Impact of climate change on the power sector

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Overview

- Energy systems analysis
  - Methodology
  - Tools
  - Models
- Project example
  - Modelling the effects of climate change on the energy system

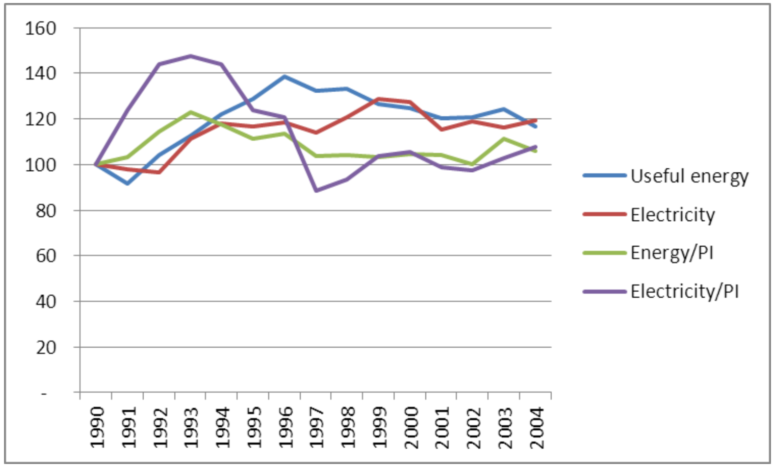
Energy system analysis at IFE

Analyse connections:

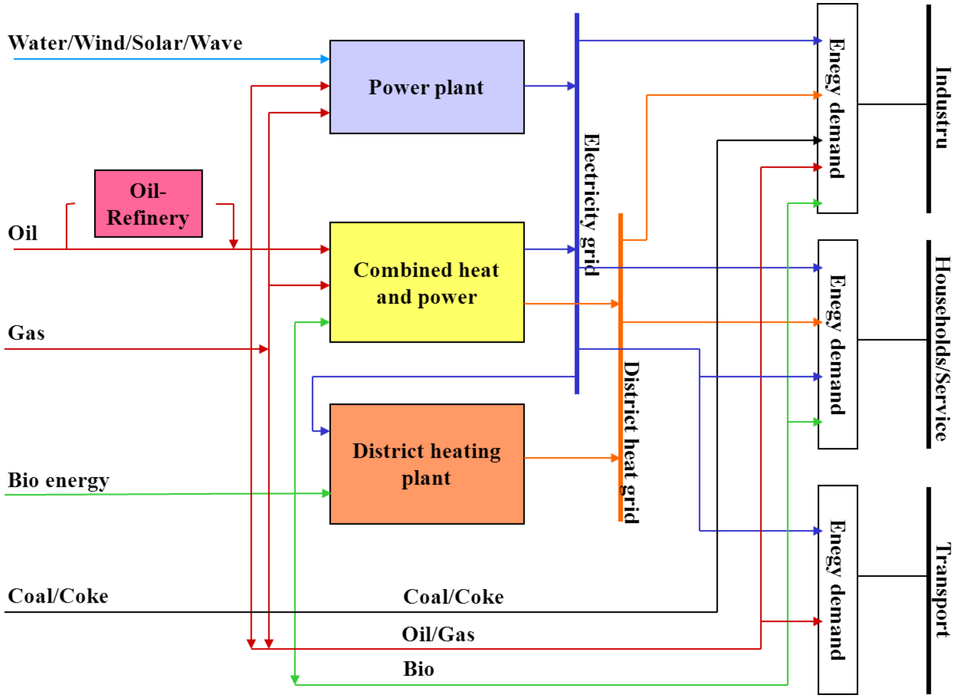
- Energy resources, conversion, transfer and demand of energy services
- Economic development
- Policies and measures
- Development of the energy system in order to satisfy future demand
- Competition between different energy carriers and technologies
- Scenario analysis

Overall studies and analysis (1 / 2)

1. Historical development of energy demand



2. Description of the present energy system

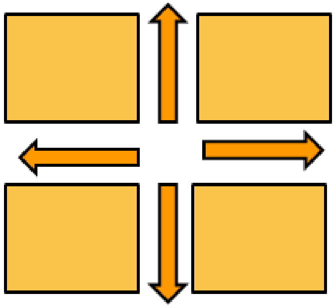


Overall studies and analysis (2 /2)

3. Analysis of future energy demand and development in technologies

4. Models balancing supply and demand

5. Scenario development, energy policy and measures

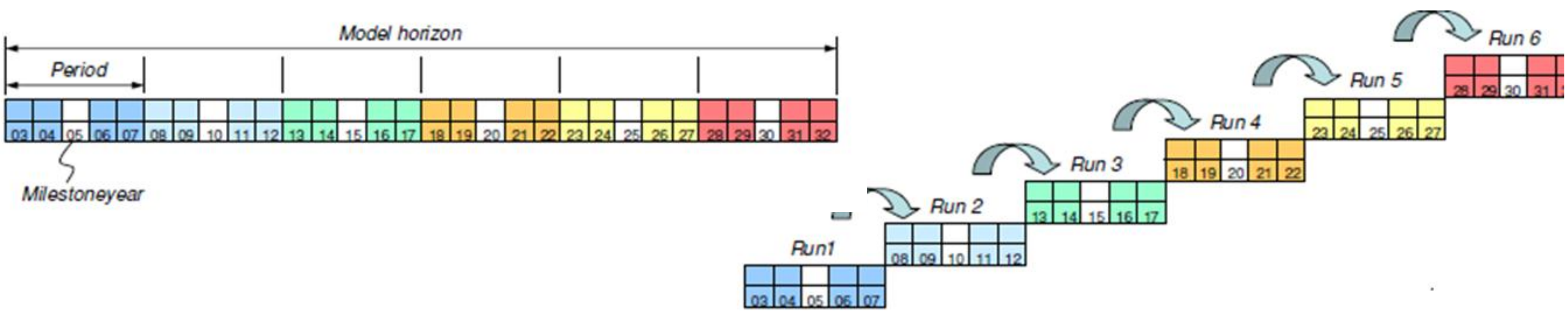


Energy system tools
MARKAL / TIMES

- TIMES is a model generator for local, national or multi-regional energy systems
- Usually applied to the analysis of the entire energy sector
  - Can also be applied to study single sectors
- The TIMES model aims to supply energy services at minimum global cost
- The scope of the model extends beyond purely energy oriented issues
  - E.g. representation of environmental emissions and material flows
- TIMES is well suited to analyse different energy-environmental policies

MARKAL/TIMES

- Developed by the ETSAP, an implementing agreement of IEA
  - Used by individuals and teams in nearly 70 countries
- Mostly used for intermediate and long term analyses (2020 - 2100)
- Implemented in GAMS
  - Solvers: CPLEX, XPRESS
- Assumptions
  - Perfect foresight (can also be run in time-stepped fashion)



Main equations

Input data

Cost data
Efficiencies
Resources
Full load hours
Loading curves
Emission factors
Demand
…
…

Objective function:	Minimise discounted system costs Min $f(x)$
Model equations:	s.t. $g(x) \leq 0$ $h(x) = 0$ Transformation relationship Energy balances Emission balances Capacity constraints Activity constraints Cumulated constraints over time Peaking constraints Load curve equations Storage equations Scenario specific constraints

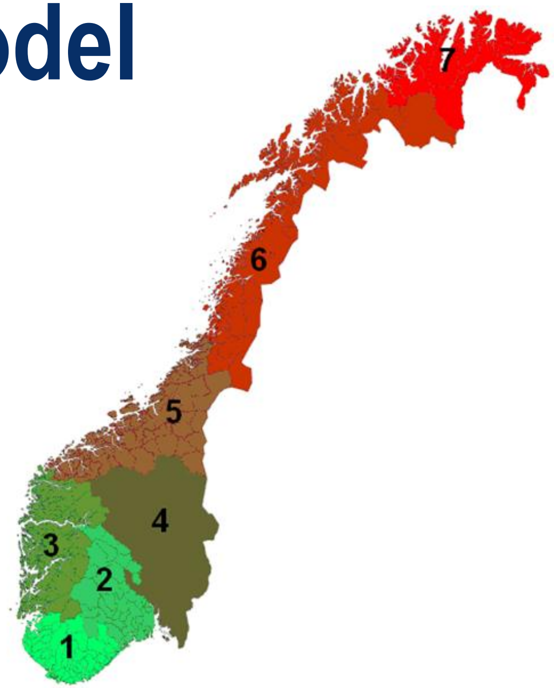
Decision variables

Process activities
Energy flows
Emission flows
New capacities
Fundamental prices
…
…

