Risk based distribution system asset management - the Norwegian experience

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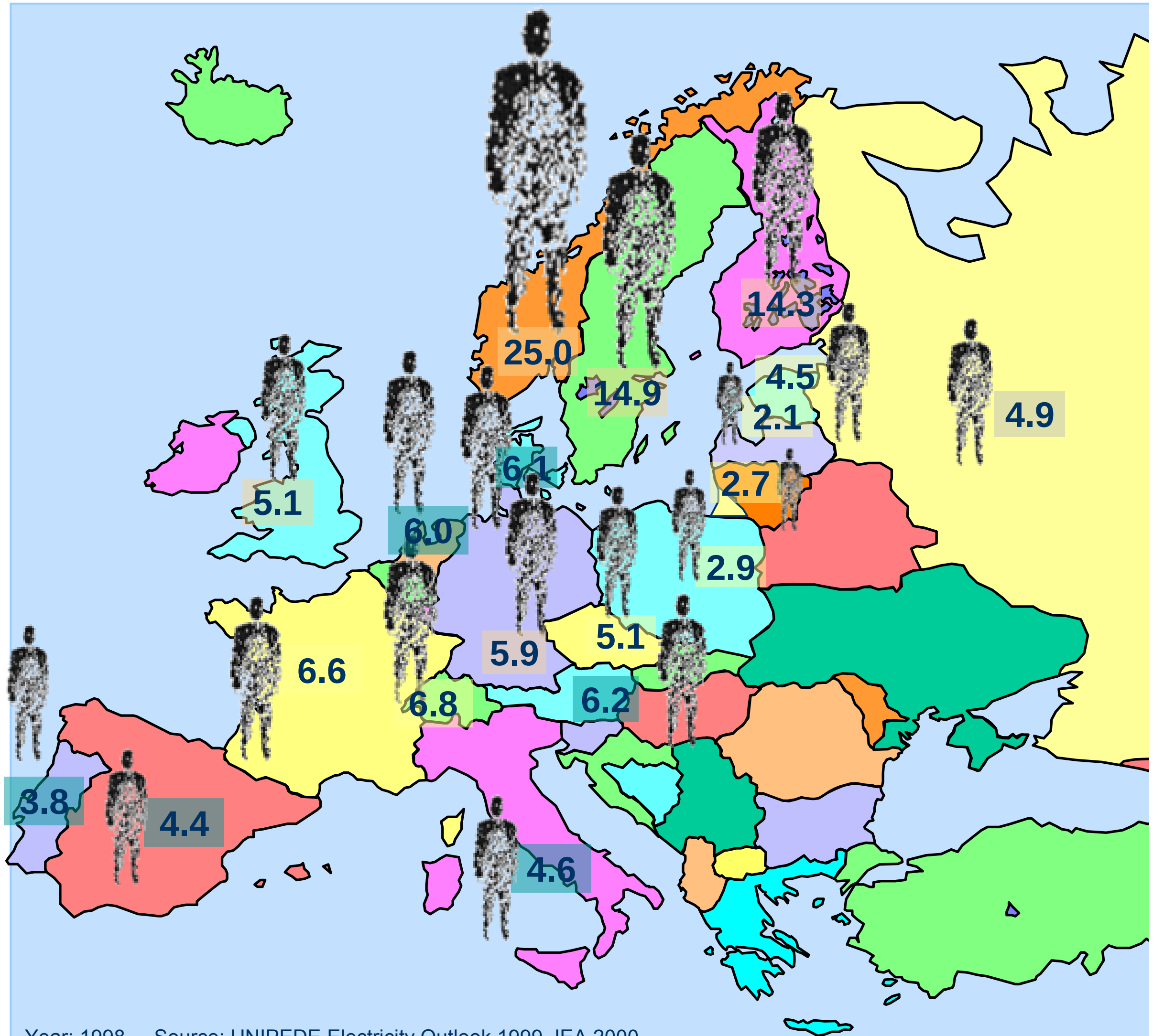
- SINTEF Energy Research
- Asset management in a T&D income cap regulatory regime
- Stakeholders' (conflicting) asset management objectives
- Quality of supply regulation and the impact on asset management
- Trends
- State of the art - risk management practices within utilities
- State of the art - available methodologies and tools
- Case studies - examples of risk based asset management projects and obtained benefits.
- Ongoing work - looking ahead

Electrical energy consumption per capita

x 1 000 kWh (2000)



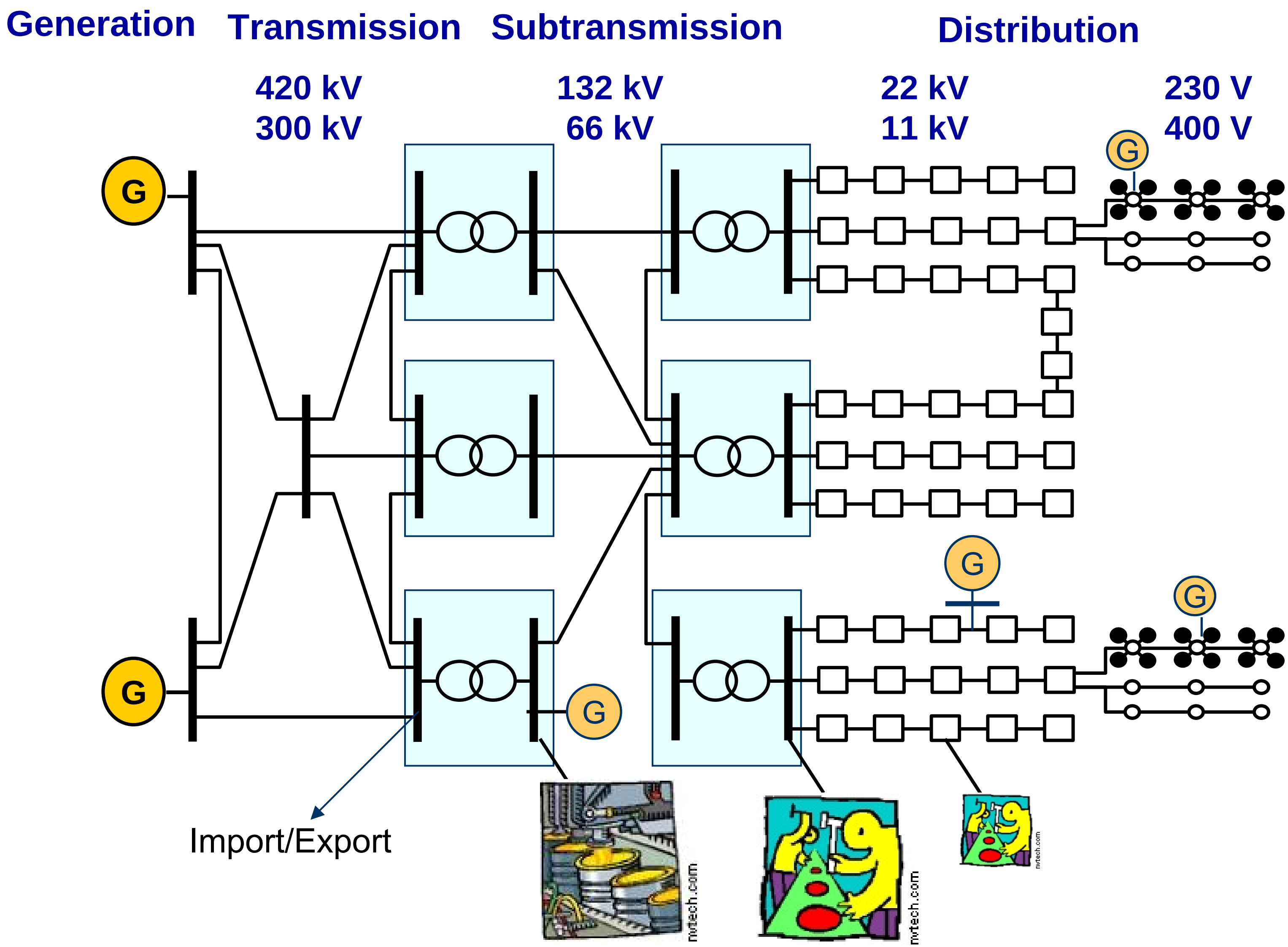
The Nordic Power System

General Overview Year 2003

		Denmark	Finland	Norway	Sweden	Nordel
Installed capacity	MW	12.830	16.893	28.081	33.361	91.165
Generation	GWh	43.754	79.855	107.122	132.547	363.278
Imports	GWh	7.163	12.262	13.472	24.367	57.264
Exports	GWh	15.707	7.415	5.586	11.438	40.146
Total consumption	GWh	35.210	84.702	115.008	145.476	380.396
Consumption per capita	kWh	6.520	16.289	25.002	16.164	15.719
Breakdown of electricity generation:						
Hydropower	%	0	12	99	40	47
Nuclear power	%	.	27	.	50	24
Other thermal power	%	87	61	1	10	27
Other renewable power	%	13	0	0	0	2

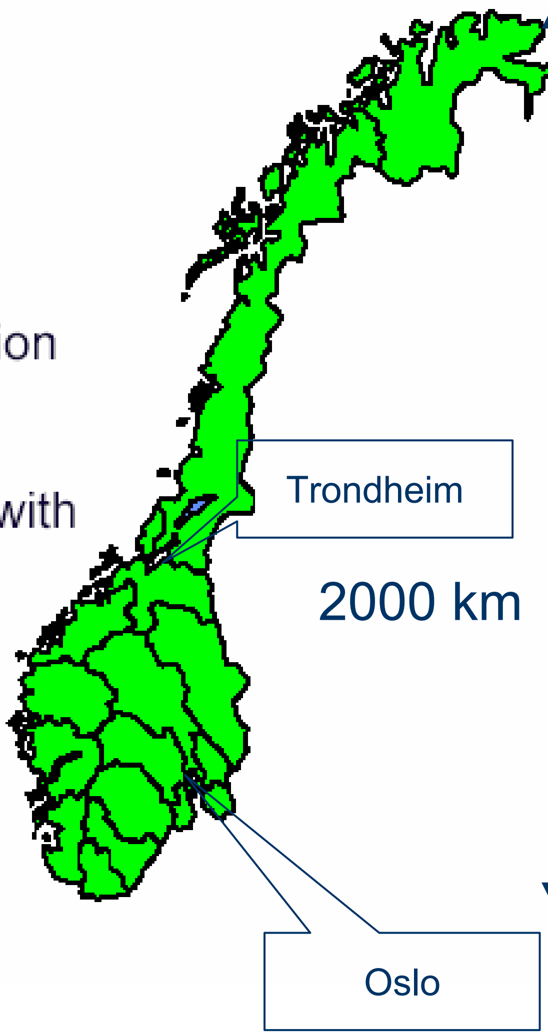
Source: Nordel

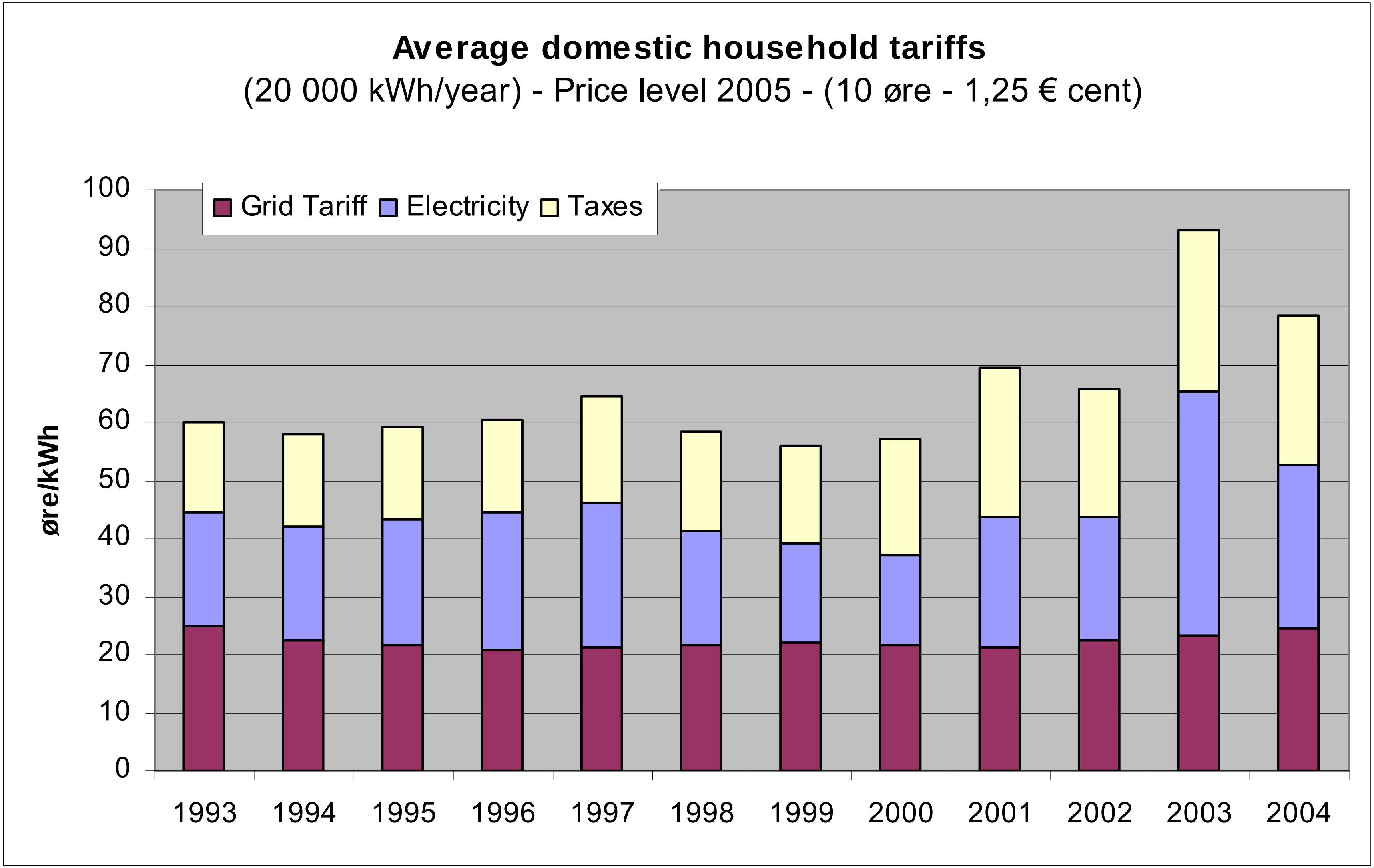
The Norwegian Power System



Electricity supply in Norway – some key figures

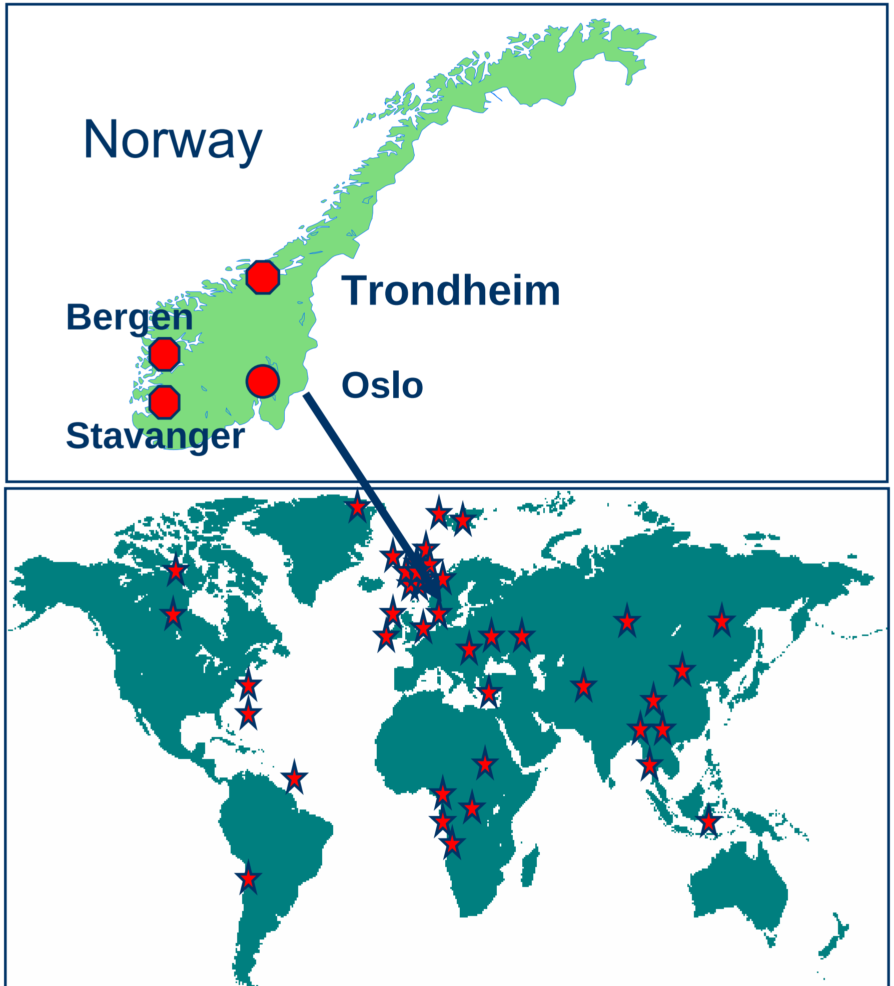
- ~ 4,55 million inhabitants
- ~ 123 000 km (overhead and underground power cables <1 - 420kV>)
- ~ 115 TWh annual el. consumption (ex transmission losses ~ 10 TWh)
- ~ 20 GWh energy not supplied in 2002 (0,017 % with reference to delivered energy)
- ~ 150 network companies (mostly owned by municipalities).
- Third party access to the electricity marked since 1991.




