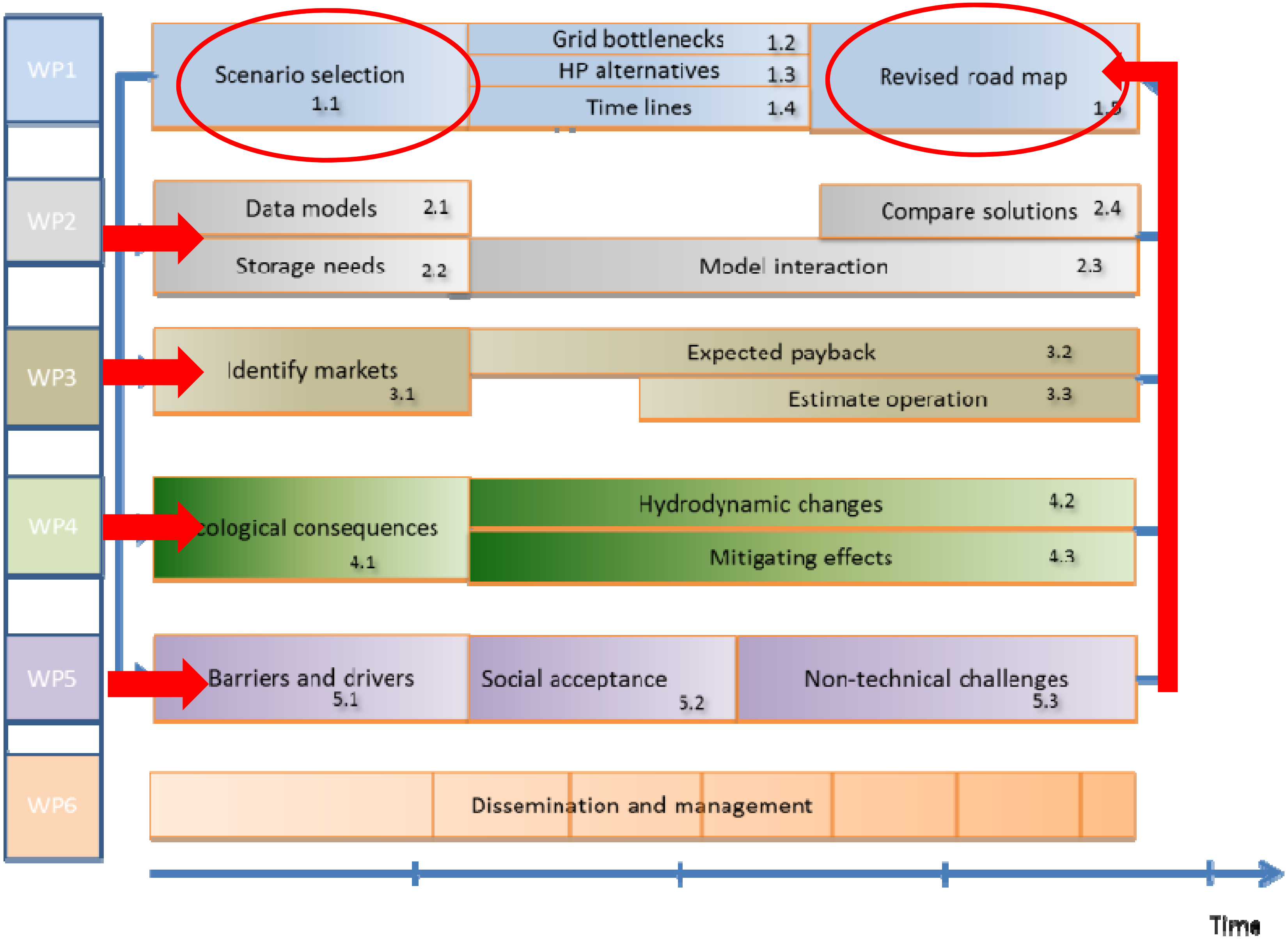
3. Run simulations of future operational regimes
   - (present regime)
   - Big Storage
   - Niche Storage