Energy system models at IFE

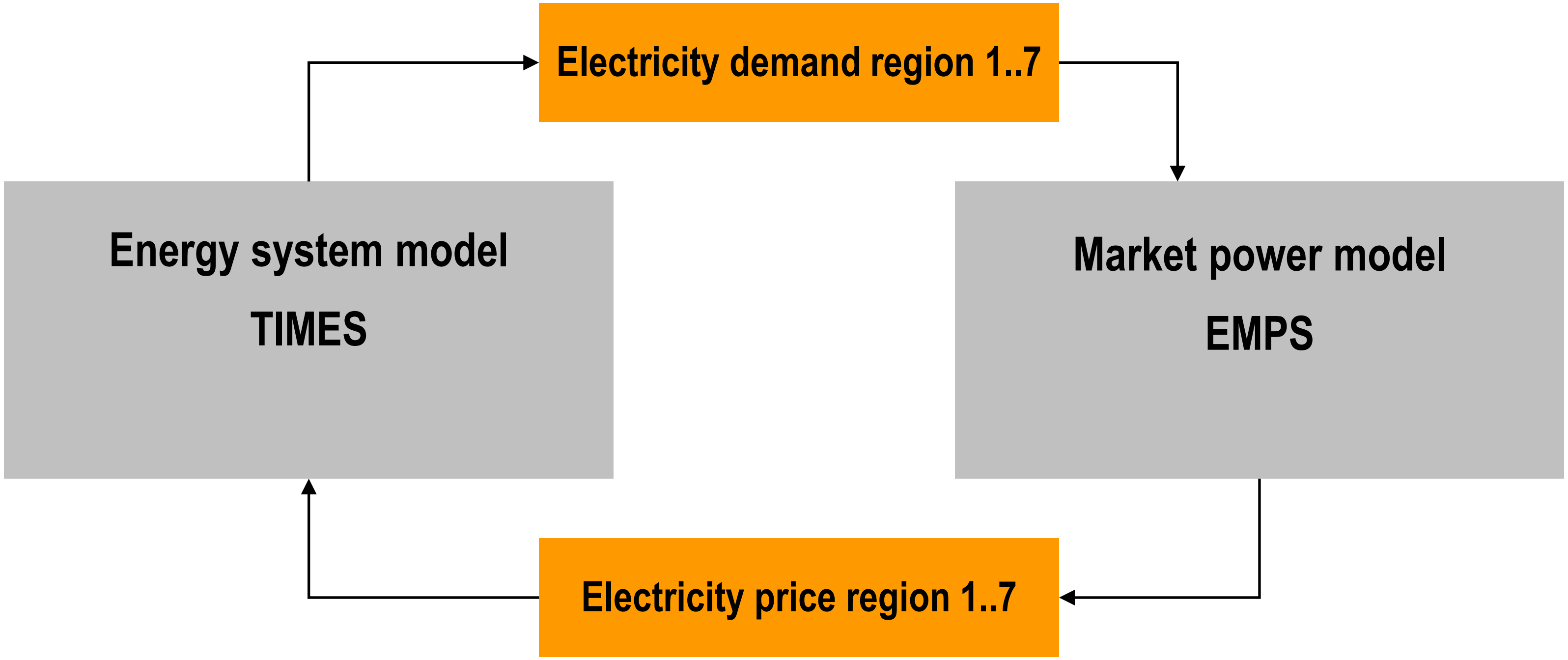
- Regional models:
  - Regional MARKAL models for several counties: Oslo, Rogaland, Telemark and Møre og Romsdal (2005 - 2050)
- National models:
  - One region MARKAL model (2005 - 2050)
  - 7 regional TIMES model (2005 - 2050)
- Global model:
  - 15 regional TIMES model ETSAP-TIAM (2000 - 2100)
- North European model (in progress):
  - Covering all Nordic and North European countries (2005 – 2100)
  - Based on the 7 regional Norwegian TIMES model
  - Improved modelling of intermittent energy sources
  - Analyse: Norway in a North European context

National TIMES model (2005 -2050)

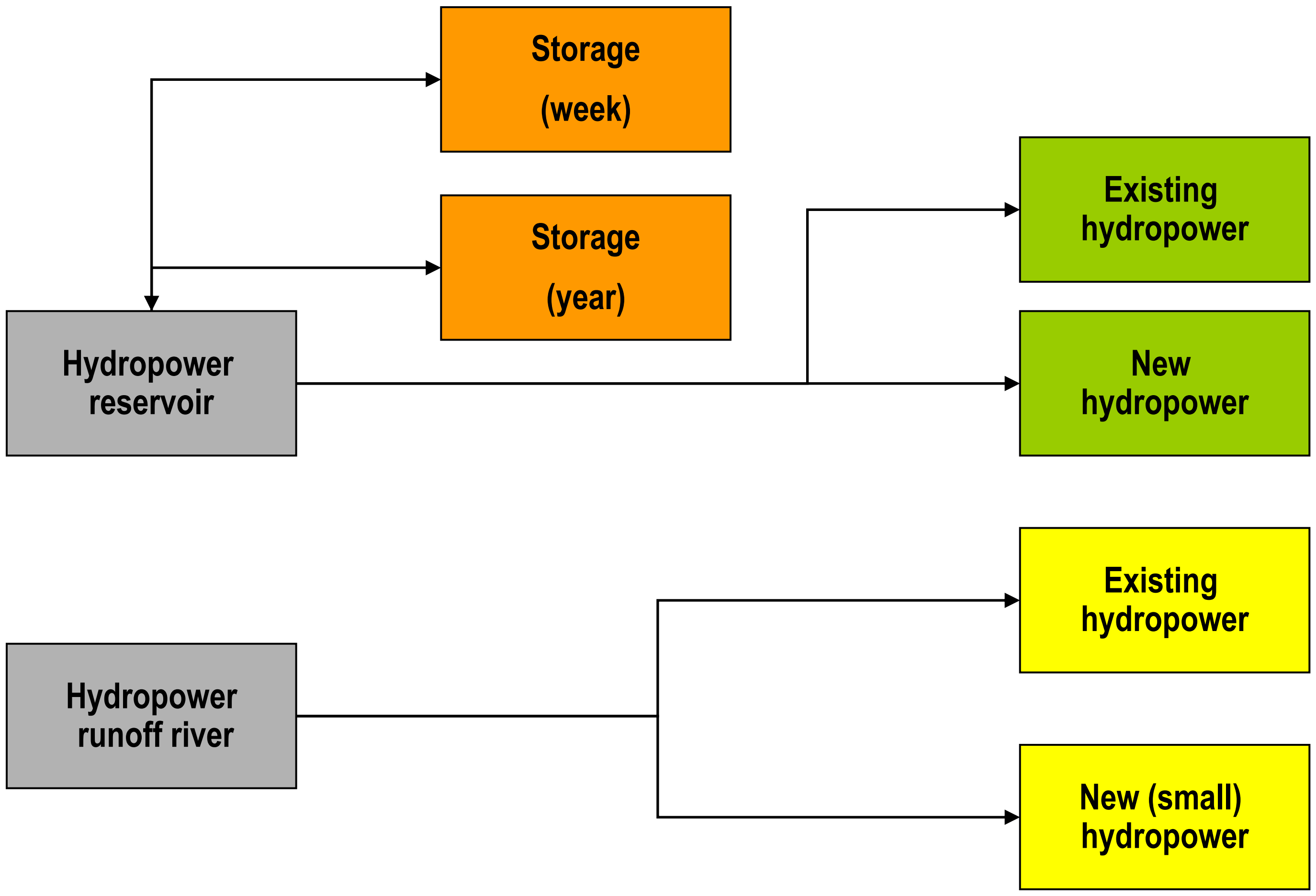


- Norway is divided into seven regions
- Demand categories in each region
  - Agriculture (3)
  - Commercial (21)
  - Industry (33 – 36)
  - Residential (10)
  - Transport (8)
- High time resolution (260 per year)
  - Better representation of intermittent power, storage, and trade
- Suitable for intermediate analysis (2020) and long term analysis (2050)
- Exchange of electricity between regions
- Can be linked with EMPS (Samkjøringsmodellen)

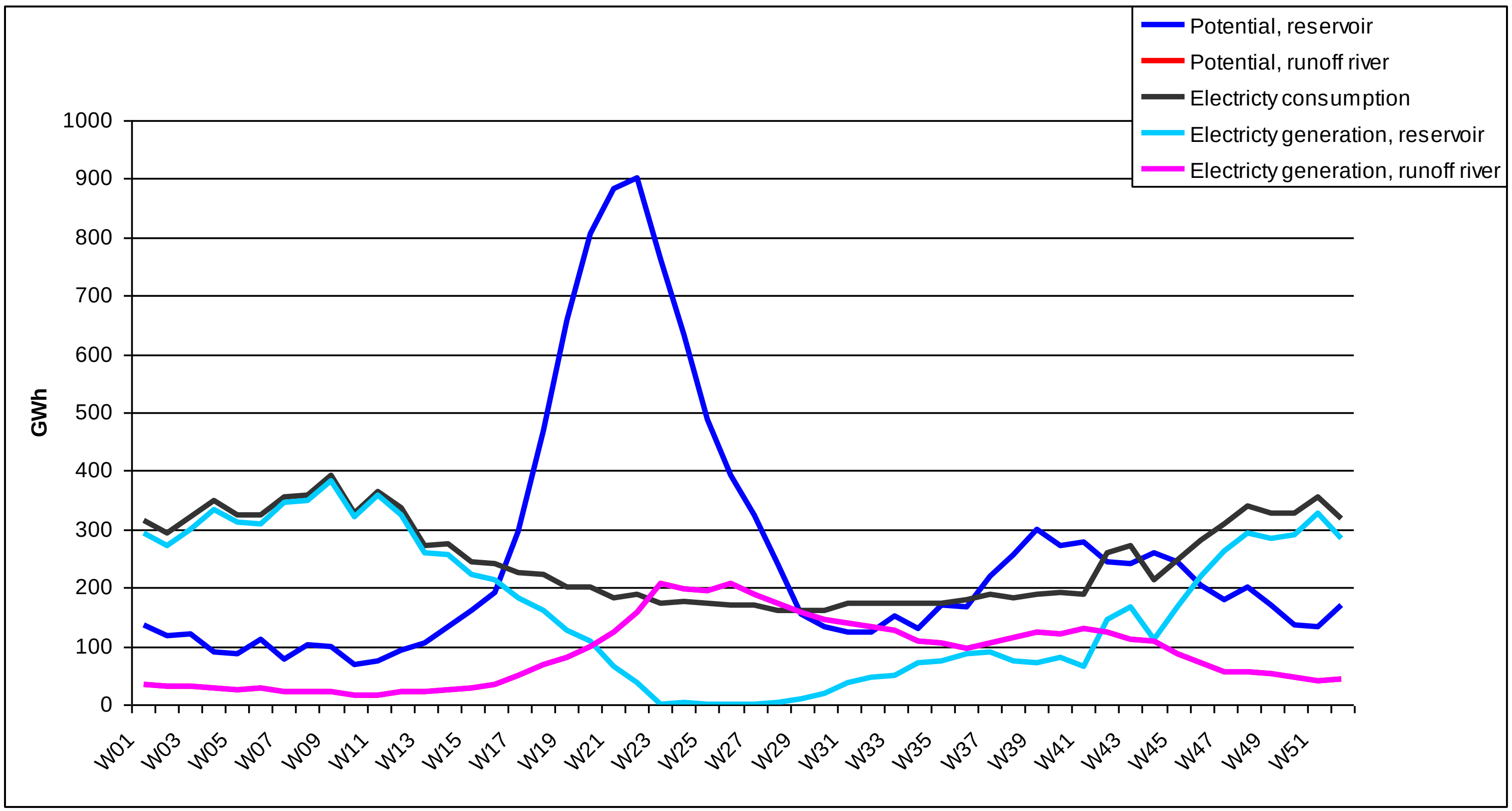
Interaction between TIMES and EMPS model