Average domestic household tariffs
(20 000 kWh/year) - Price level 2005 - (10 øre - 1,25 € cent)
Grid Tariff
Electricity
Taxes
øre/kWh
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

SINTEF - A contract research organization based in Trondheim, Oslo, Bergen and Stavanger

SINTEF is one of the largest independent research organisations in Europe.



Business concept

SINTEF sell research-based knowledge and related services to Norwegian and international clients.

SINTEF has 1750 employees, 1407 situated in Trondheim and 363 in Oslo with offices in Bergen and Stavanger.

SINTEF Energy Research
- a part of SINTEF

- *Vision:*
  With the energy industry for a better environment

focusing on
- research and development
- dissemination and information

concerning the
- production
- generation
- transmission/distribution
- consumption of energy
- industrial processes and commercial products

in order to stimulate developments in the industry and the public sector

GLØSHAUGEN CAMPUS (Trondheim)

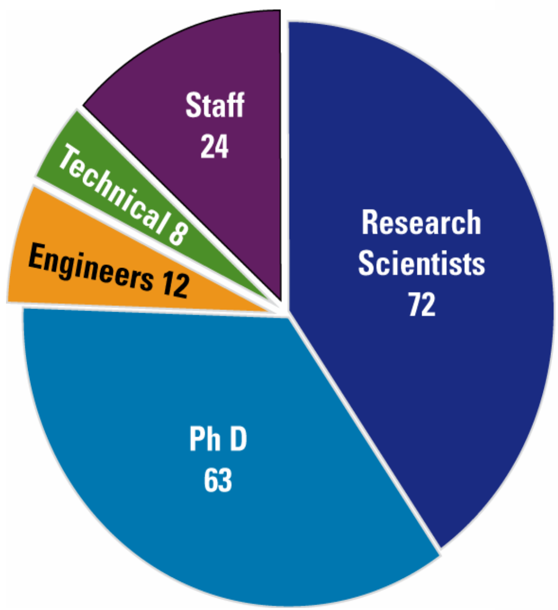
SINTEF and NTNU,
The Norwegian University of Science & Technology

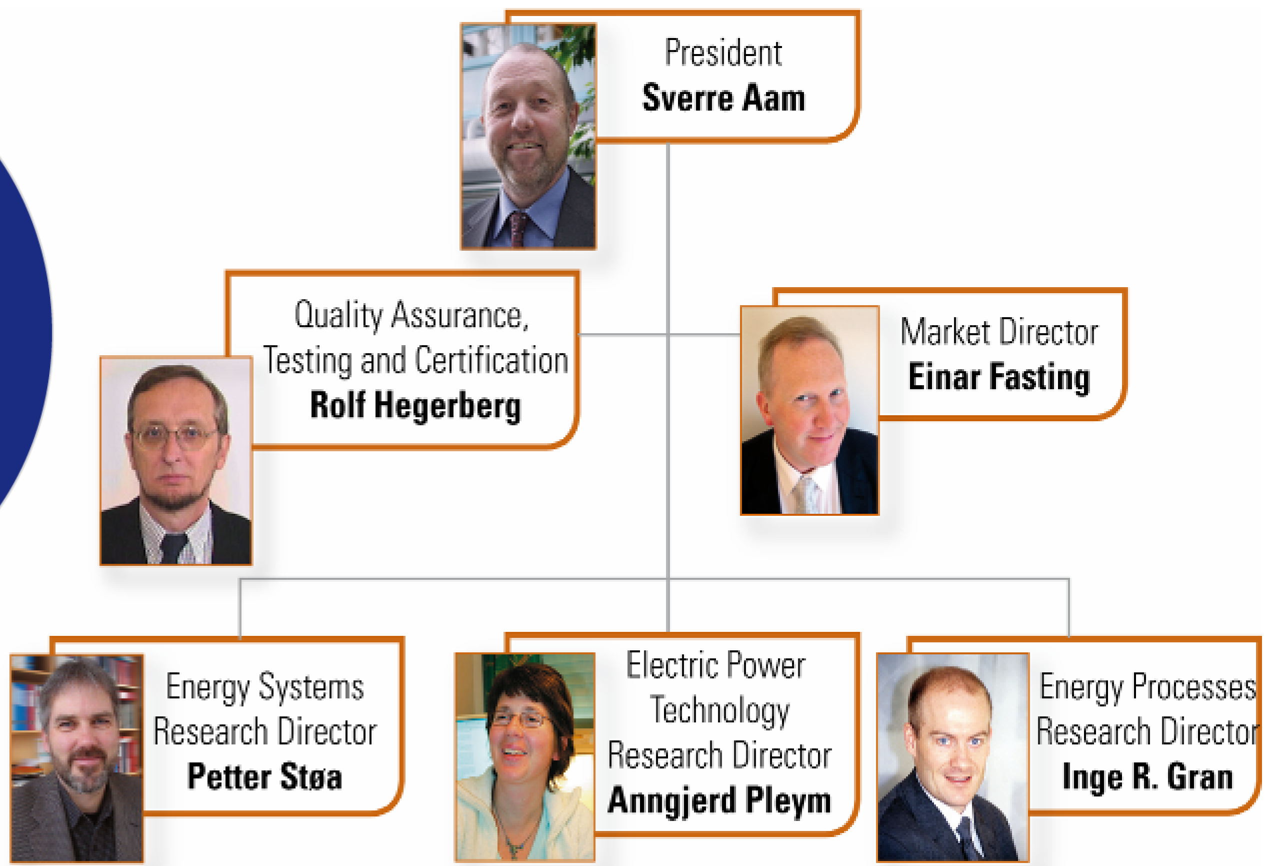
Number of employees:

NTNU	3.300
Scientific	1.800
(incl. Post.doc and PhD Students)	
SINTEF	1.400
(Scientific	1.100)
Students:	20.000
Around:	8.000
in Engineering & Sciences	

Organisation

Number of employees: 179

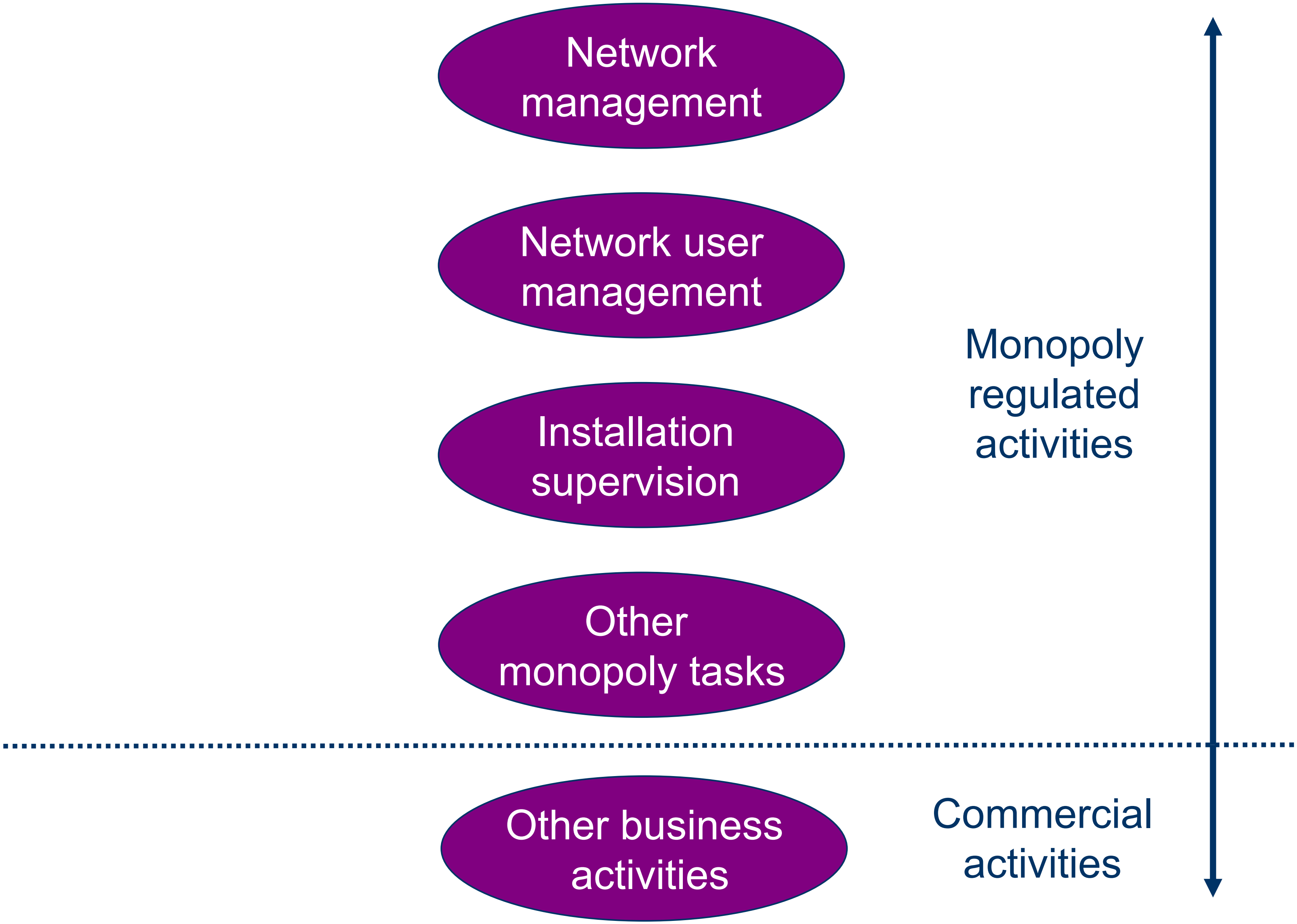




Asset management

- *The process of managing demand and guiding acquisition, use and disposal of assets to make the most of their service delivery potential, and manage **risks** and costs over their entire life.*

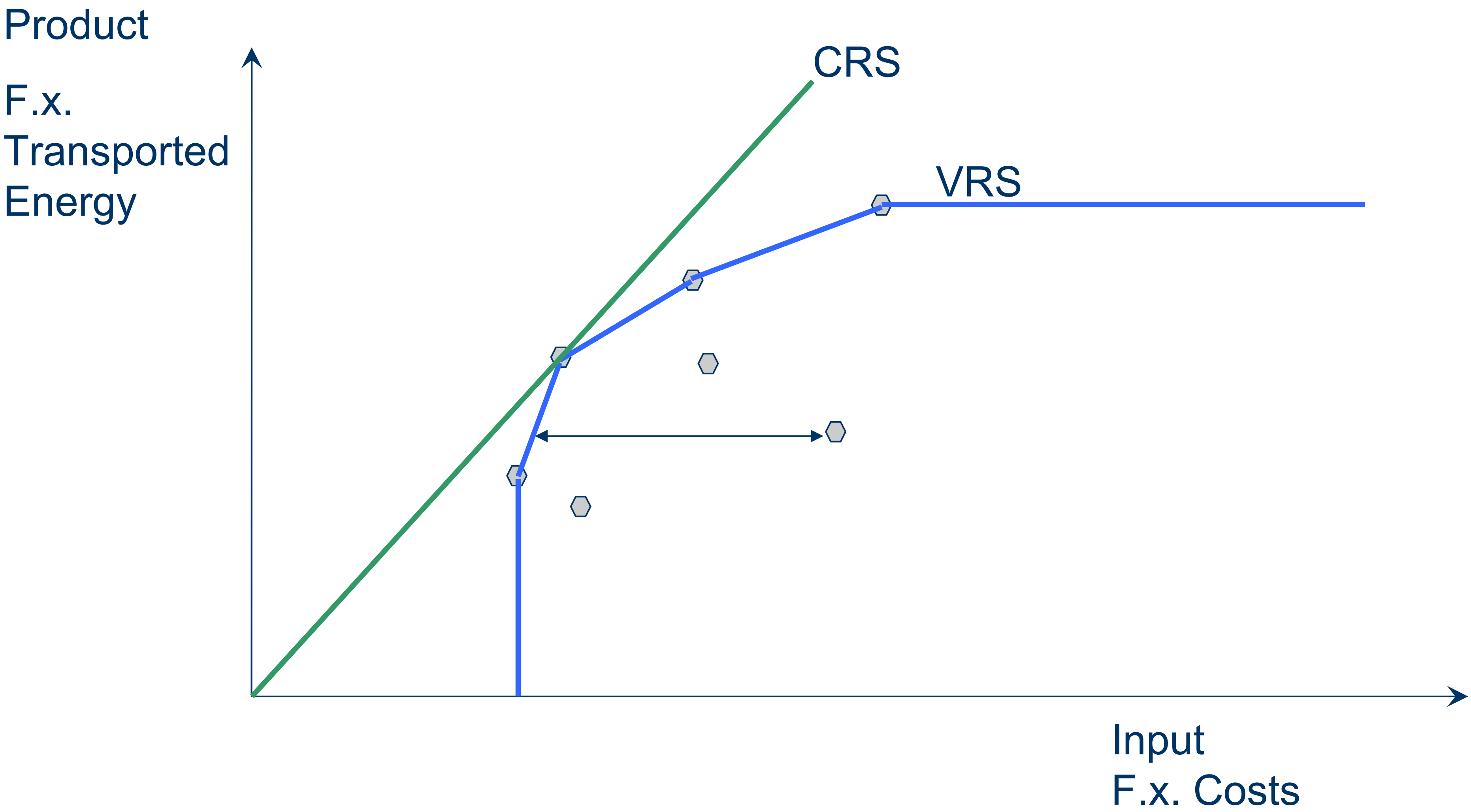
Main utility value chains - Norway



Norwegian T&D Regulation
The history so far…

- Rate of return regulation (ROR) at first (1991)
  - **giving incentives for possible over investments in T&D and high service levels**
- Income cap regulation from 1997
  - maximum permitted income separate from actual costs
  - maximum permitted income dependent on benchmarking performance (DEA used for subtransmission and distribution)
  - **giving incentives for possible under investments and reduced service levels**

DEA – Data Envelopment Analysis



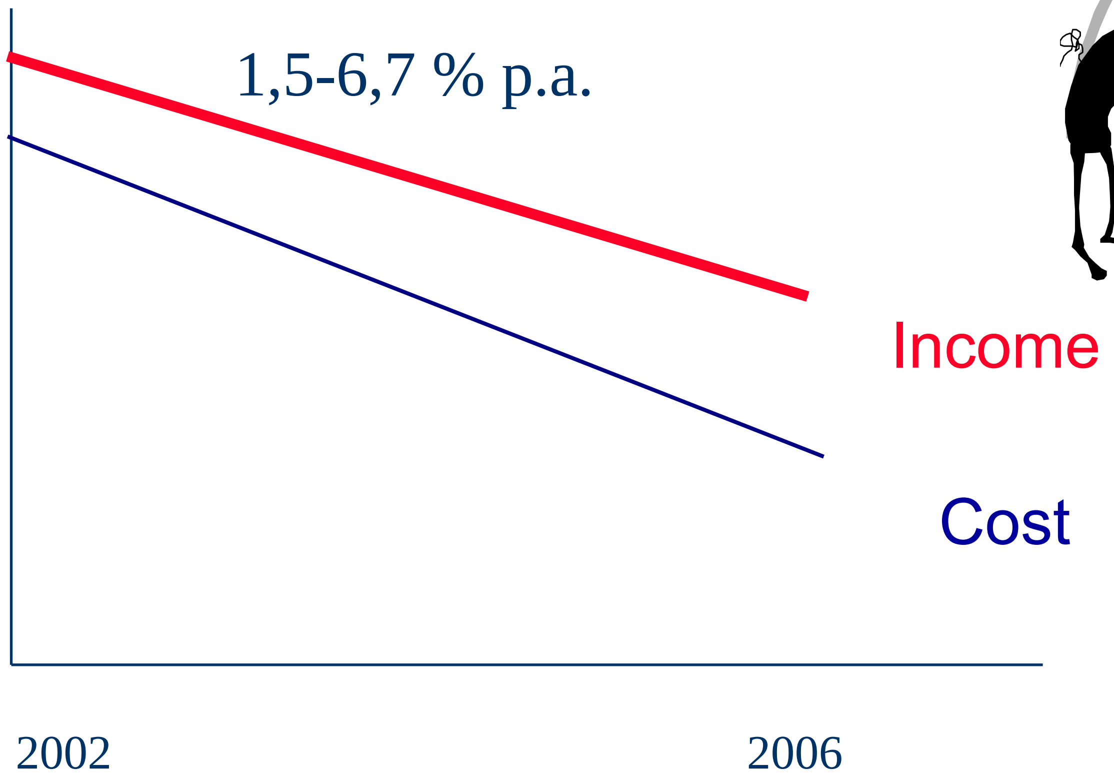
The history so far…

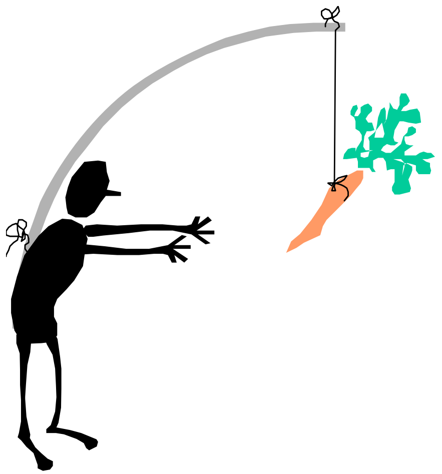
- Quality dependent revenue caps and individual service interruption payment 2001
  - maximum permitted income separate from actual costs
  - maximum permitted income dependent on benchmarking performance (DEA)
  - **giving incentives to counteract possible under investments**

