RISØ

Systems Analysis Department

Annual Progress Report 1998

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Abstract

The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1998. The department is undertaking research within Energy Systems Analysis, Energy, Environment and Development Planning – UNEP Centre, Industrial Safety and Reliability, Man/Machine Interaction and Technology Scenarios. The report includes lists of publications, lectures, committees and staff members.

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Introduction

Hans Larsen, Head of Department

In 1998 the research has covered Danish, European as well as global issues, addressing both the requirements of industry, e.g. the chemical and process industries, transport sector, and electric utilities as well as those of Danish public authorities and international organisations like UN, WB, and EU. The research activities of the department are undertaken within the following research programmes:

- *Energy Systems Analysis*, Frits M. Andersen
- *Energy, Environment, and Development Planning, UNEP Centre*, John M. Christensen
- *Industrial Safety and Reliability,* Nijs J. Duijm (Kurt E. Petersen until March)
- *Man/Machine Interaction,* Leif Løvborg
- *Technology Scenarios,* Per D. Andersen, from ult. 1998.

It was decided in 1998 to merge the two research programmes, Industrial safety and reliability, and Man/machine interaction and form a new programme: Safety, reliability, and human factors. The new programme was operational from 1. January 1999 and is headed by Nijs J. Duijm. During 1998 a contract was signed with the Danish National Research Foundation regarding the establishment of a Danish Centre for Human-Machine Interaction. The centre is managed by Risø, with Annelise M. Pejtersen as centre leader, and is implemented in collaboration with the Computer Science Department (DAIMI) and Institute for Information and Media Science at Aarhus University. Other participants are DTU, DMI and Danfoss A/S. Finally, Risø has in 1998 signed an agreement with the National Environmental Research Institute (NERI) on the establishment of: Centre for Analysis of Environment, Economy and Society. The centre comprises the Energy Systems Analysis programme and Systems Analysis Department at NERI. The centre is managed jointly by Risø and NERI and was operational from January 1999. In 1998, 61 per cent of the department's activities were financed through national and international research contracts or contracts with national agencies and international organisations as well as industrial companies and utilities. The remaining 39 per cent were financed by governmental appropriations. The total turn-over of the department in 1998 amounted to approximately 50 mil. Dkr. By the end of the year, the total number of employees in the department was 60. This included an academic staff of 54, namely, engineers, natural scientists, and economists as well as social and behavioural scientists, of whom 10 were either PhD students at various Danish universities or postdoc fellows. There were 6 secretaries and technical support staff.

Energy Systems Analysis Programme

The aim of the research programme is to develop methods for analysing energy, environmental, and economic issues and the interactions between them, and to adapt new technologies to complex energy systems. In 1998 the major activities can be grouped into: analysis of instruments and markets for energy, development of methods for analyses and projections of energy consumption and emissions, and analyses of new technologies and their integration/adaptation into energy systems. In 1998 activities have included analyses of instruments for international reductions of greenhouse gas emissions such as Joint Implementation and tradable CO_2-permits, and analyses of liberalised power markets in Northern Europe and possible effects of imperfections in these markets. Work has been undertaken on the update and further development of the INDUS-model, which is used for extrapolating energy consumption and emissions for industrial sectors in Denmark. Other important activities in 1998 were analyses of interactions between structural changes in the economy, technological development and energy consumption, and the development of methods and models for projection of air emissions and generation of waste. In collaboration with the World Bank, local authorities, and research institutes, Danish models and methods are being adapted for planning purposes in Mexico. Finally, activities have focused on sustainable energy including large-scale wind energy and the potential for electrical vehicles as players in the electricity market.