Modelling hydropower



Hydropower modelling
(Example region 1)



Load profiles- structure

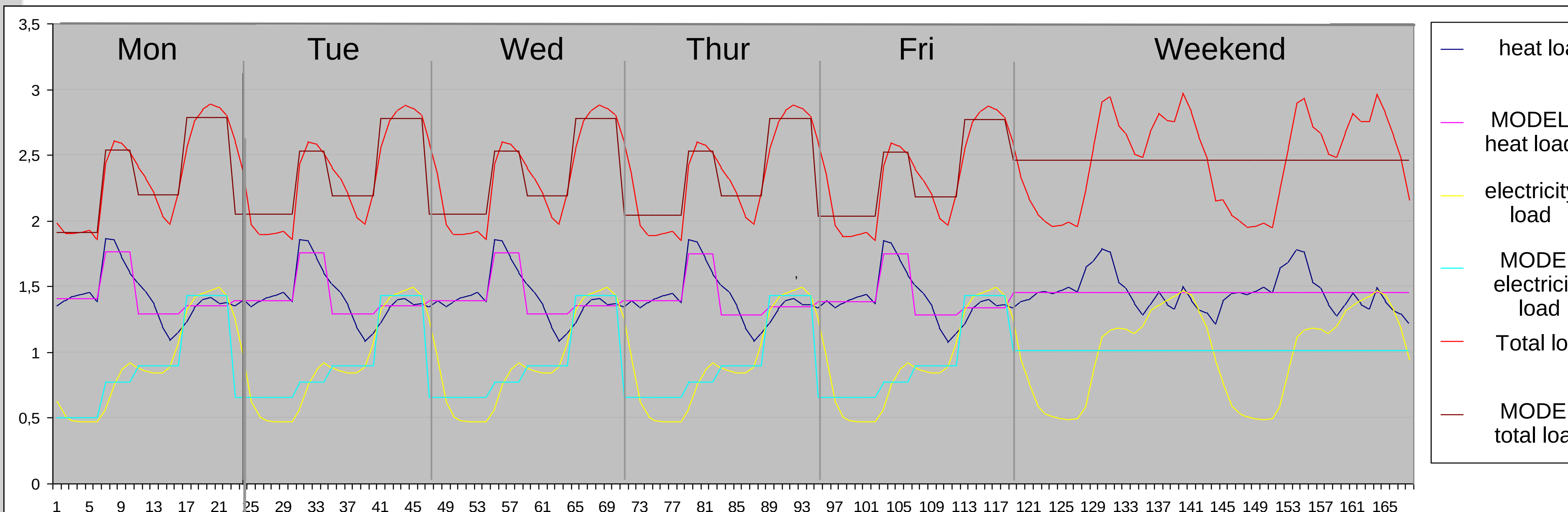
- Five load segments per week
  - Morning, afternoon, evening, night and weekend
  - In total: 5 * 52 = 260 load segments

		Hours pr load segment	Hours pr week
Day1	07-11	4	20
Day2	11-17	6	30
Day3	17-23	6	30
Night	23-07	8	40
Weekend	23 Friday 23 Sunday	24	48
Sum			168

- Load profiles
  - electricity demand and thermal demand
  - In total: 25 * 2 = 50 load profiles
    - Each containing 260 load segments.

Weekly load profile - example

- Households
  - Mid February (week 7)



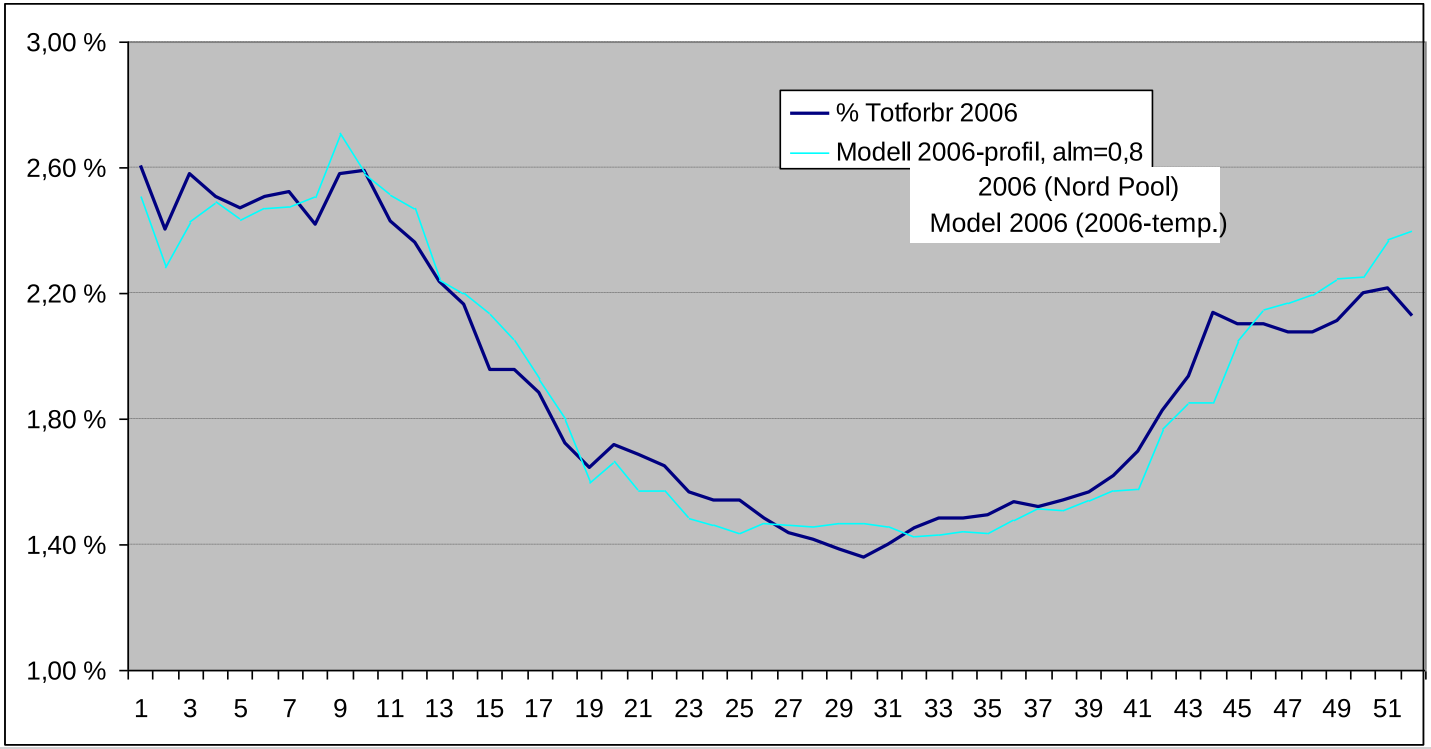
Methodology- load profiles

- 1) Testing on 2006-data
  - MODEL:
    - Daily outdoor temperature in 2006 in 7 regions in Norway
      - This gave an estimated load profile in 2006 for Norway
      - electricity consumption was exctracted
  - Testing against hourly national electricity consumption from Nord Pool ASA in 2006
  - Result: calibrated profiles

- 2) Load profile for an average year
  - Replacement of 2006-temperatures with ”normal”-year temperatures
    - Gives load profile for an average year.
  - Testing against temperature-corrected electricity demand in 2006.