The history so far…

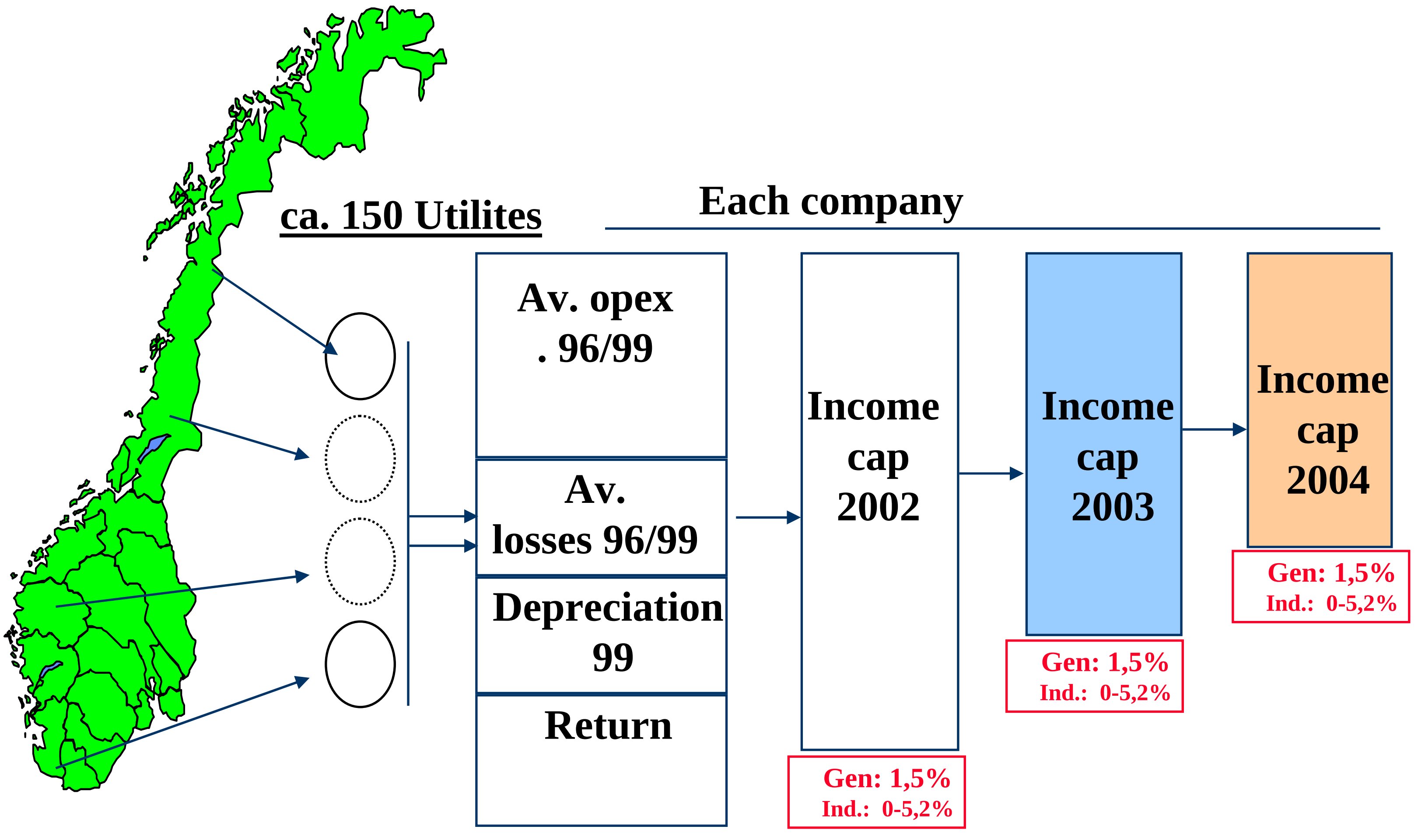
- From 2002 – Quality dependent income cap regulation/ Delayed cost plus…(hybrid)
  - maximum permitted income separate from actual costs
  - but updated by actual investments (delayed)
  - maximum permitted income dependent on benchmarking performance (DEA)
  - **slightly increased incentives for investments**

The main concept

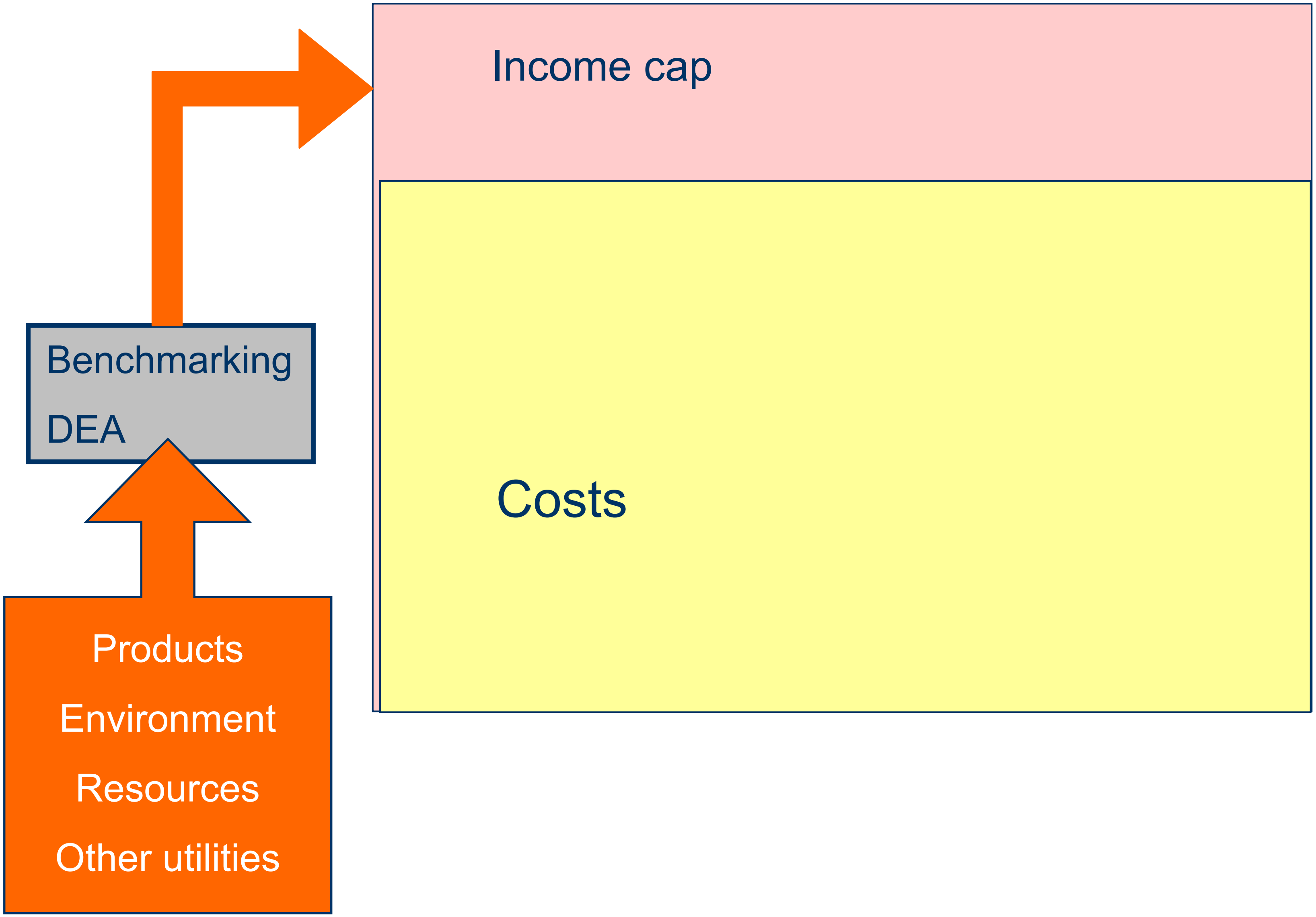




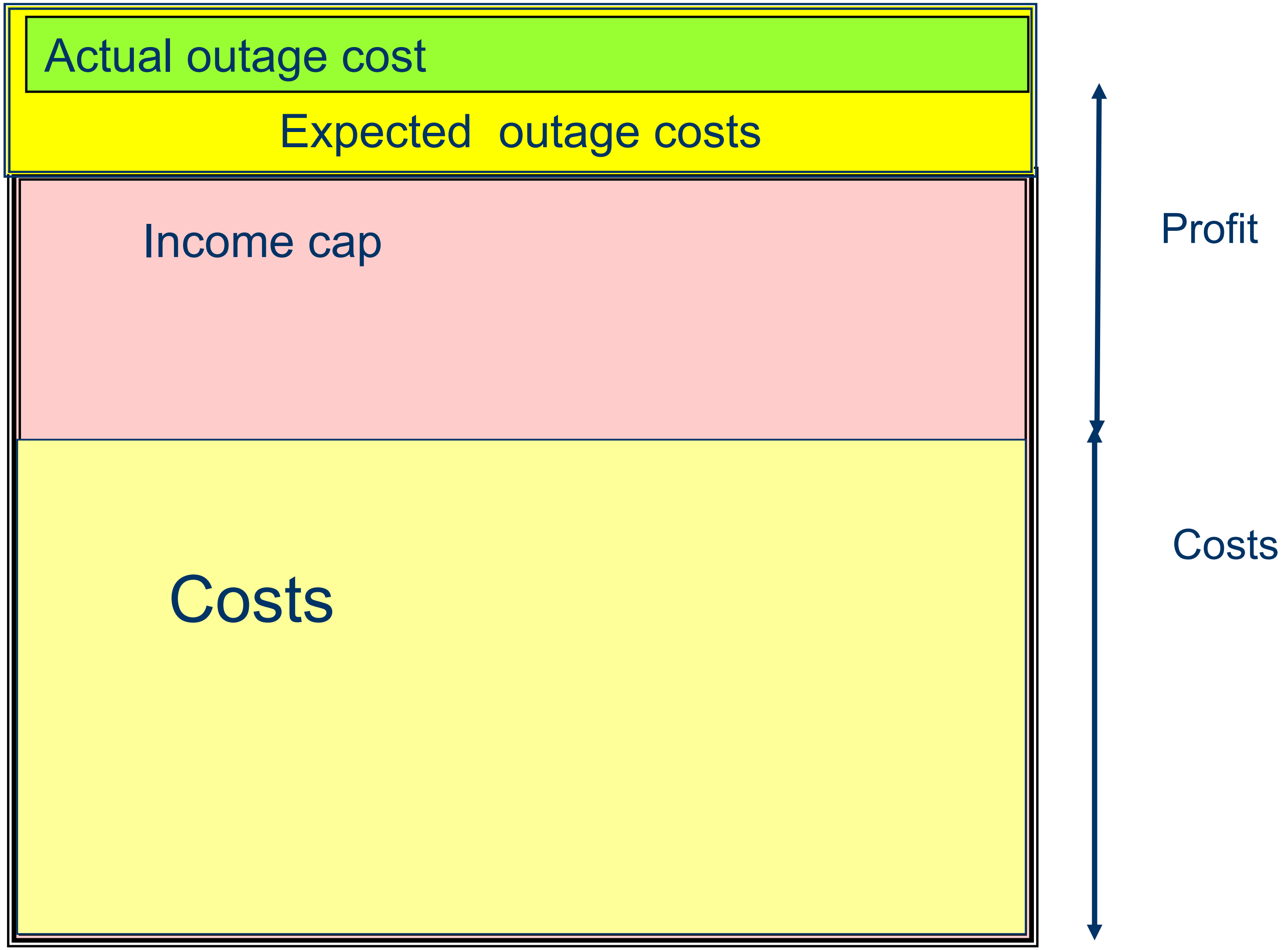
Income cap 2002 - 2006



Income cap regulation principle (ex-ante) from 1997



Including customer outage costs (CENS) 2000-2001



Asset management - Decision making - regulation: Lessons learnt

- closer integration between technical, administrative and economical processes within the utility
- more consistent criteria and regulation applied at different system levels (transmission, sub-transmission, distribution)
- problems in giving the right incentives for investments

Asset management - Decision making - regulation: Lessons learnt

- how to balance costs, power quality, safety, environment still unsolved to some degree
- more short term focus
- regulation – a dynamic process

Asset management - Decision making - regulation: Lessons learnt

- Focus change from technical administration to more businesslike management
- Focus on new business areas outside the regulation
- More profit-seeking owners – often more demanding than the regulator
- Mergers – new business models – more outsourcing
- Interface network owner - service providers (entrepreneurs) a new challenge

Results - experience: Efficiency as observed by the regulator - DEA model

- Improved data quality and reporting system – but more heterogenic utility behaviour
- 17,5 % improvement in technical efficiency 1997-2001
- 82% have improved their efficiency 1997-2001
- Positive experience with stepwise development

Experience - survey results

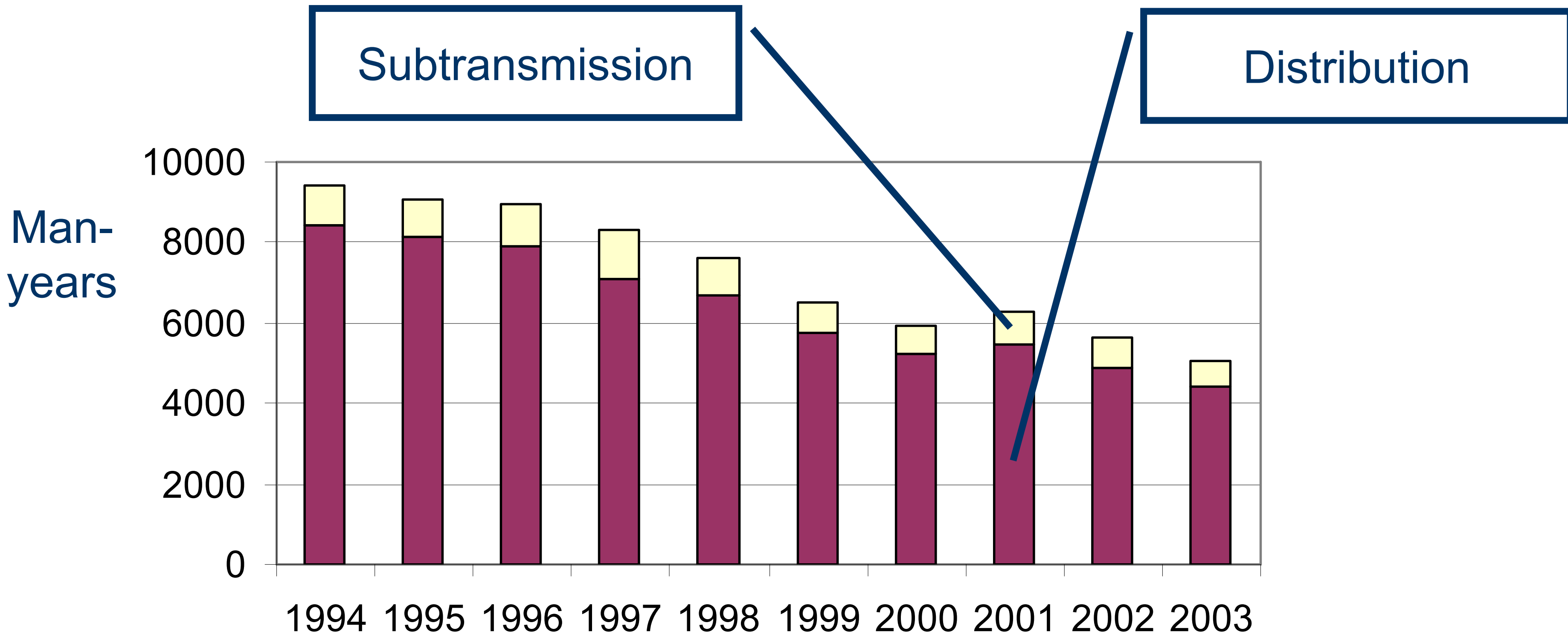
- 91% of the utilities found their activities influenced by the regulation
- 91% had cut their workforce of which 72% were motivated by the regulation.
- 59% had employed new skills to adapt to the new regime.
- 85% had changed their investment objectives.

Experience - survey results

- 79% reported changes in the demands from the owners of which 96% reported higher demands on returns on capital.
- 48% found that the regulator’s benchmarking was reasonable.