Energy, Environment, and Development Planning

The programme on Energy, environment, and development planning is hosting the UNEP Collaborating Centre on Energy and Environment. The centre has the overall objectives of promoting the integration of sustainable development concerns in energy policy and planning, especially in developing countries, and supporting the formulation and implementation of UNEP's programmes within the areas of energy and climate change. Activities on the establishment and application of methodological guidelines for national climate change mitigation analysis continued under a project sponsored by the Global Environment Facility and UNEP. The project also includes collaboration with national teams in 15 countries in Africa, Asia, Latin America, and Eastern Europe with emphasis on capacity building. The establishment of the so-called Kyoto-mechanisms – Joint Implementation, Emissions Trading, and the Clean Development

Mechanism (CDM) – as part of the Kyoto Protocol has added new tasks to the centre's activities. A major activity in 1998 was the organising of an African regional workshop on "New Partnerships for Sustainable Development – The CDM Under The Kyoto Protocol". Further, centre staff is actively involved in the activities of the Intergovernmental Panel on Climate Change (IPCC). Staff members have been selected as lead authors to various reports. In 1998 the centre has been selected to support UNDP & UNEP in the implementation of a major new "National Communications Support Programme", funded by GEF and a number of bilateral donors. Activities related to renewable energy technologies (RET) have increased significantly including the start-up of national RETs implementation studies in Ghana, Egypt, and Zimbabwe, a workshop for Caribbean islands, and finalisation of a report on policy instruments to promote RETs in Thailand.

Industrial Safety and Reliability

The aim of the research programme is to develop methods for analysing the safety and reliability of complex technical systems taking into account organisational and human aspects. The activities include both theoretical and experimental work. In 1998 two projects that have been undertaken are related to the co-operation with the OECD-Halden Reactor Project. One project covers the development of strategies for display design for control systems. The second project is about online diagnosis of control systems to anticipate failures at an early stage. Within the national energy research programme, the investigations in reliability of wind turbines continued in close co-operation with Risø's wind turbine test centre and the Danish wind turbine industry. A number of new EU-funded projects were initiated in 1998, all related to risk analysis and atmospheric dispersion of hazardous materials. A project was started on the dispersion of anhydrous hydrogen fluoride (AHF), a highly toxic substance used in some industrial processes. Risø is involved in the experimental design and theoretical modelling by expanding the existing GReAT dispersion model. Another project looks at concentration fluctuations in plumes. A new EU-network project, Safety-Net, has been launched with the purpose of disseminating information from EU-projects on industrial safety to European industries. Within the EU-LIFE project on environmentally acceptable disposal of ammunition, a preliminary assessment of a series of treatment and disposal techniques was performed.

Man/Machine Interaction

The aim of the research programme is to develop methods for analysing the interaction between people and advanced technical systems with a view to establishing concepts for safe and efficient execution of complex industrial work tasks. The final evaluation of a novel type of flight simulator was carried out in 1998 as the conclusion of a large Esprit project (MATE – Multi-Aircraft Training Environment). The evaluation demonstrated that the MATE flight deck trainer compares well with conventional means of supporting aircraft procedures training. The MATE trainer was awarded a European IT prize under the theme "Novel products with a high IT content and evident market potential". A project (HERA – Human Error in Air Traffic Management) was started in 1998 in collaboration with National Air Traffic Services (UK), funded by Eurocontrol. The project will establish and seek to validate a human error taxonomy to be applied to incident reports involving air traffic control. In collaboration with research partners in Denmark, the USA, and Japan, an extensive survey of attitudes to safety critical issues among seafarers – officers and non-officers – in several ship companies in Europe and Asia has been undertaken. Finally, a new project, CANTOR (Converging Agreement by Networking Telematics for Object Recognition), funded by the EU Telematics Healthcare programme, has been launched with Risø as the co-ordinator.

Technology Scenarios

The aim of the research programme is to undertake analyses of commercial, societal, and scientific possibilities as well as the consequences in relation to selection, development, and commercial application of new technologies. In 1998 three test cases have been selected with the purpose of developing research methodologies. In collaboration with NKT Research Centre A/S, superconducting thin-layer technology has been selected as the first test case. Furthermore, in collaboration with the Plant Biology and Biogeochemistry Department at Risø, two cases concerning the development and application of genetically modified crop plants are under consideration. During 1998 a small technology strategy project has been carried out for Dantec Measurement Technology A/S in co-operation with Risø's Optics and Fluid Dynamics Department. Finally, a workshop on Technology Forecast and Scenario Development was held at Risø with 45 participants in conjunction with the 2nd meeting of the Scientific Advisory Panel.