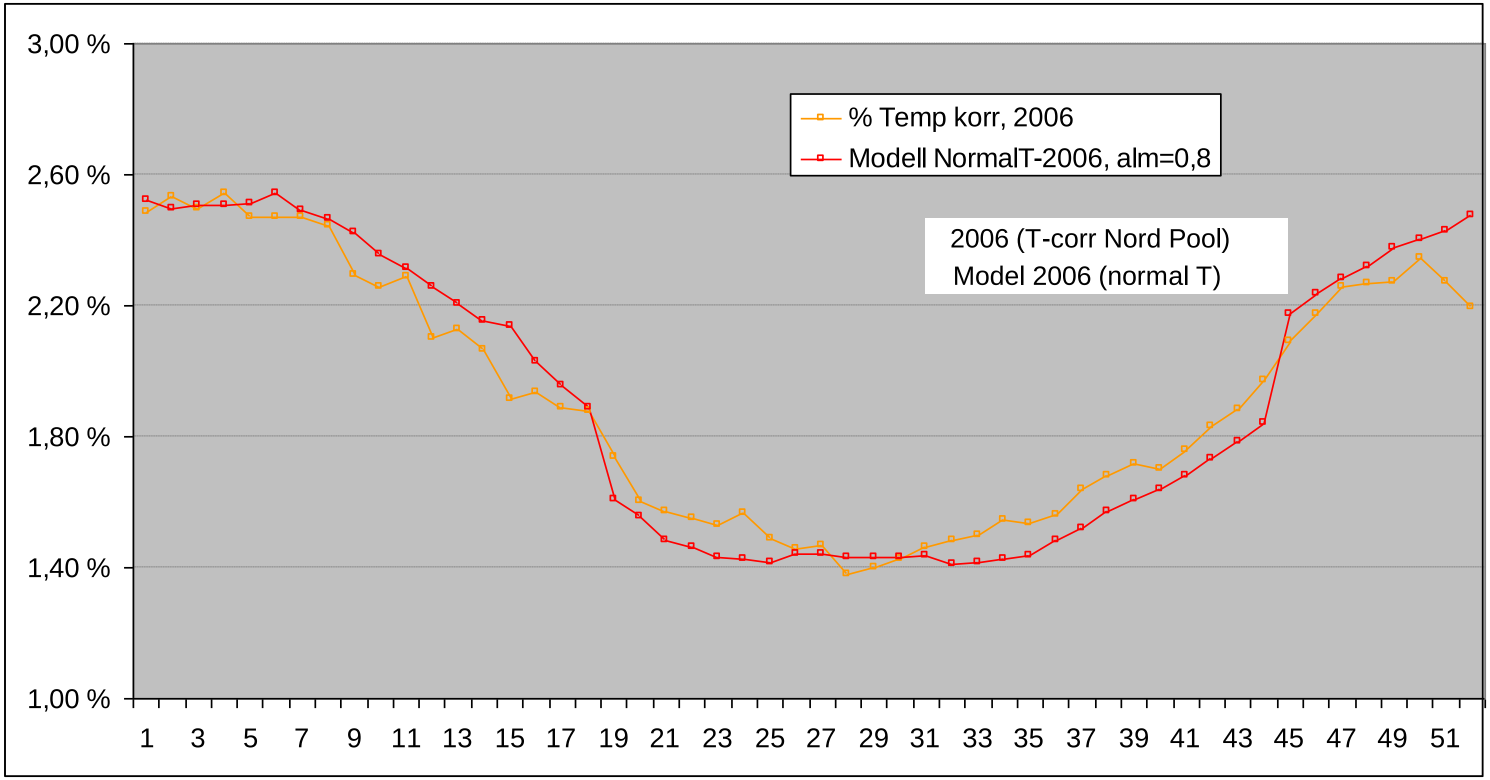
1) Testing on 2006-data

- Weekly electricity demand in 2006
  - National electricity demand 2006 (NordPool ASA)
  - Modelled load profile with temperatures in 2006



2) Load profile for average year

- Weekly load i 2006 as percentage of total load
  - Temperature corrected electricity demand in 2006.
  - Modelled load profile with ”normal” outdoor temperature



Experience with the TIMES model

- The iterations with EMPS show reasonable response from the TIMES model to changes in electricity prices
- Different response in different regions due to existing stock of alternatives
- Options for storage of hydropower (weekly) improves the models in hydropower dominated systems significantly

Overview

- Energy systems analysis
  - Tools
  - Models
- Project example
  - Modelling the effects of climate change on the energy system

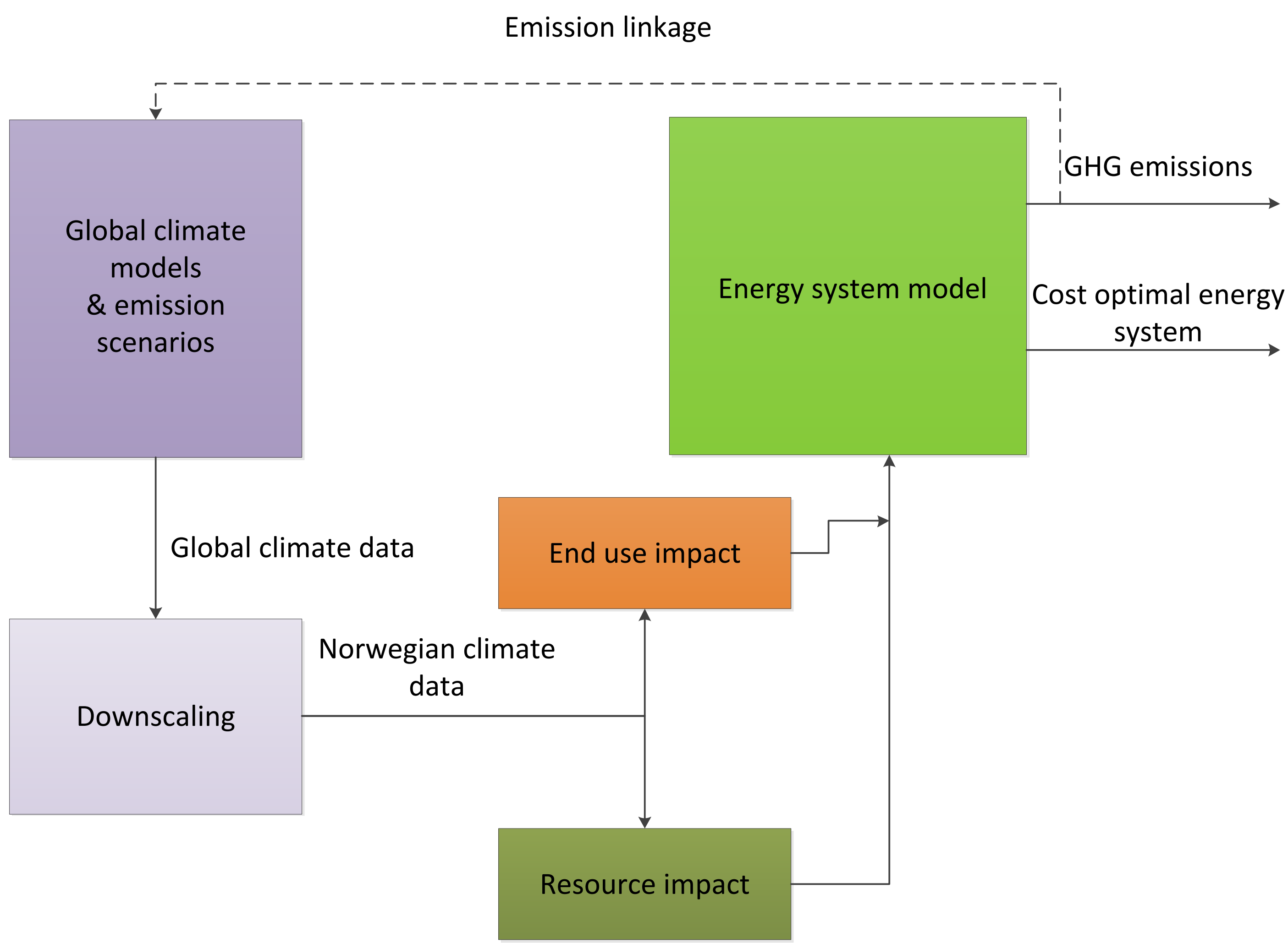
Modelling the effects of Climate Change on the Energy System

Goal:	Identify how changes in renewable energy resources and end use demand, due to climate change, influence the entire energy system
Input:	10 Norwegian climate data experiments – Derived from various global climate models and emissions scenarios
Tools/models:	SolDat & MARKAL
Results:	**The climate impact on the end use demand and on the renewable resources**
Financing	Research Council of Norway and NVE
Research partners	The Norwegian Metrological Institute, UiO and IFE