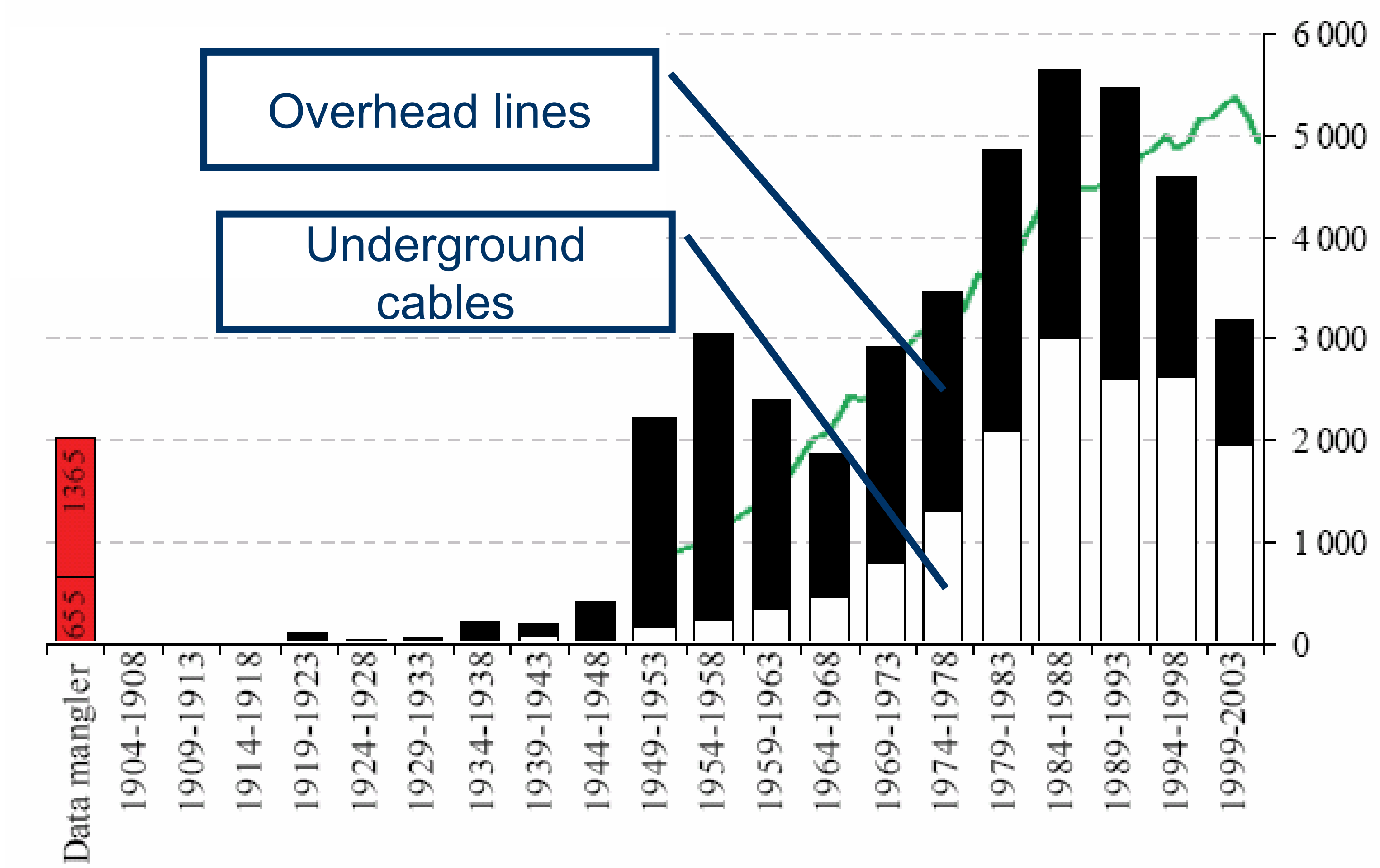
Concequences of regulation:

To manage more with less people



Consequences of regulation: Postponement of reinvestments

Aging infrastructures is a challenge



Age profile MV overhead lines and cables

Asset management hierarchy

Economy	**Economy** (Income, Investment costs, operation costs, maintenance costs, cost of electrical losses, outage costs…)
Performance	**Performance indicators:** Quality of supply , EMC, Health, Environment, Security, Safety, Vulnerability

Work Planning

Operation, Control,	Customer management	Maintenance, repairs	State control, Diagnosis	Construction work	Crisis & emergency preparedness

Physical "assets"

Components Plants, Apparatus	System topology System protection	Customers Loads	Production	Neighbouring-grids

The value chain is getting longer and more integrated - long distance from component level to economical regulation - challenge to establish a holistic and consistent asset management approach

Asset management objective - as defined by the regulator

Minimize overall costs:

- Investments, reinvestments
- Cost of power losses
- Outage costs (utility and customer costs)
- Congestion costs
- Maintenance and operating costs

while satisfying relevant restrictions

Investment drivers

Grid level	New connections (new grid customers) (%)	Improvement of existing grid (%)	Total (%)
Transmission	10	90	100
Subtransmission	10-40	90-60	100
MV	20-50	80-50	100
LV	40-60	60-40	100

Investment drivers - economy versus restrictions

(new grid customers are classified under restrictions)

Grid level	**Restrictions (%)**	**Economy (%)**	**Total (%)**
Transmission	10-15	90-85	100
Subtransmission	20-60	80-40	100
MV	60-90	40-10	100
LV	80-90	20-10	100

Quality regulation – development
An ongoing process

1991	1995	1997	2000 - 2001
Energy Act Socioeconomic optimization Mandatory information about quality of supply Results from customer survey	Mandatory reporting of interruptions > 3 minutes FASIT [1)] introduced	Mandatory reporting of failures and disturbances 33 - 420 kV Revenue cap regulation introduced	Standardized method for estimation of Energy not supplied (ENS) Mandatory reporting of ENS per end-user group CENS introduced

[1)] FASIT - standardized system for reporting of failures and interruptions

Quality regulation – cont.

2002	2003	2005	2006
A new regulation period Results from a new customer survey	New specific interruption costs used in the CENS arrangement	New regulations relating to the quality of supply	Revision of the regulations relating to the quality of supply Registration and reporting of short interruptions according to FASIT [1] requirements

[1] **FASIT - standardized system for reporting of failures and interruptions**

New PQ regulation in Norway

- Developed by the Norwegian Regulator (NVE)
- Includes rules for measurement and information
- Includes response times for management of complaints
- Based on EN 50160 – but EN 50160 not considered sufficient by the regulator
- Stricter limits for some characteristics based on experience – complaints – problems with equipment
- Covers voltage quality and interruptions i.e. the characteristics in EN 50160
- Implemented by 2005-01-01

Characteristic LV	EN 50160-1999	Norwegian PQ Code
Power frequency The interconnected system	50 Hz ± 1% (99,5% yr) 50 Hz + 4/-6% (100% yr)	Referring to the Nordic system operation agreement. 50 Hz ± 0,2% in normal operating conditions
Supply voltage variations	230V ± 10% - (95% week) 230V+10/-15%	230V ± 10% - (all 1 min values)
Magnitude of rapid voltage changes	Generally < 5% Up to 10%	≤ 1 (per day): 10% <24 (per day): 5% ≥ 24 (per day): 3%
Flicker severity	Plt ≤ 1 (95% week)	Pst ≤ 1,2 (95% week) Plt ≤ 1 (100% of time)
Supply voltage dips	Few tens up to one thousand	No limit *1)
Short interruptions	Few tens up to several hundreds	No limit *1)
Long interruptions	Less than 10 up to 50	No limit *1)
Temporary overvoltages live/earth	Indicative < 1.5 kV	No limit *1) Apply also between phases.
Transient overvoltages	Generally less 6kV peak	No limit *1)

*1) NVE may order to reduce the consequences of such events.

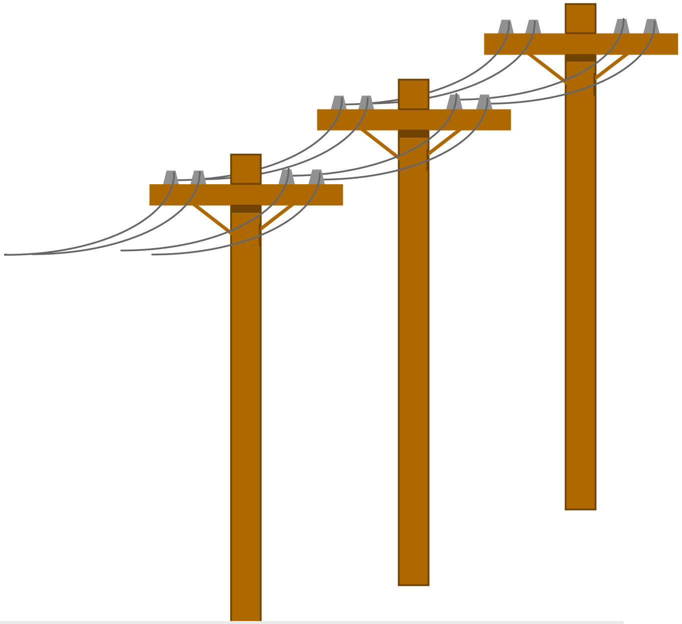
FASIT: Fault and interruption statistics

Norwegian standard

Nordic cooperation and harmonization

Enforced by the regulator. Main purposes:

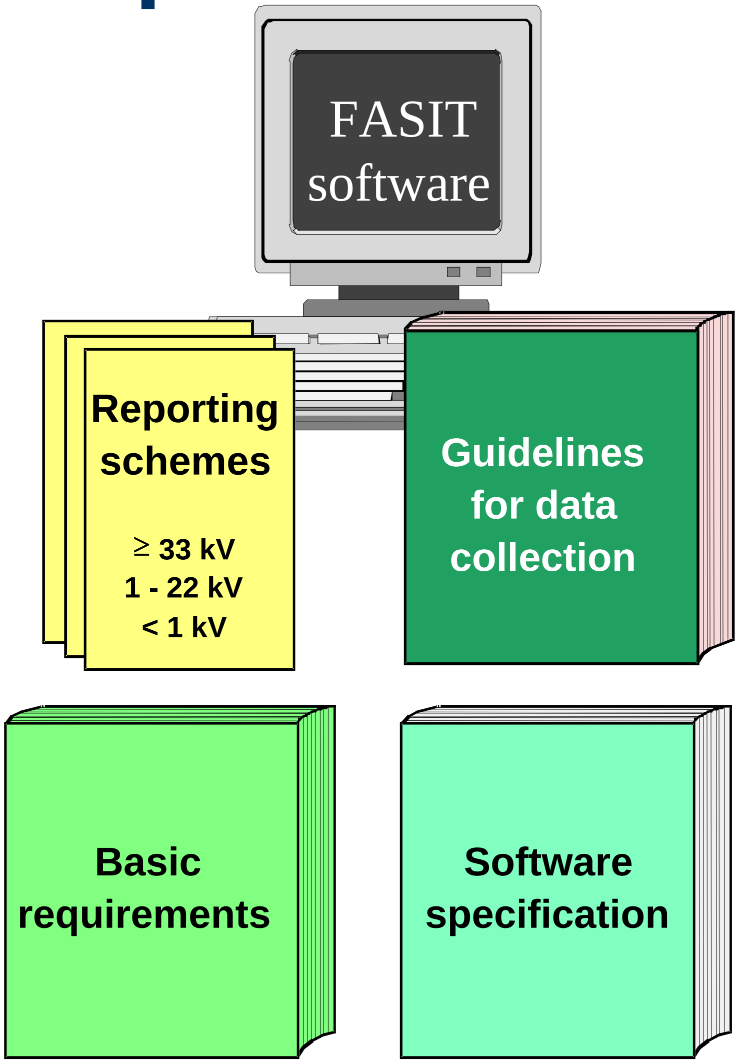
- Network expansion planning
- Planning of operation and maintenance
- Design and technical measures
- Standards for quality of supply
- Information to customers
- Quality adjusted revenues (CENS)
- Reporting of key figures
- Benchmarking



Heggset, J., Kjølle, G.: Experiences with the FASIT reliability data collection system, IEEE WM 2000, Singapore

Overview of the concept

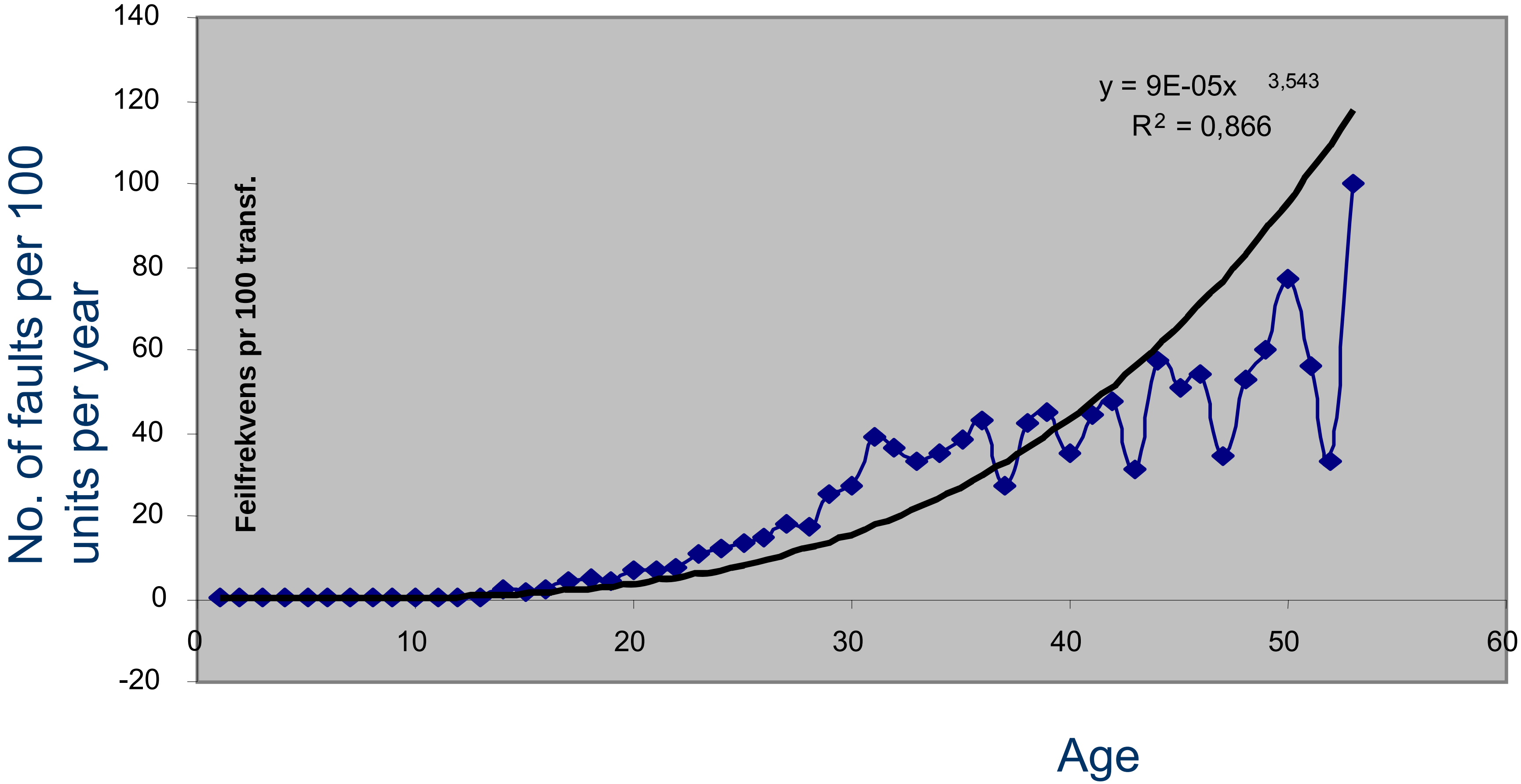
- Used by all T&D companies in Norway
- Software quality assurance (contracts and acceptance test)



Examples indicators :

Fault statistic information Fault rate distribution transformers

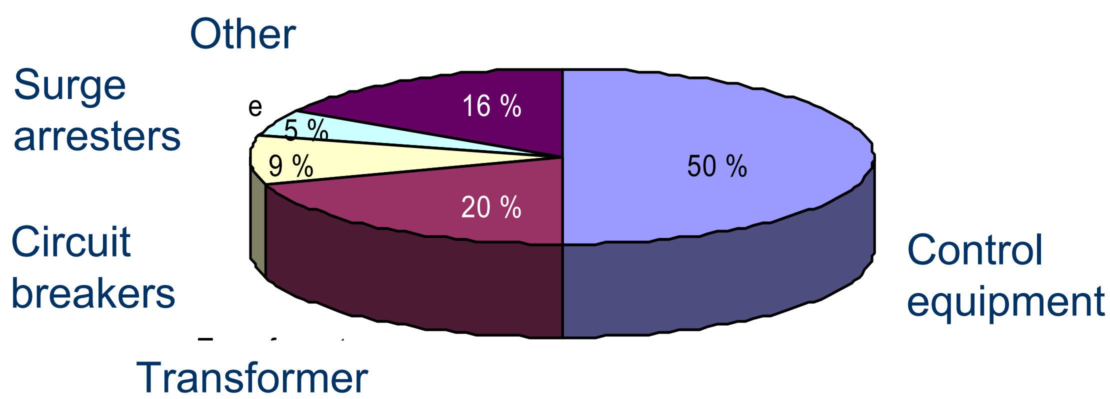
- from one utility with 6500 distribution transformers