WP 5: Research questions

WP 5
Social acceptance and regulatory framework

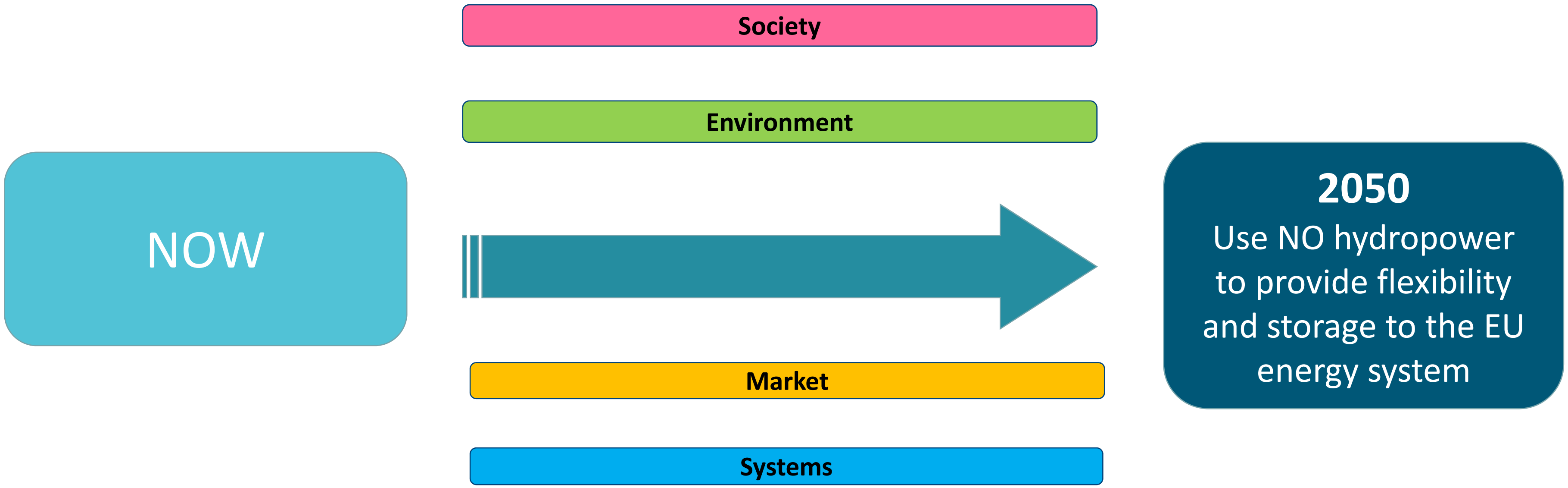
WP 5: Results from interviews

	Drivers	Barriers
National level	• Hydropower **reservoirs**	• **Environmental consequences** due to new operational regimes
	• **EU**'s climate ambitions • **Demand** for balancing services	• **Uncertainties** about both development of an integrated energy system and demand for Norwegian balacing power
	• **Cables** to EU • **Export/import** possibilities	• Cables ownership • **Profitatability** • Electricity prices
		• **Grid** capacity and flexibility
Local level	• Early **involvement** • **Information** • Identification of local inconveniences consequences	• **Visual** impacts (low water level), • **Environmental** impacts • **Economic** impacts (electricity prices)
	• **Compensation measures:** Investmenst in loca l infrastructrures (roads, internet access,…)	• Consequences for **local infrastrutures** (unstable ice and passage, quay and boat traffic)
	• **Compensation measures**: Electronic warning system	• **Security issues** related to reservoir and ice cover


WP1
Scenario selection
1.1
Grid bottlenecks 1.2
HP alternatives 1.3
Time lines 1.4
Revised road map
1.5
WP2
Data models 2.1
Storage needs 2.2
Model interaction 2.3
Compare solutions 2.4
WP3
Identify markets
3.1
Expected payback 3.2
Estimate operation 3.3
WP4
Ecological consequences
4.1
Hydrodynamic changes 4.2
Mitigating effects 4.3
WP5
Barriers and drivers
5.1
Social acceptance
5.2
Non-technical challenges
5.3
WP6
Dissemination and management
Time

Roadmap

- Detailed plan to guide progress from a defined starting point towards a goal



Thank you for your attention!

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