Climate experiments

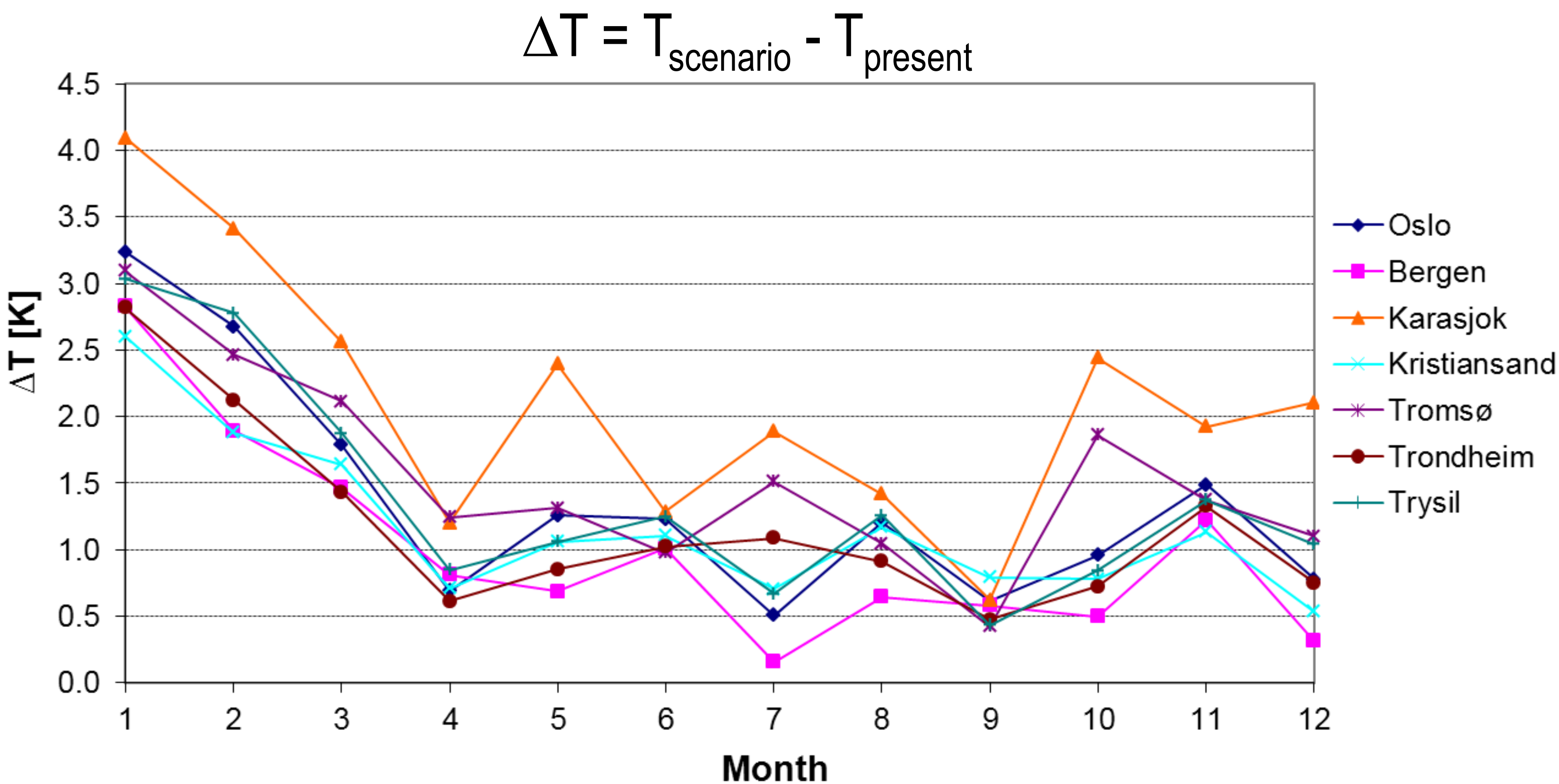
Exp. No	Centre	Climate Model	Emission Scenario	Scenario characteristics	Increase in CO_2 emission 1990-2100
1	Max Planck Institute, Germany	ECHAM4	IS92a	Business As Usual (medium/high growth in population, low growth in GDP)	174 %
2	Max Planck Institute, Germany	ECHAM4	SRES B2	Medium growth in population, GDP, energy use	98 %
3	Hadley Centre, UK	HadAM3H	SRES B2	Medium growth in population, GDP, energy use	98 %
4	Hadley Centre, UK	HadAM3H	SRES A2	High growth in population and energy use, medium growth in GDP	386 %
5	Bjerknes Centre, Norway	BCM v1	CMIP2	1 % annual CO_2 increase	270 %
6	Bjerknes Centre, Norway	BCM v1	CMIP2	1 % annual CO_2 increase	270 %
7	Bjerknes Centre, Norway	BCM v2	SRES A1B	Low growth in population and, very high growth in GDP and energy use	98 %
8	University of Oslo	CAMSOslo	1.63xCO2		Not a transient run
9	Max Planck Institute, Germany	ECHAM4	SRES B2	Exp. 2 with 25 x 25 km grid	98 %
10	Max Planck Institute, Germany	ECHAM4	IS92a	Exp. 1 with 25 x 25 km grid	174 %

Methodology



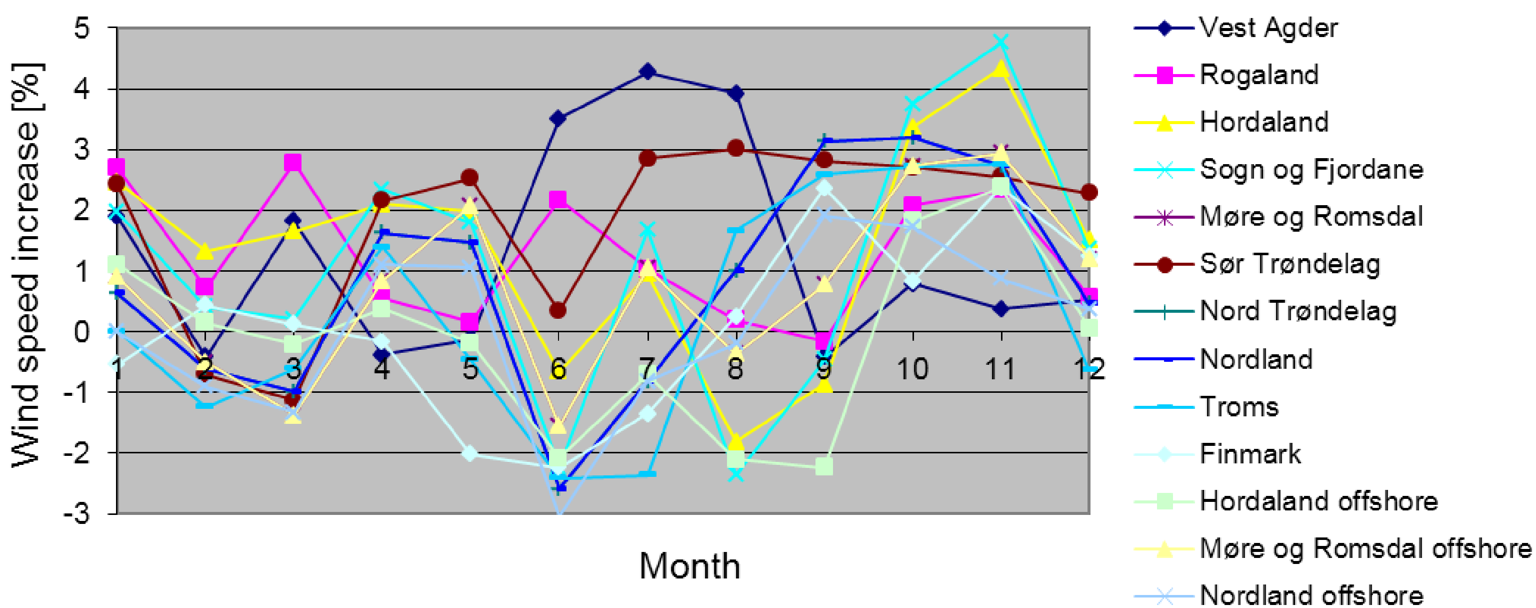
Temperature difference for 2050

- Largest temperature increase in winter months
- Largest increase in the north and in the inland



Wind speed change for 2050

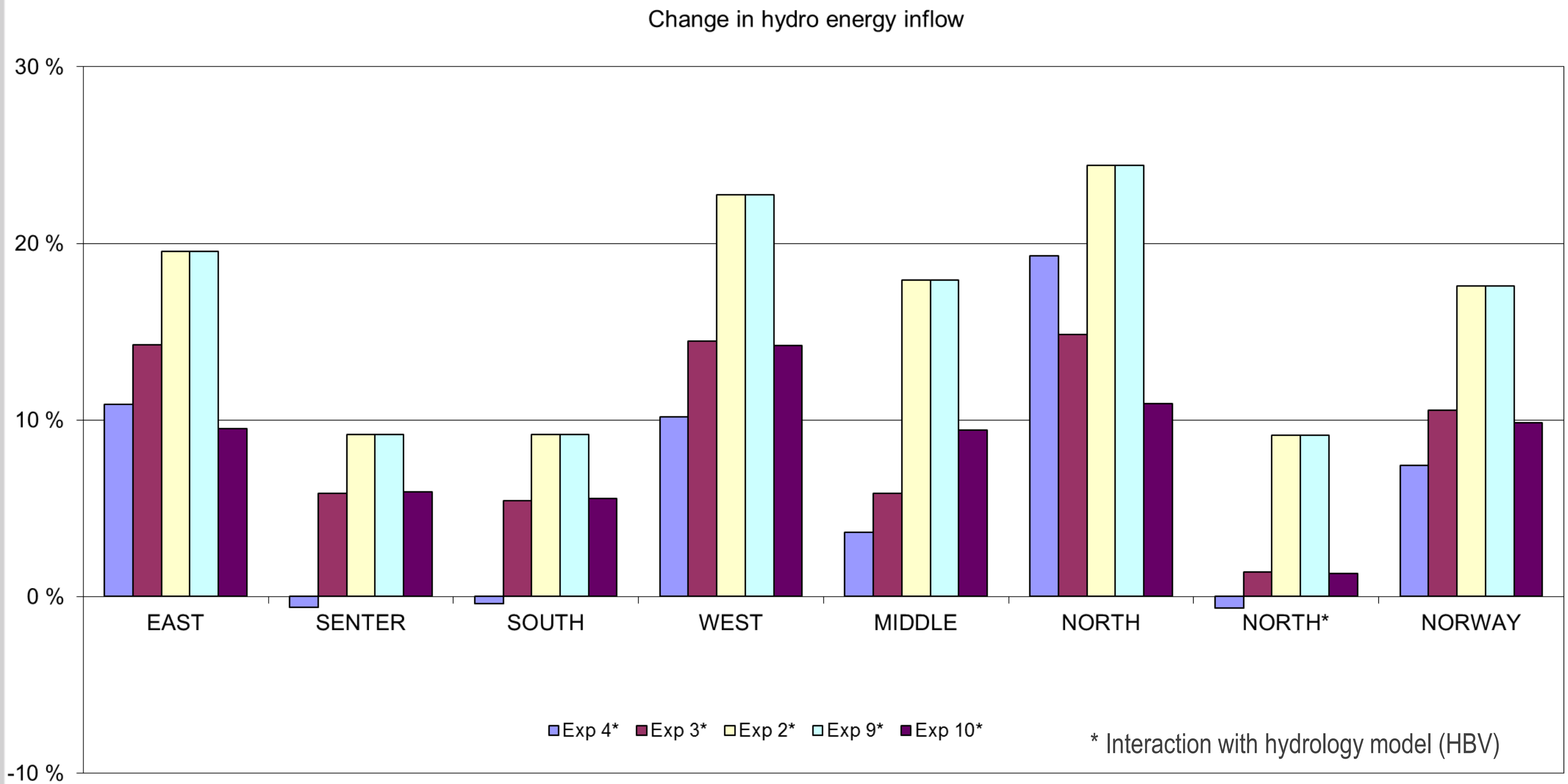
- Climate changes seem to have very little effect on the wind power potential
- The uncertainty in the wind speed seems to be higher than the changes in wind speed