Examples indicators :
Fault statistic information: Power transformers and aging

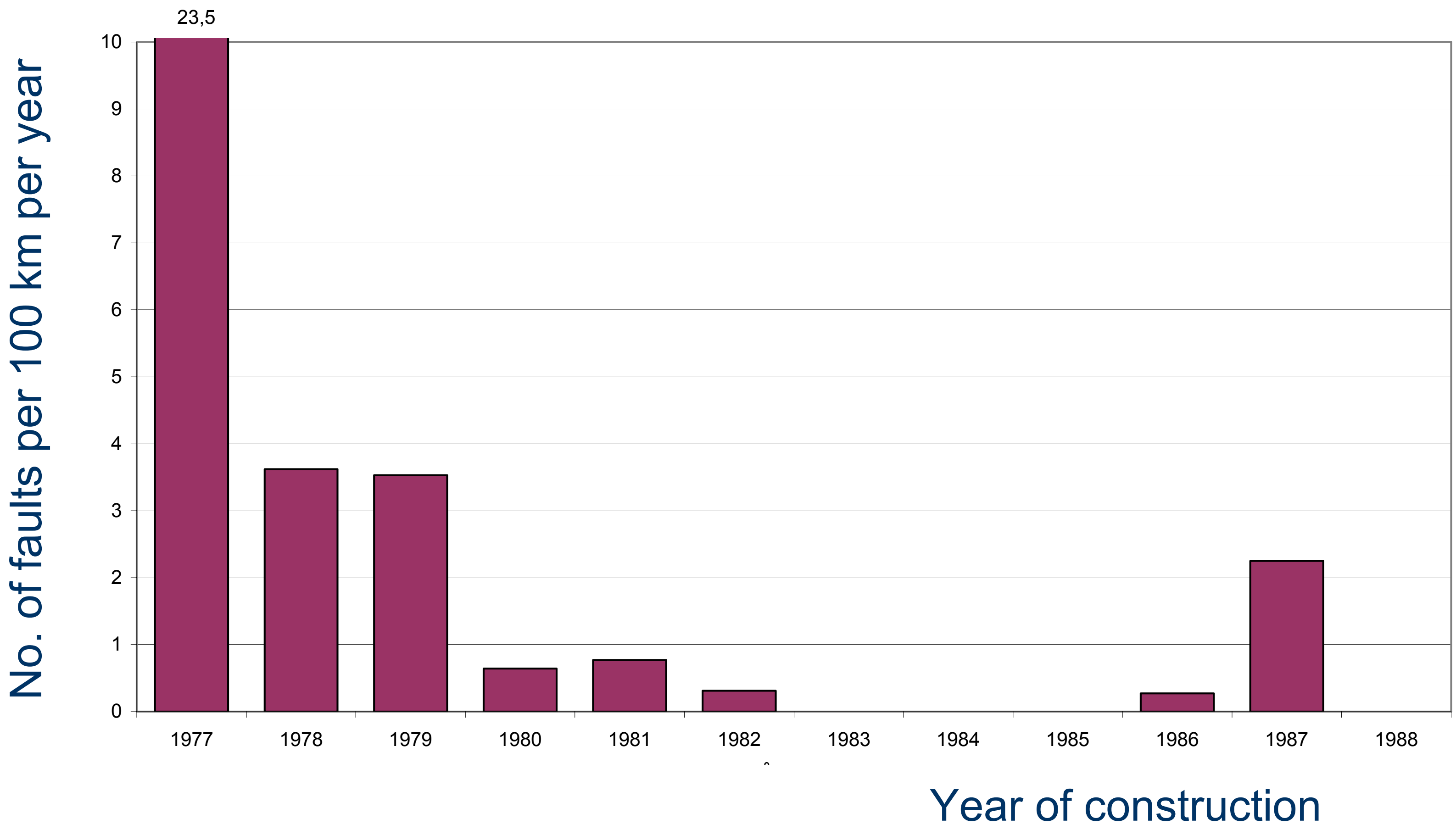
Statnett - (The Norwegian TSO)

Analysis of   1700 power transformers faults 1700 that occurred in the period 1983-95.



- No correlation between fault rate and age or voltage level or rating
- No correlation between age and repair time

Fault XLPE cable (crosslinked polyethylene) – of a spesific type



Spesific outage costs long outages (>3min)

Consumer	Non notified (1,3 hours) NOK/kWh	Notified (2,85 hours) NOK/kWh
Industry	66,4	46,0
Trade & Services	98,8	68,4
Agriculture	14,8	10,3
Household	8,4	7,4
Public offices	12,8	9,7
Wood processing & heavy industry	13,3	10,6

1 € - 8 NOK

Short interruptions and voltage dip

Consumer	Voltage dip (50% depth – 1 sec.) [NOK/kW]	Short interruption [NOK/kW]
Households	-	-
Industry	30,45	38,40
Trade & services	22,07	34,64
Agriculture	13,55	4,53
Public offices	1,60	1,41
Wood processing and heavy industry	5,64	8,23

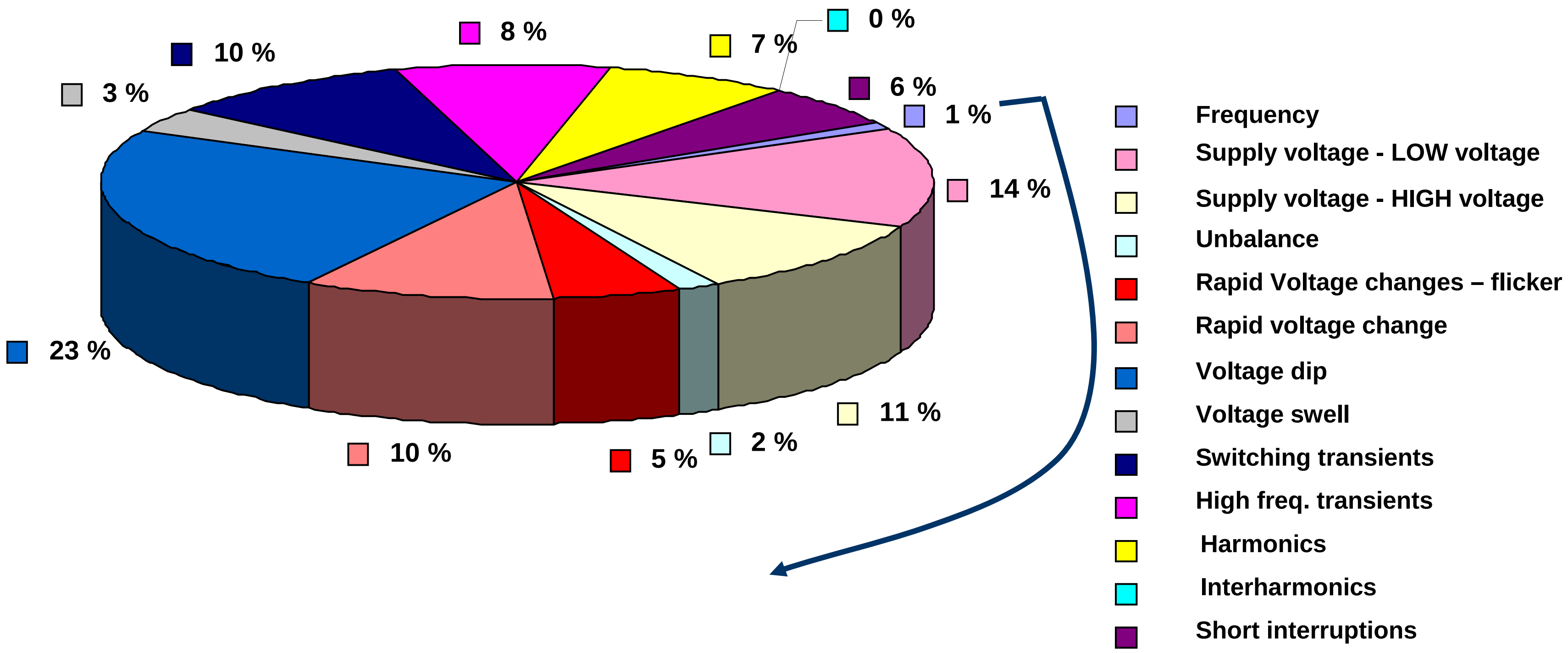
1 € - 8 NOK

National Power Quality Costs

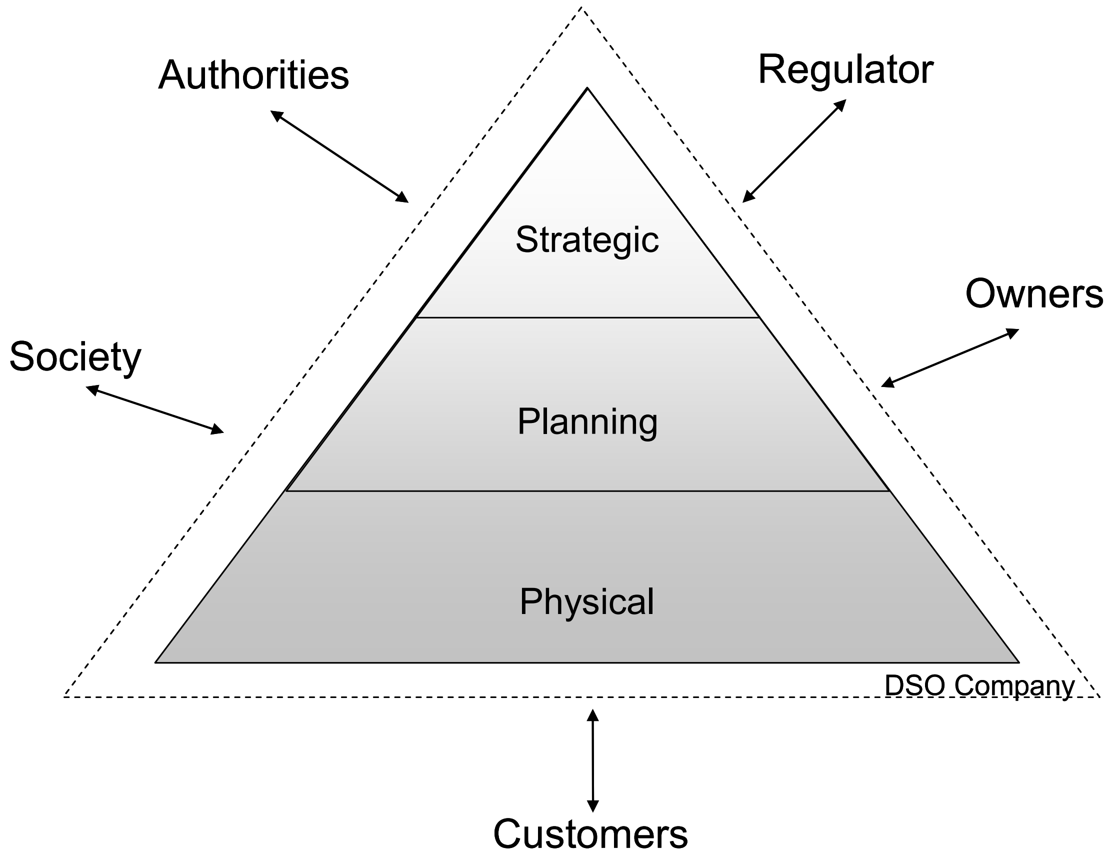
(per year)

Long interruptions (> 3min)	100 mill €
Short interruptions (< 3min)	75 mill €
Voltage dips	20-40 mill €
Total	195 – 215 mill €

Voltage quality - State of the art
142 analyzed customer complaints - all voltage levels



The DNO forces



Stakeholders - objectives

Stakeholder	Objectives
DNO - TSO	Good performance - good service - good reputation - fair/high income
Owner	Rate of return on assets - new spin-off business areas - regional industrial development. Good reputation
Economical regulator	Maximum efficiency - incentives for quality of supply
Safety regulator	Maximum safety - limit environmental impact
Customer	Low tariffs - 100% reliability. (Voltage quality not commonly understood) - safe installations
Producers of electrical equipment	100% reliability - Perfect voltage quality - Reasonable high emission limits (EMC)
Electricity generators	No congestion, low in-feed tariffs, high reliability

National and international Regulation - have great impact on the asset management agenda

Council of
European
Energy
Regulators

THIRD BENCHMARKING REPORT
ON QUALITY OF ELECTRICITY SUPPLY
2005

Trends - Norway

- Political decisions – regulation
  - National regulation uncertainty (Safety regulation, incentive regulation)
  - Harmonisation of the regulatory framework with the Nordic Countries and EU
  - Distributed Generation promoted and supported - increased influx of DG (small hydro)

- More demanding and professional DNO ownership
  - risk seeking owners
  - more budget constraints
  - increased documentation requirements (decision base, cost-benefit…)
  - utilizing grid infrastructure to develop new business areas
  - Outsourcing - new organizations

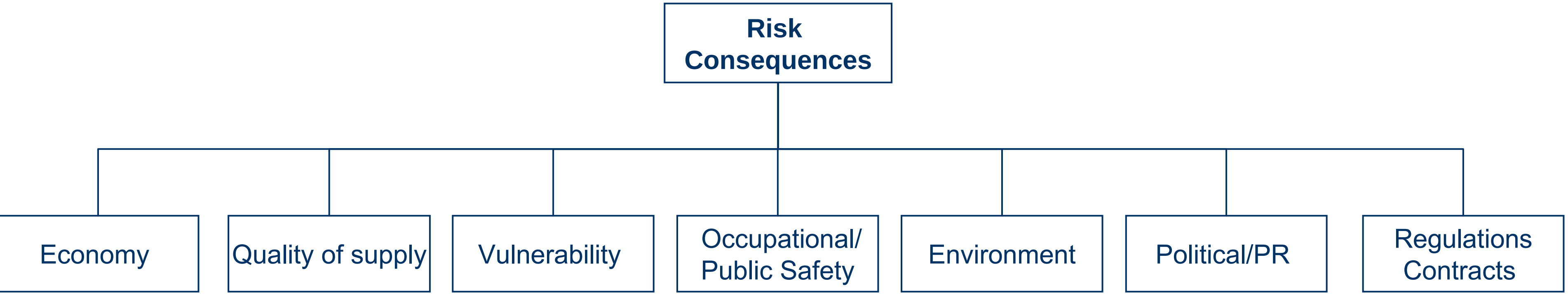
- Environmental consciousness increases
  - Transformer oil
  - SF_6
  - Wood poles creosote, chromated copper arsenate..)
  - Electric and magnetic fields (EMF)
  - Scenery etc.

- Increased electricity prices
  - Increased influx of heat pumps
    - reducing electrical winter load
    - increasing electrical summer load
  - Increased use of bioenergy sources for space heating and hot water generation
    - reducing electrical load
    - Micro CHP

Trends - Norway (cont.)