Solar radiation

- The climate impact on the solar radiation is varying between different locations
  - Oslo: Slight increase in radiation in spring and autumn
  - Bergen: Slight decrease for most months
  - Tromsø: Slight increase for some months and slight decrease for others

Hydro energy inflow



- Climate changes will also result in a larger share of flooding
  - ✓Can be reduced by upgrading existing plants

Drivers influencing the demand of energy services in the building sector

Driver	Annual change
Number of dwellings	1.7 %
Population growth	0.93 %
Average area per new built dwelling	0 %
Demolition rate	0.6 %
Energy intensity for space heating - new dwellings - existing dwellings	 0 % -1 %
Specific energy use per employee	0 %
Number of employees in - public services - in private services - transportation	 1 % 0.5 % 0.9 %
Private consumption	3.2 %
Value added - other services - wholesale and retail	 2.3 % 3.4 %

Outdoor temerature effect on space heating

Two methods to calculate heat demand:

- SolDat (1 representative experiment)
- HDD (10 climate experiments)

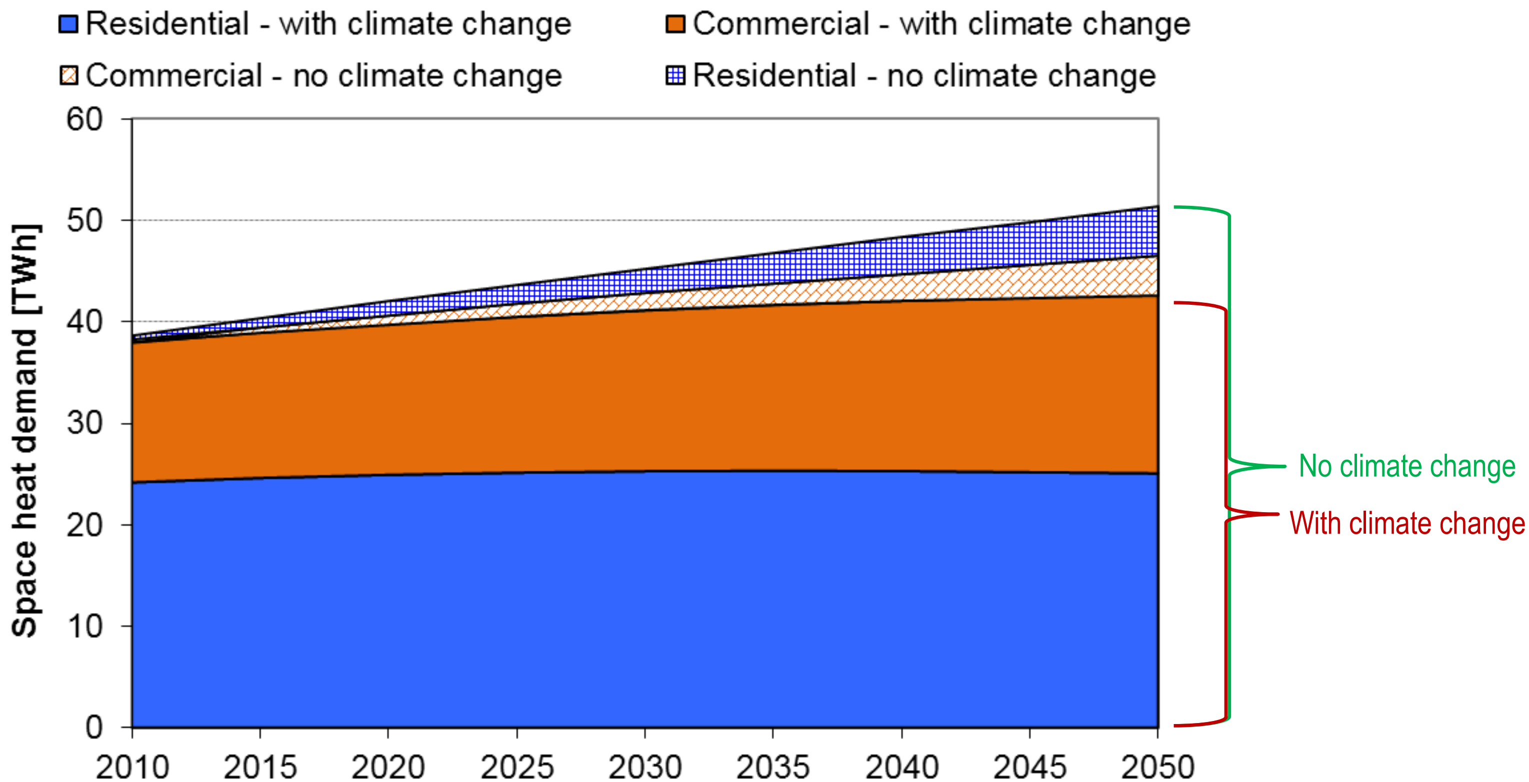
The HDD method is mathematical expressed in the equations:

$$HDD = \sum_{i=1}^{365}(T_i - T_{base}) \quad T_i < T_{base}$$

$$HDD = 0 \quad T_i > T_{base} \quad (2)$$

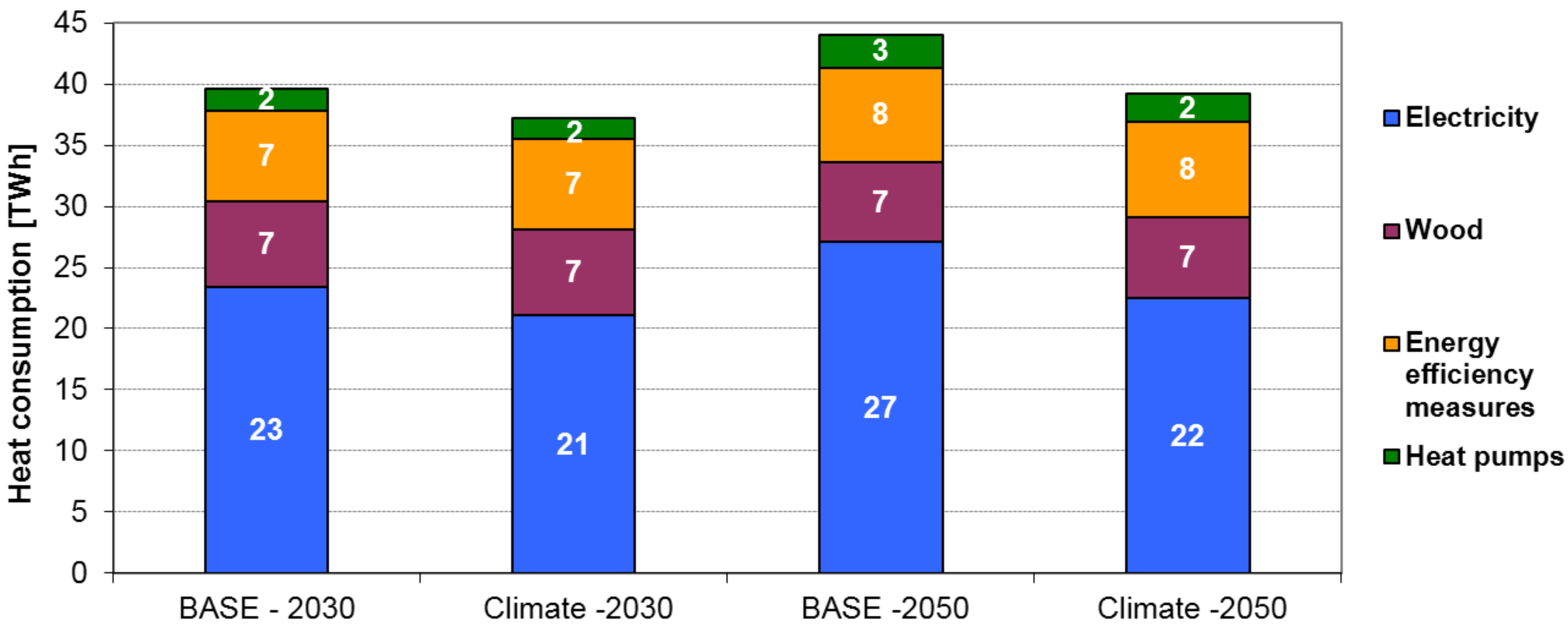
Heat demand

- The space heating demand for the commercial and the residential sector will decrease → Max 10 TWh