- Increased use of district heating and district cooling in urban area
  - reducing winter and summer load
- Increased metering requirements
  - AMR - hourly metering - two-way communication - increased data management challenges
- Increased quality of supply requirements
  - more measurements and documentation
  - increased financial risks when quality of supply limits or contracts not are met
  - increased customer expectations – requirements with a possibility of jeopardizing corporate brand if quality of supply performance decrease
- Aging people, aging work force
  - Technology expertise retired
- Aging assets (in general)
  - Increased fault rates for main components and protection
  - Asset life prolongation a big issue
  - Increased use of condition monitoring and diagnostics
  - Reduced safety
  - Spares difficult to obtain
- Risk elements climatic change: storms, floods, snowfall
- Lack of data - poor data quality in ICT systems and data bases

By and large - at lot at risk



State of the art - asset management - risk management

Risk = Probability x Consequence

Probability → Frequency of occurrence of Events

Probability category	Description
Unlikely	Less than 1 per 100 year
Infrequent	1 per 100 year or more
Occasional	1 per 10 year or more
Probable	1 per year or more
Frequent	10 per year or more

Consequence classification

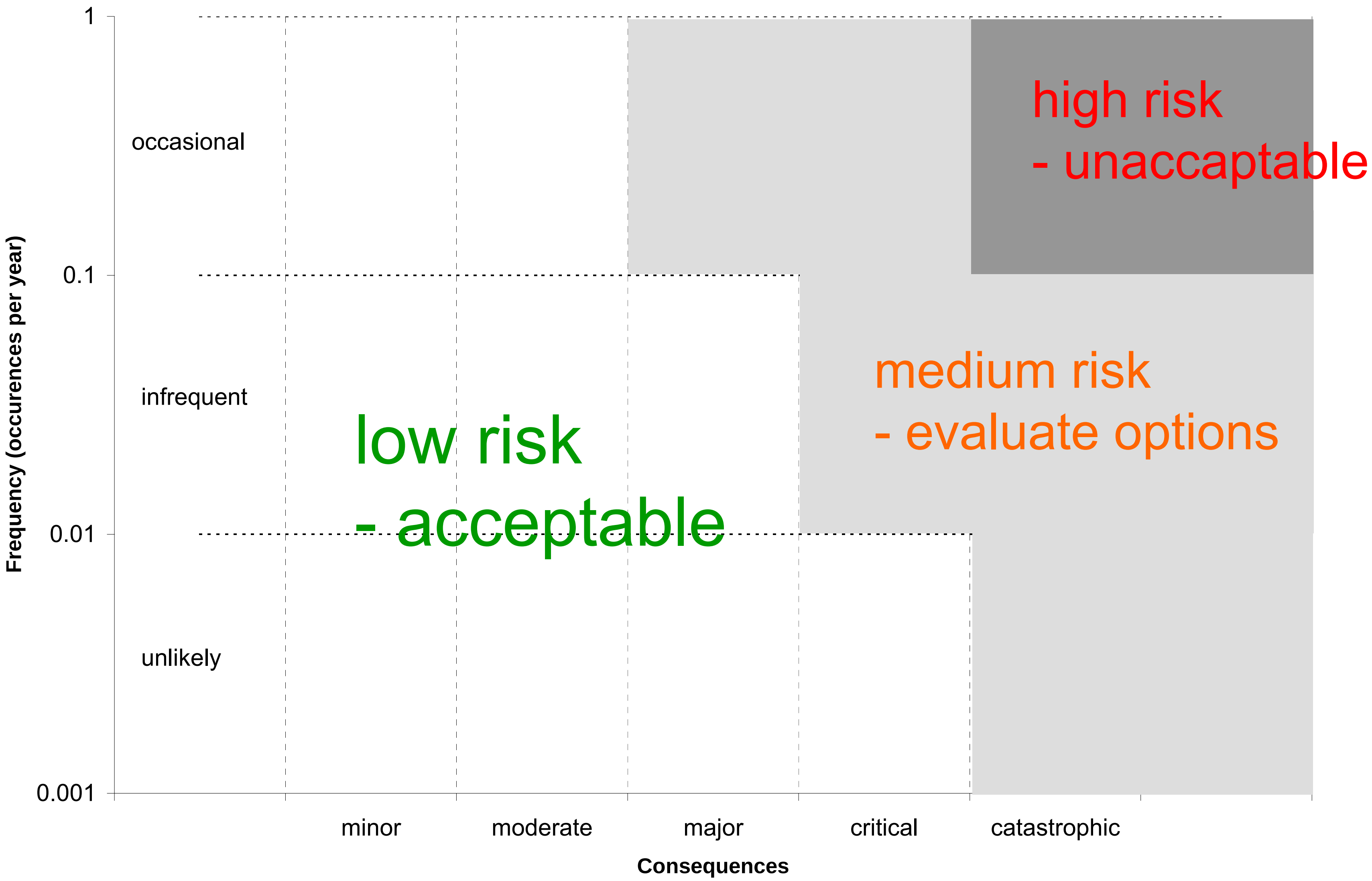
Consequence category
Minor
Moderate
Major
Critical
Catastrophic

Events:

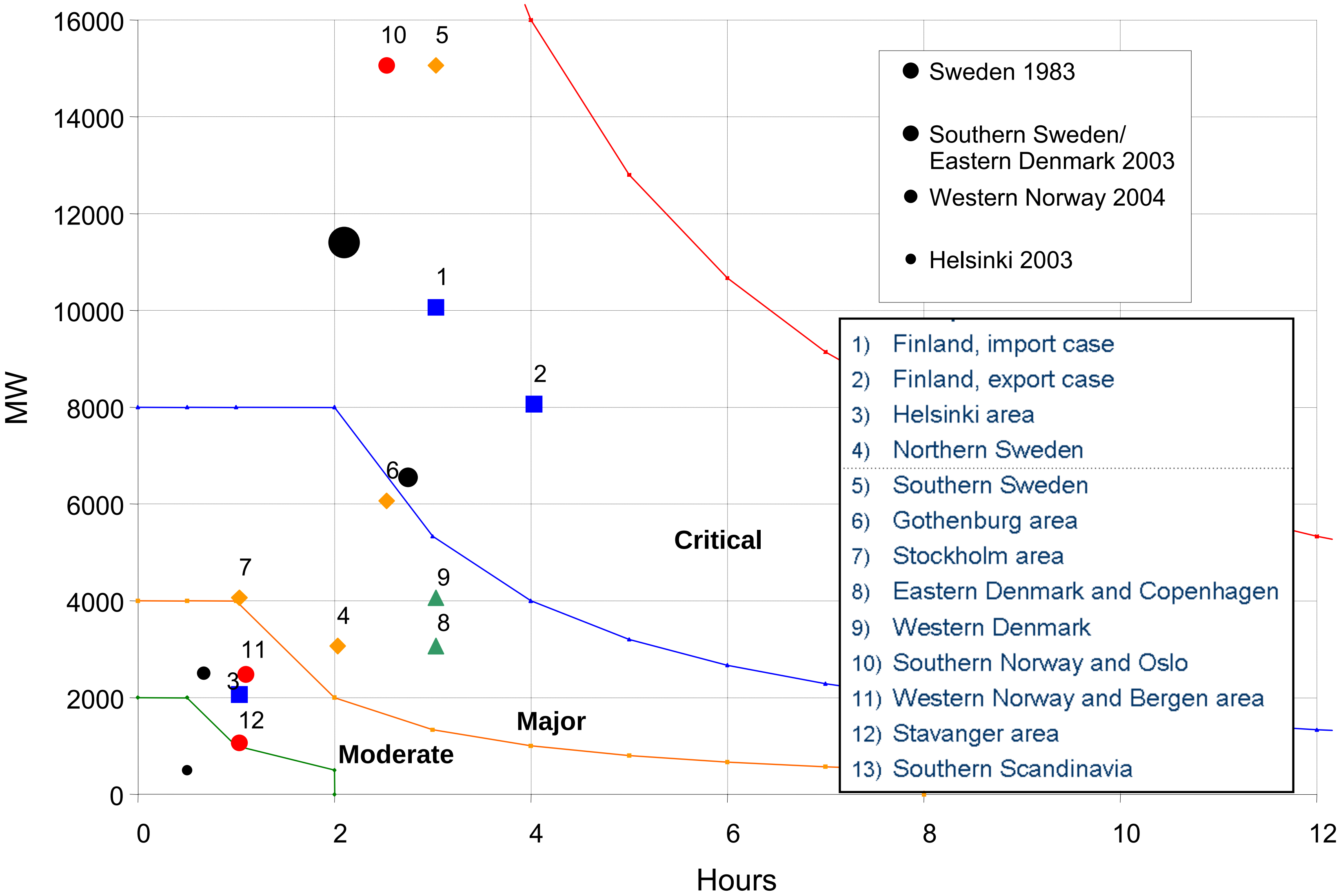
- **High price scenarios**
- **Blackout scenarios**

Vulnerability of the Nordic Power System, report no A5962

Risk Graph is commonly used

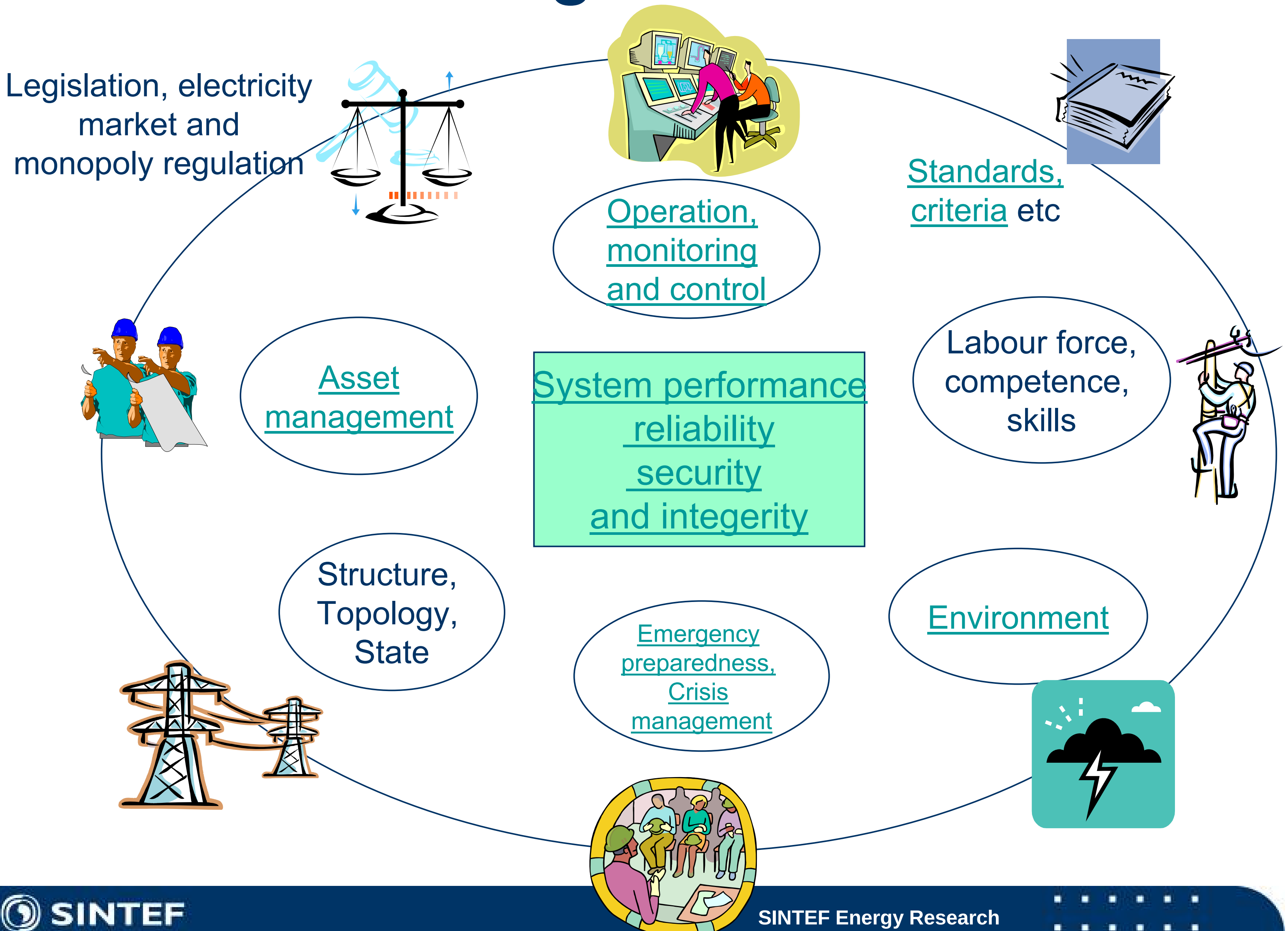


Results blackouts 2005

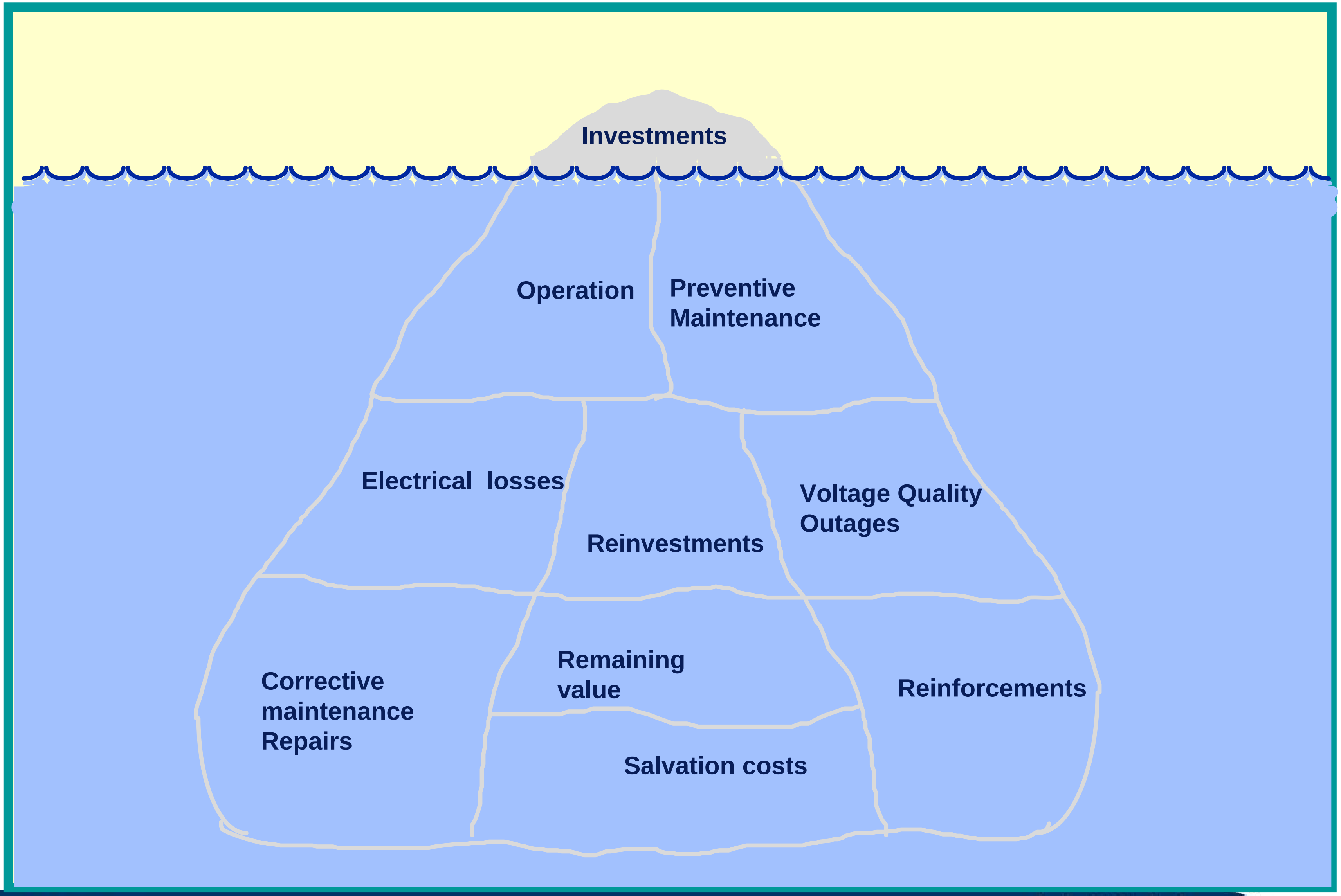


Vulnerability of the Nordic Power System, report no A5962

Risk Influencing Factors

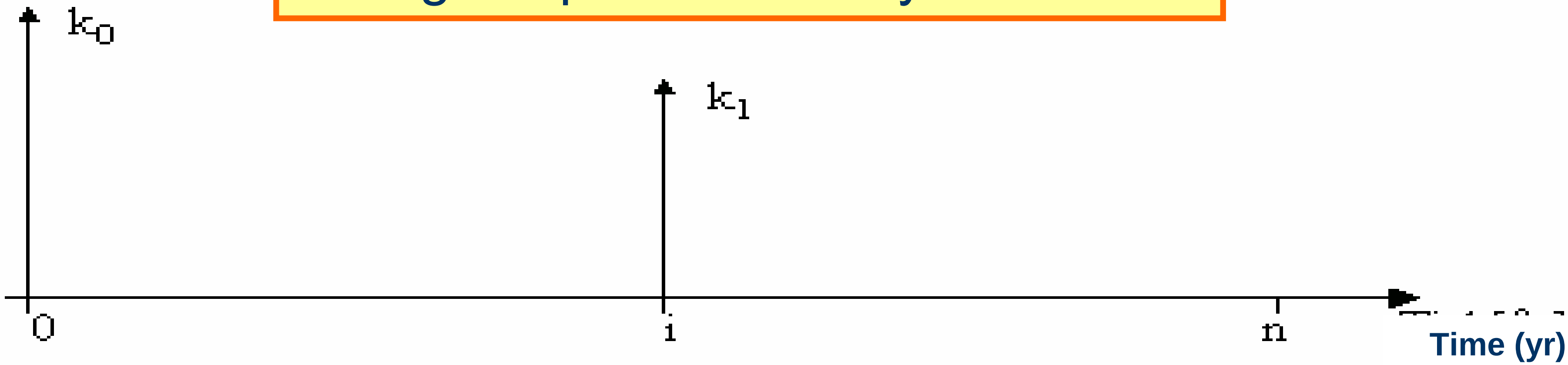


Life-cycle-cost management is used by some utilities.
Known as a philosophy by most DNOs, but not implemented by all

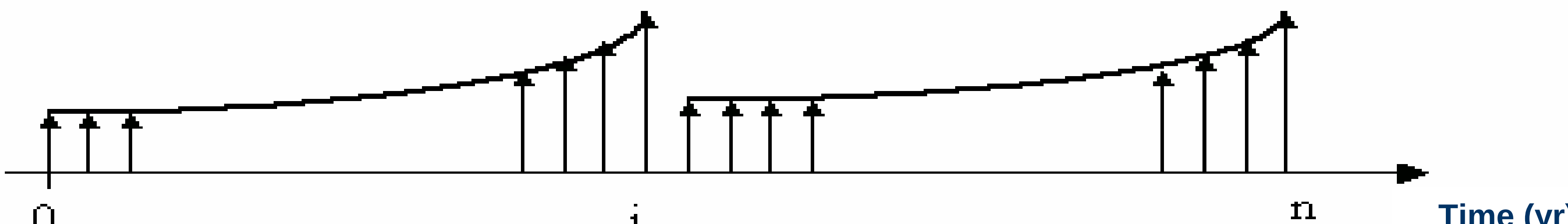


LCC Problem formulation:

Cost of measures at some stages during the period of analysis



Annual expected costs :
Electrical losses , outages, maintenance, repairs...