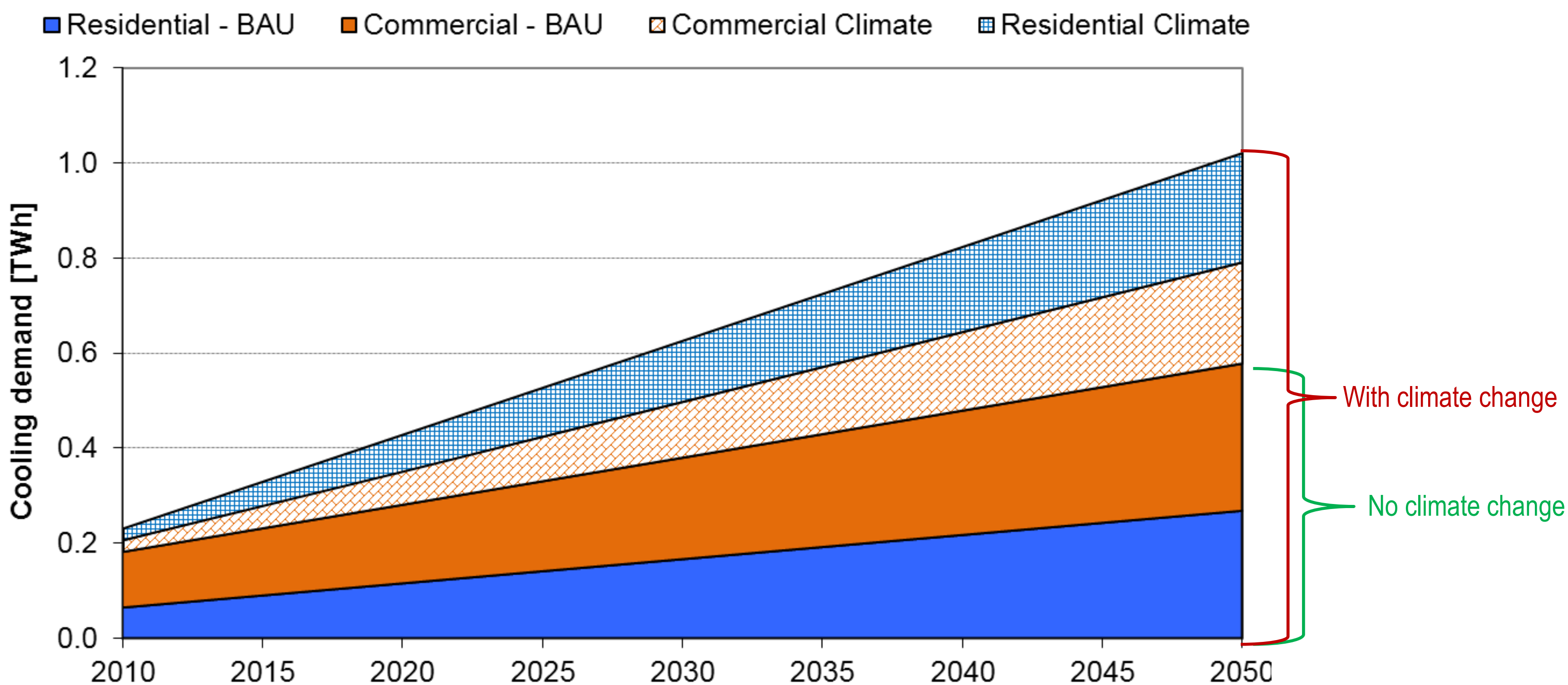
Residential heat consumption

- Climate scenario: Reduced heat demand in the residential sector
- Climate scenario: Reduced use of electricity and heat pumps

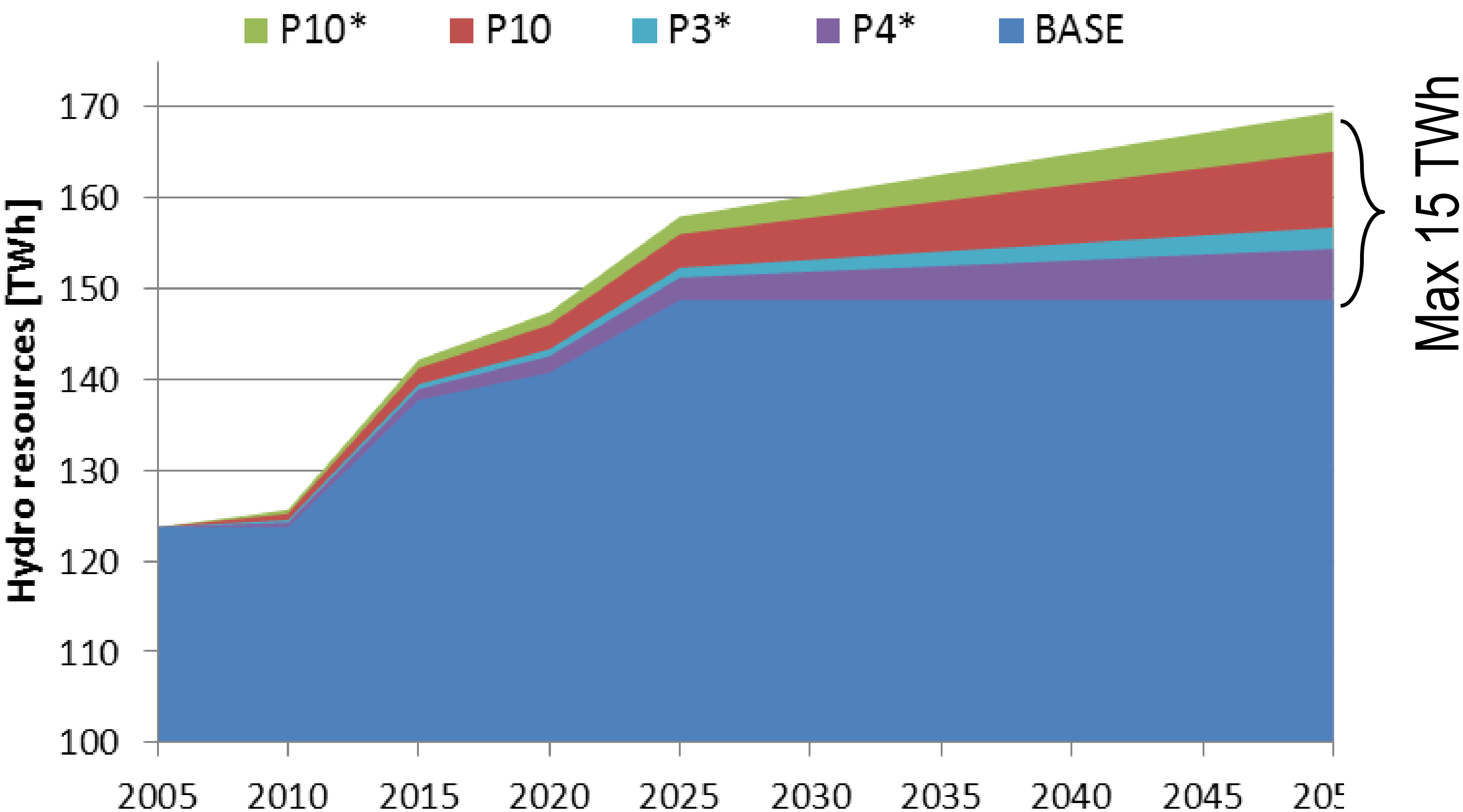


Cooling demand

- The cooling demand for the commercial and the residential sector will increase → Approx. 0.4 TWh