Analysis - data sources

Data source	Analysis	Output parameters
Inspections, Monitoring, Electrical simulations	Evaluation	Tasks for priority Fault rate implication Component state indicator
Component state indicators Asset cost catalogues	Estimation Aggregation	Subsystem indicators
Fault statistics	Evaluation/ component statistics	Distribution system weak points to be considered in reinforcement planning
Maintenance management history	Evaluation, statistics	Distribution system maintenance intensive points to be considered in reinforcement planning
Asset planning system – Maintenance system	Plan revision Task revision	Revised plans incl. costs Revised tasks incl. costs
Asset database Scada	Load flow Reliability analysis	Cost of electrical losses Asset loading Asset criticality (importance) Asset outage contribution Asset outage cost contribution
Asset database Plan database Cost catalogues	LCC analysis	Decision support: Ranking of plans and tasks Optimal timing

Power system LCC chain :

Inspection

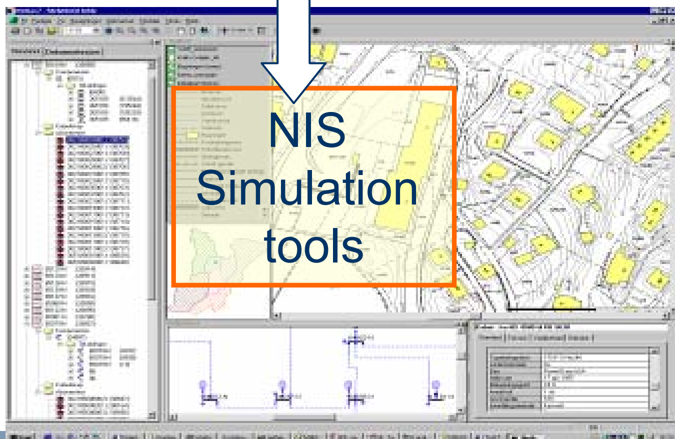
Component state/ state indicators

Objectives

- Regulations
- Contracts
- Power quality
- Electrical state
- Technical state
- Environment/esthetics

Documentation

(component register state info., component history, fault statistics)



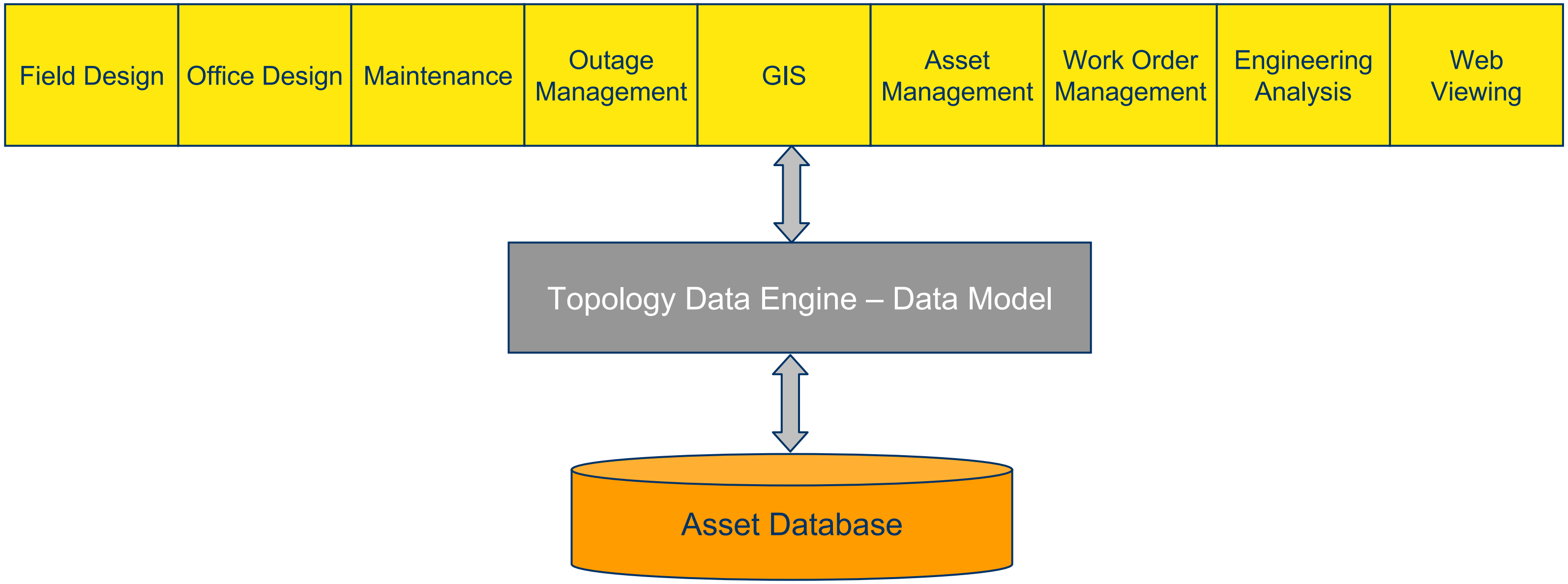
NIS

Simulation tools

LCC analysis

LCC optimization

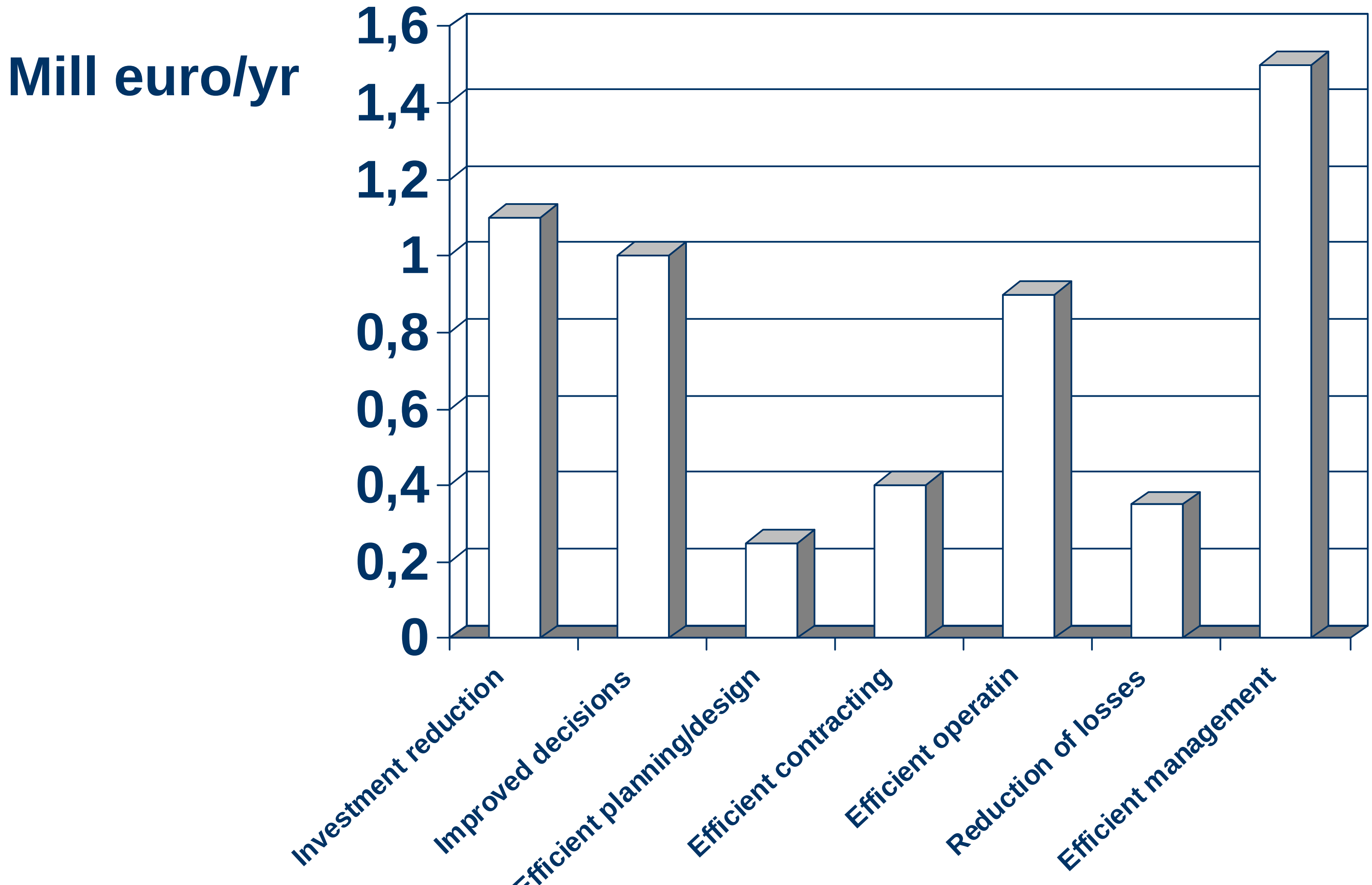
Utility Decision Support Platform(UDSP)
NetBas used by most utilities in Norway
- also used in other Nordic countries and outside



POWEL | miniMax

Annual NIS benefits -

BKK:	Annual revenue	70 mill euro/yr
	Annual investments	10 mill euro/yr
	NIS estimated benefits	5.4 mill euro/yr

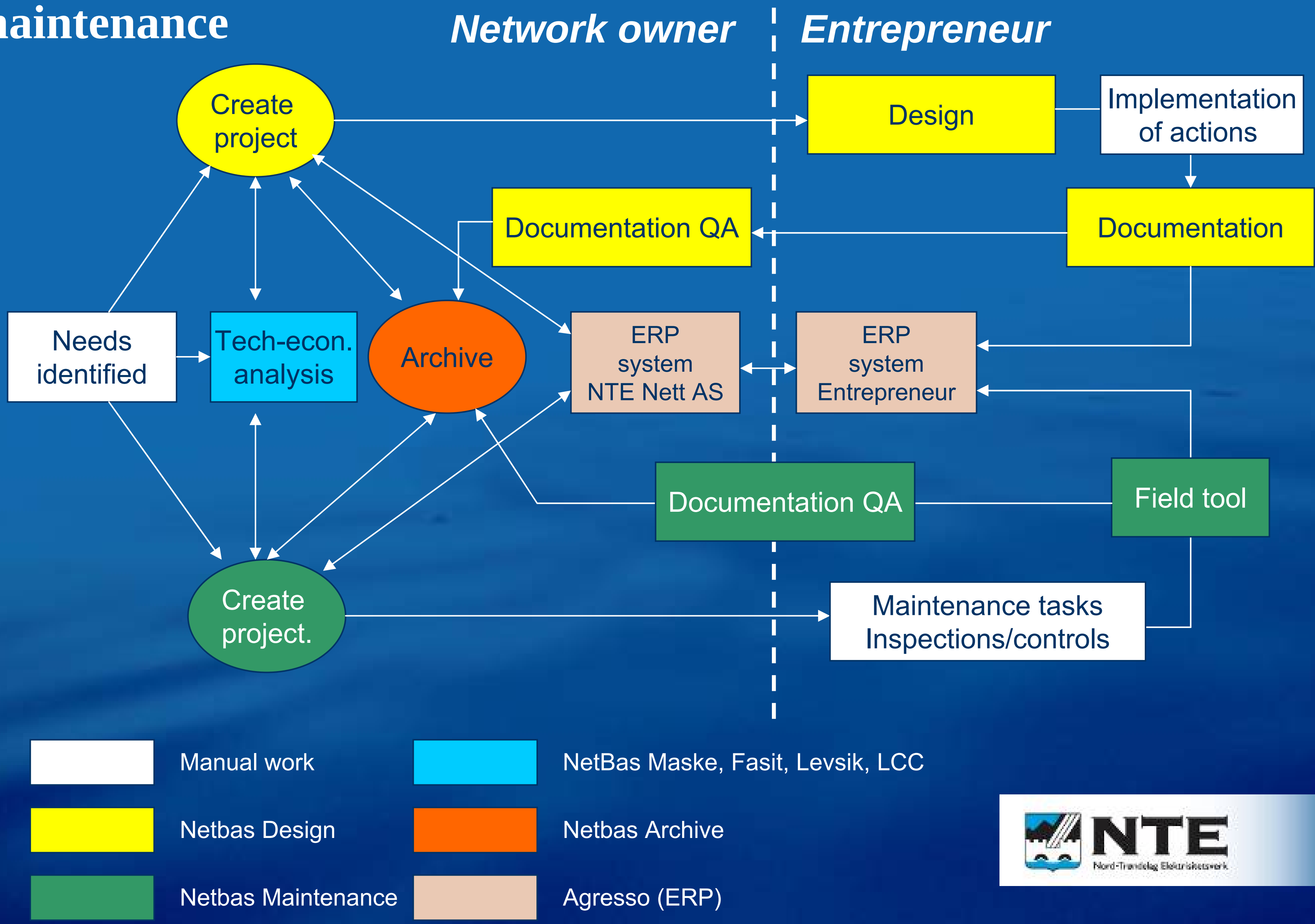


Re. Paper:CIRED, Nice 1999

Example support system relationship:

IT-system support Asset managent -planning – design – maintenance

Powel-dagene 2006

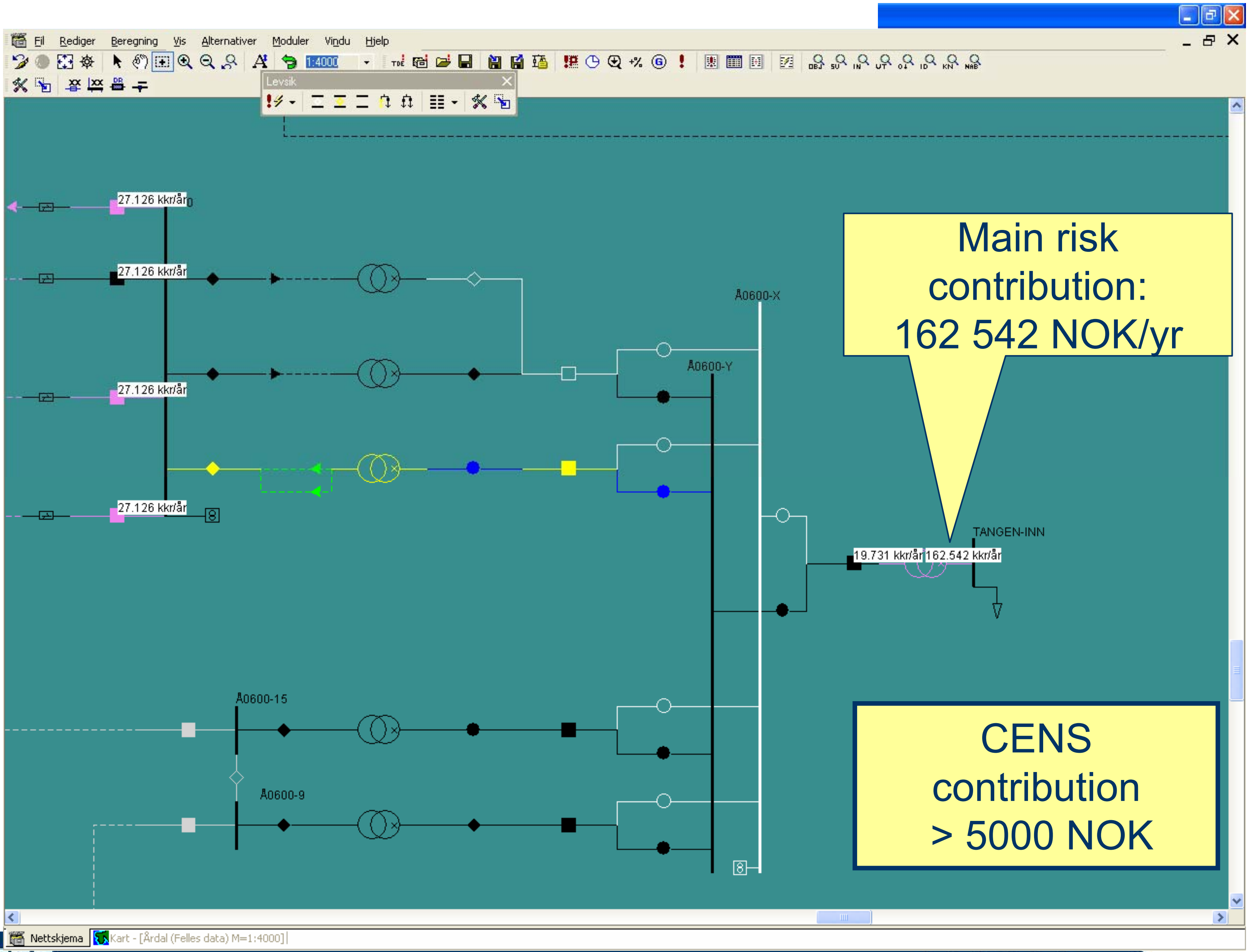


NTE
Nord-Trøndelag Elektrisitetsverk

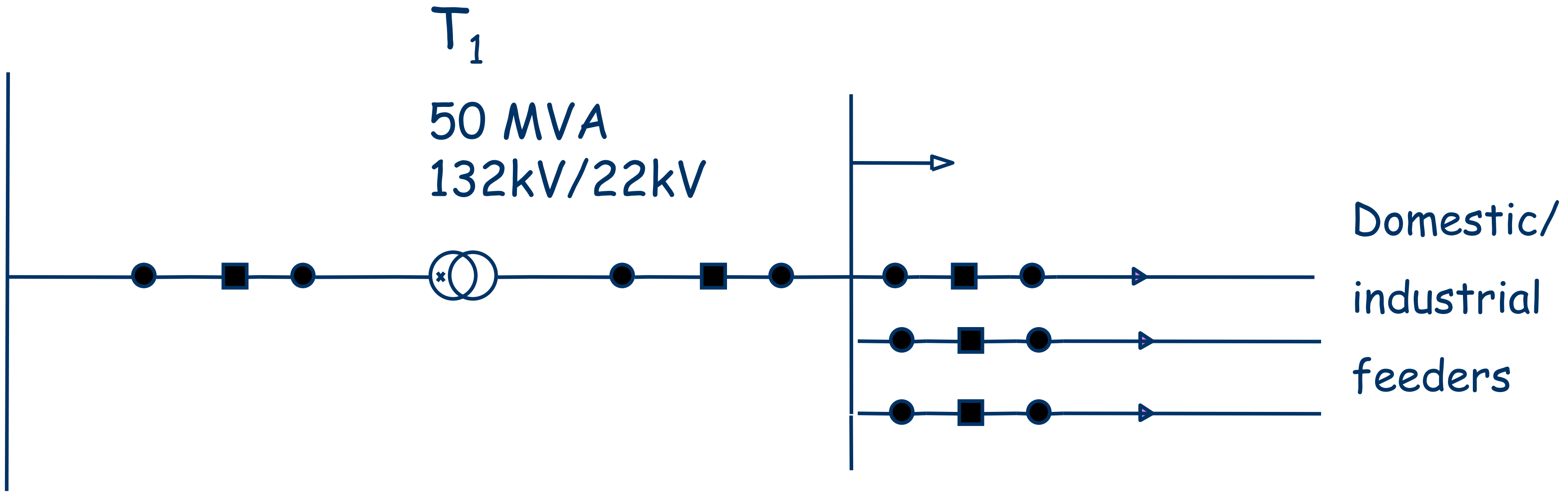
Reliability analysis in NetBas used for criticality evaluation.