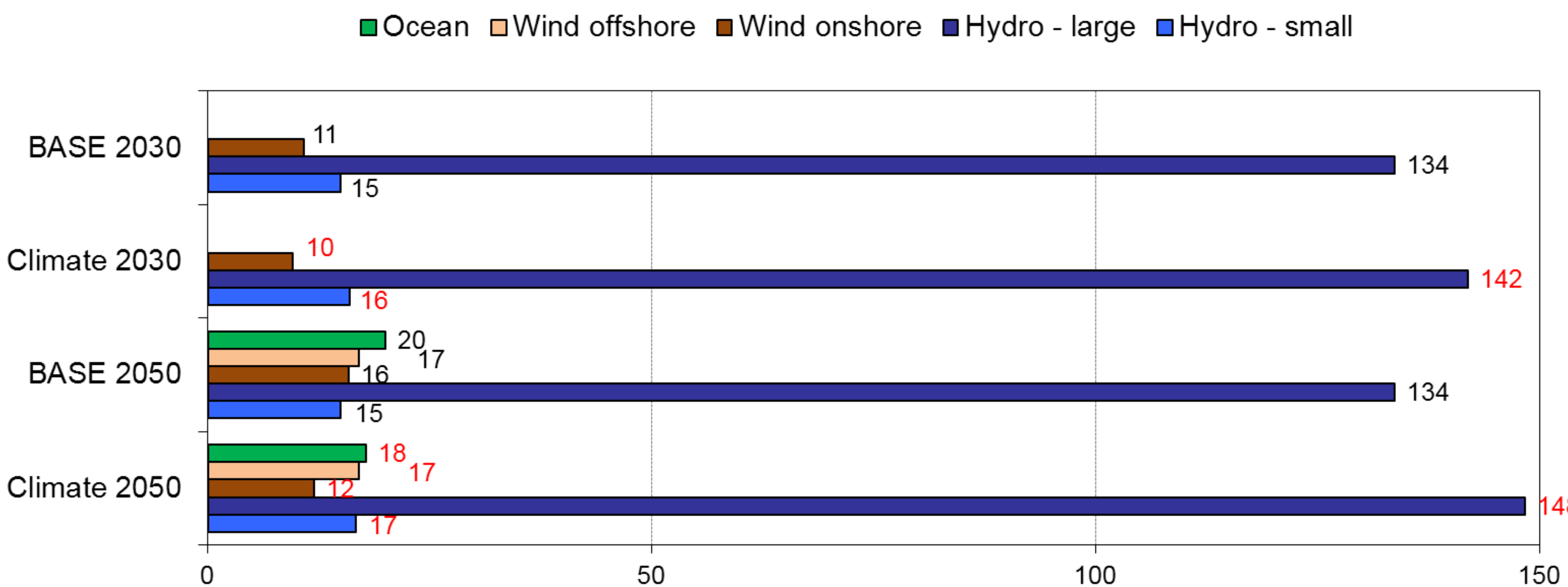


Hydro resources



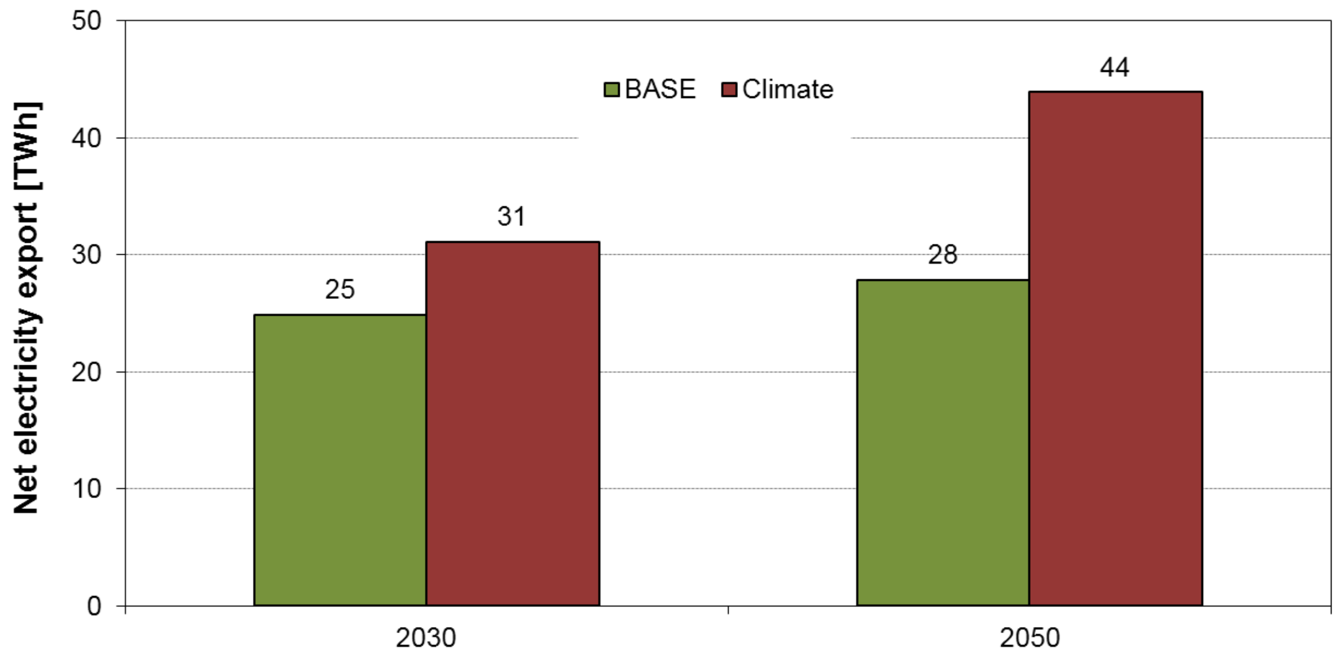
Norwegian electricity production in 2030/2050

- The climate assumptions give
  - Increased production of hydro power (both large and small scale)
  - Decreased power production from ocean and wind



Export of electricity in 2030/2050

- Climate scenario: Reduced heat demand and increased hydro potential increase the Norwegian electricity export
- Base scenario: Increased export due to increased electricity price, decreased investment costs, energy efficiency measures and decreased demand (industry)



Conclusions from the project

Climate Change on the Energy System

- For Norway, climate change will:
  - **Reduce the heat demand**
  - Increase the cooling demand
  - No major impact on the wind power potential
  - **Increase the hydro power potential**
- 10 climate experiments were used
  - All showed the same trend regarding the climate impact effects on the Norwegian energy system
    - ✓ The magnitude of the impact varies
- The future climate can influence cost optimal investments, especially for technologies with long lifetime
  - Current cost optimal solutions are affected by the uncertainty of the future

Climate Change on the Energy System

Modelling the effects of climate change on the energy system — A case study of Norway

- **Energy Policy, Volume 39, Issue 11,** November 2011, Pages 7310–7321
- http://www.sciencedirect.com/science/article/pii/S0301421511006513

Future research ideas

- Regional effects of climate change
- Including the human behaviour aspect
- Intermittent energy resources
- Pumped hydro
- Smart grids
- Cross elasticity of demand in the transportation sector
- Linking with macro economic models

New project with funding from RENERGI:

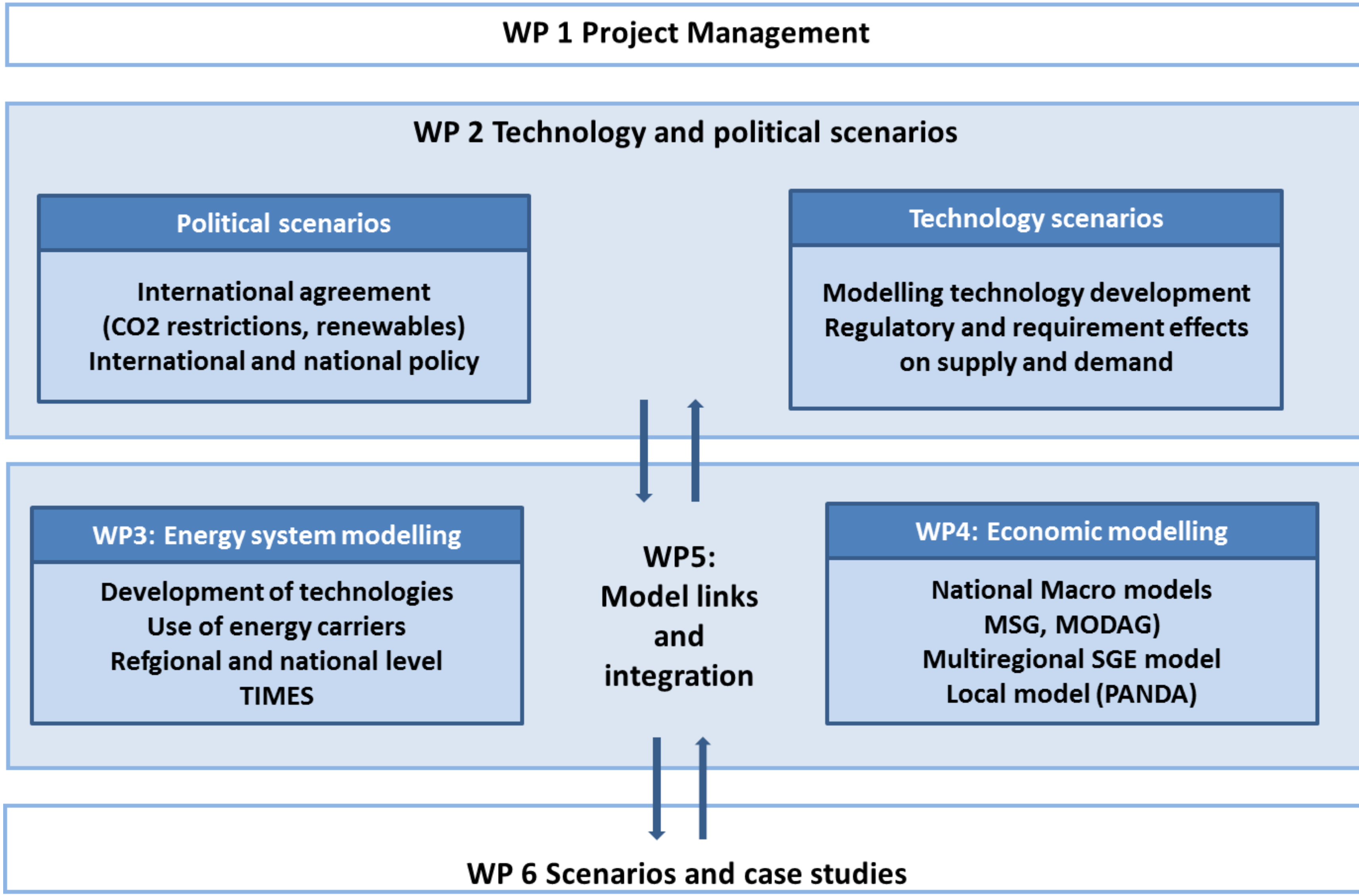
Regional effects of energy policy

- The project will develop a hybrid modelling approach for the regional level combining a TIMES model of the regional energy system, a macro economic equilibrium model at the national level and a multiregional SCGE model at the regional level.

- Study the interface between the energy system and the economic system by focusing on:
  - Improving geographical representation of transport links, production and demand in energy system models
  - Better representation of the energy sector and related sectors like transport and industry in regional economic models
  - Strengthening the link between energy system models and regional economic models to avoid sub-optimization in the energy system

- Project periode: 2012-15
- Partners: SINTEF T&S, NTNU IØT and IFE

Regional effects of energy policy



Thank you