- Three equal transformers 132/22 kV carry the same load
- Supply different customer categories
- Difference in substation layout (Case A and Case B)

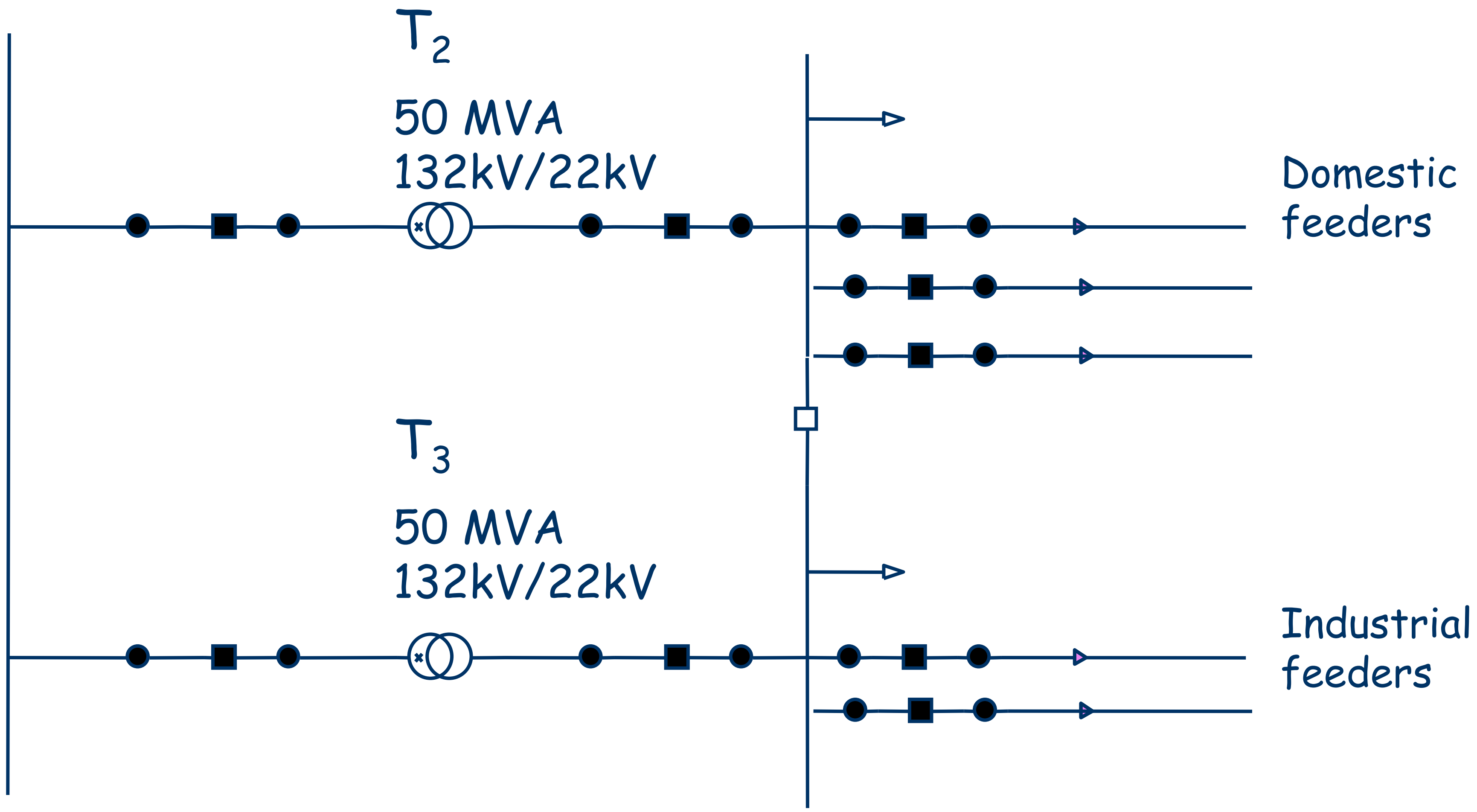
Example Tools: Reliability analysis



Case A



Case B

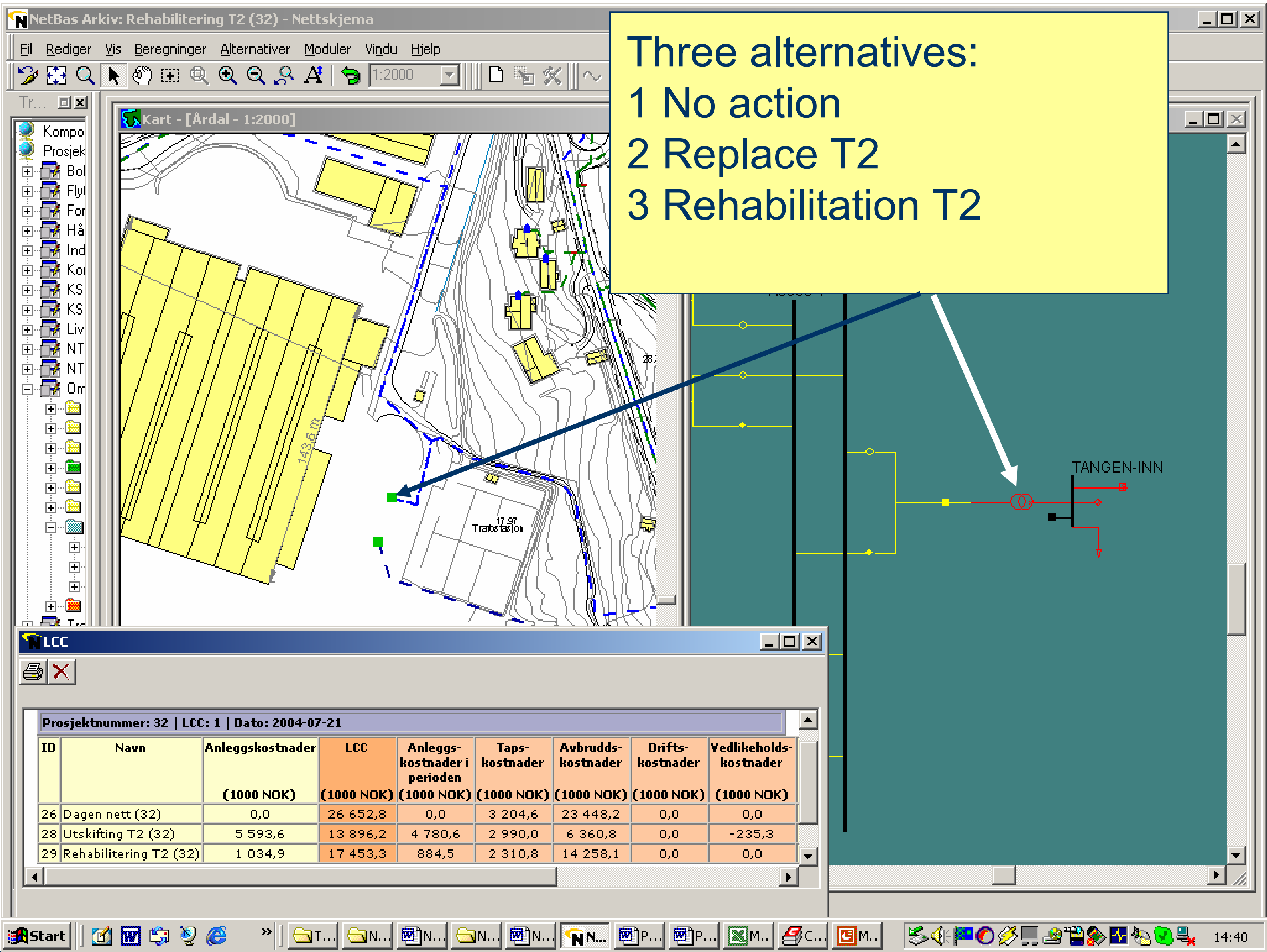

T_2
50 MVA
132kV/22kV
Domestic feeders
T_3
50 MVA
132kV/22kV
Industrial feeders

Criticality measured by outage costs evaluation using a NIS reliability tool

	Penalty and repair costs due to T_1 [1000 NOK/yr]	Penalty and repair costs due to T_2 [1000 NOK/yr]	Penalty and repair costs due to T_3 [1000 NOK/yr]	Penalty and repair costs due to remaining power system [1000 NOK/yr]
Average transformer conditions i.e. average fault statistics				
Case A	4111	-	-	768
Case B	-	594	1981	1037
Aged transformer conditions i.e. 10 times increased probability of winding fault compared to average statistics				
Case A	7451	-	-	768
Case B	-	849	2548	1037

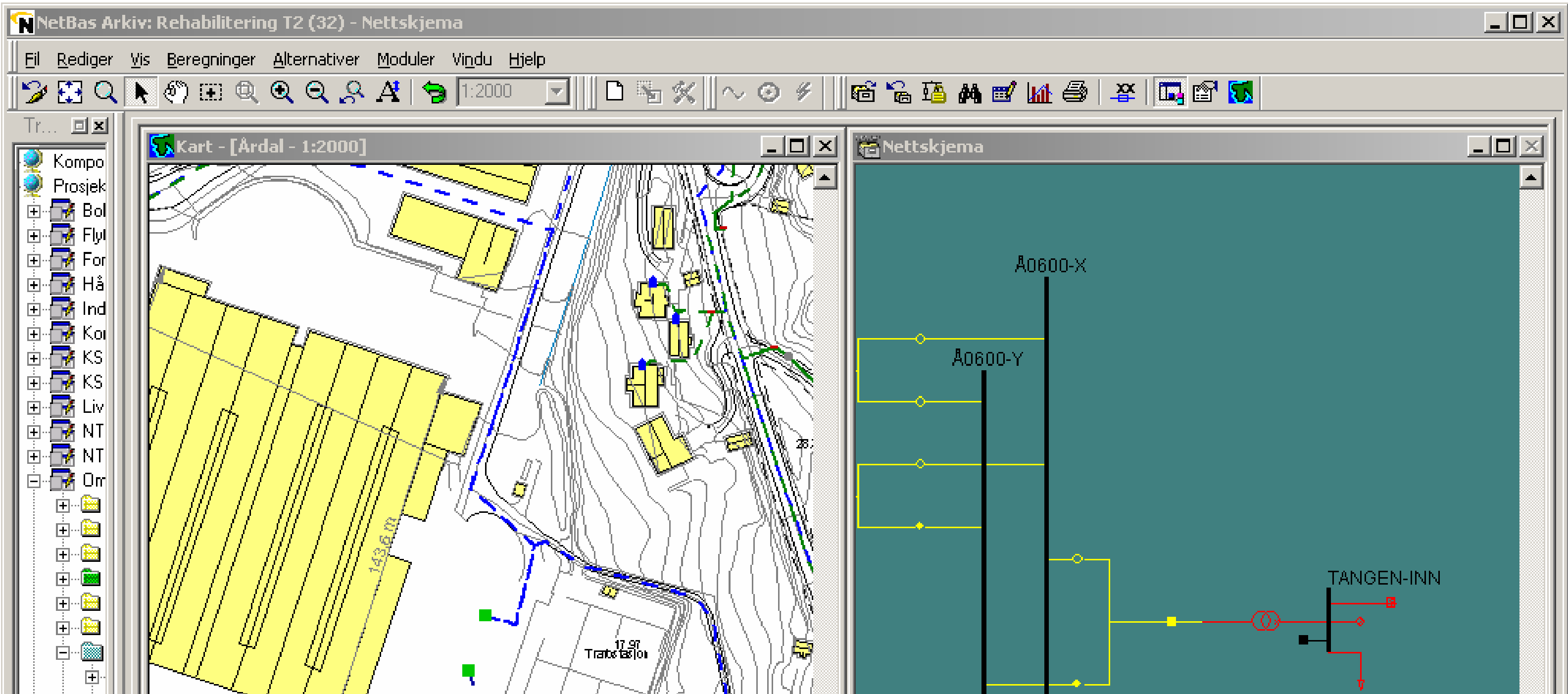
LCC in practice

Three alternatives:
1 No action
2 Replace T2
3 Rehabilitation T2



ID	Navn	Anleggskostnader (1000 NOK)	LCC (1000 NOK)	Anleggs-kostnader i perioden (1000 NOK)	Taps-kostnader (1000 NOK)	Avbrudds-kostnader (1000 NOK)	Drifts-kostnader (1000 NOK)	Vedlikeholds-kostnader (1000 NOK)
26	Dagen nett (32)	0,0	26 652,8	0,0	3 204,6	23 448,2	0,0	0,0
28	Utskifting T2 (32)	5 593,6	13 896,2	4 780,6	2 990,0	6 360,8	0,0	-235,3
29	Rehabilitering T2 (32)	1 034,9	17 453,3	884,5	2 310,8	14 258,1	0,0	0,0

LCC results - period of analysis 20 year



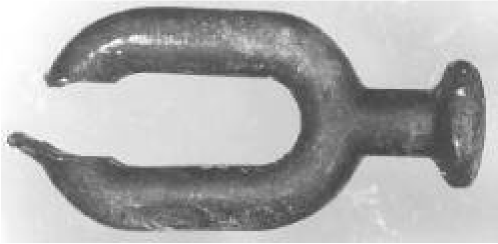
Name	LCC (1000 NOK)	Invest-ments (1000 NOK)	Cost of losses (1000 NOK)	Outage costs (1000 NOK)	Operating costs (1000 NOK)	Maintenance costs (1000 NOK)	Benefit compared to existing system (1000 NOK)	Benefit compared to existing system (%)
No action	26 652,8	0	3 204,6	23 448,2	0	0	0	0
Replace T2	13 896,2	4 780,6	2 990,0	6 360,8	0	-235,3	12 756,6	47,9
Rehab. T2	18 347,2	884,5	3 204,6	14 258,1	0	0	8 305,6	31,1

Conclusions

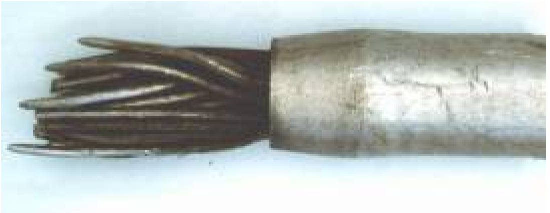
- Regulation heavily influences asset management
- Benchmarking a great challenge still
- Regulatory requirements improve documentation for asset management
- Quality of supply regulation - an important issue-developing
- More short term focus - a challenge
- Risk based tools more used - detailed fault statistics a challenge
- The utilities are improving, but slowly -disturbed by new business areas

Condition monitoring and diagnosis to be utilized better in the asset management chain

Overhead line suspension



OH joint damage due to increased current



Damage due to increased current

Woodpecker damage

Rot

Concrete Pole foundation damage

Corrosion OH line - colored conductor

Corrosion - stay

The Norwegian distribution system anno 2030?

or…