Energy Systems Analysis

Flexible instruments for CO_2 reduction on the European electricity market

Shared Analysis logo

The European energy sector faces the dual challenge of markets being liberalised and environmental standards being tightened: The traditional command-and-control regulation will not be adequate for the new market conditions and new instruments are needed that will be consistent with the further development of the competitive European market for electricity and gas. In the Protocol of the Kyoto Conference on Climate Change in December 1997, the European Union and its member states were committed to reduce the emissions of CO_2 and five other greenhouse gases by 8% during the 2008-12 period, compared with the 1990 baseline. As a contribution to the burden sharing among the EU member states, Denmark has agreed on a reduction of 21% compared to the 1990 emission level, corrected for the very substantial import of hydro power in that year.

The agreement includes a set of flexible instruments, all of which have the aim of reducing abatement costs. Some of these instruments are regional burden sharing, tradable emission permits, and joint implementation. Tradable permits are licenses to pollute that are initially distributed to polluters, either free of charge – so-called grandfathering – or auctioned away. Once distributed, the permits are property rights that may be traded on a market. Joint Implementation (JI) is a mechanism whereby a 'donor' country (or countries) funds emissions reduction projects in a 'host' country in return for a relaxation of its own emissions targets. Both of these instruments have been much debated within international climate policy.

Policy instruments for implementing renewables in a liberalised energy market

A number of different policy instruments have been used in Denmark to promote the development of renewables. Among these can be mentioned: Investment and production subsidies, power purchase agreements, tax credits for different ownerships, and carbon and energy taxes on conventional energy supply technologies. Can these instruments be used in a liberalised market context to regulate the development of wind power? If this is the case, how will the effect of these instruments eventually be changed? Will there be a need for supplementary instruments, especially designed for use in a free market context? These issues are addressed in a project on the use of policy instruments in the long-term implementation of renewable energy technologies under free market conditions, which is carried out under the Danish Strategic Environmental Program.

The project will include new model development to quantify the necessary changes in taxes and subsidies, eventually facing a total restructuring of the existing Danish system for promoting renewable energy technologies. The project will continue until 2000.

A European market for tradable CO_2 permits?

Tradable emission permits may be seen as a politically attractive alternative to harmonised European energy and carbon taxes. In the United States a market for SO_2-permits was successfully introduced as a part of the Acid Rain Programme. Will it be possible to transfer this experience to a future European market for CO_2-permits?

This issue is addressed in a project started in 1998 by ELSAM Projekt, Aarhus School of Business, and Risø, financed by the Danish Energy Research Programme.

The aim of the project is to assess the possibility of using tradable permits as a way to meet the agreed reduction targets for CO_2-emissions within a liberalised electricity market, focusing on the institutional framework and economic consequences for example: who will be the traders, how can compliance be monitored and enforced, where will the trades take place and what will be the price of the permits, and who pays in the end?

The quantitative impact for electricity production and international electricity trade are analysed by well-established modelling tools, focusing on techno-economic optimisation models, which can be used as bottom-up elements in econometric and macroeconomic models (top-down models). These are used for co-operative studies within the EU, e.g. PRIMES and E3ME. The project will be finished in 1999.

Joint Implementation

Risø has participated in two projects on Joint Implementation. One is a European project that is co-ordinated by University of Surrey, UK and funded by the European Commission DG XII under the Environment and Climate RTD Programme. The other is funded by the Danish Energy Research Programme 97 (EFP). Both projects will be finished in 1999.

The objective of the EFP-financed project is to give a systematic description of Joint Implementation as an instrument used within

international climate policy, both from a theoretical and practical point of view. One of the aims is to deliver a background for Danish political decision making in this field.

Joint Implementation is compared to alternative international instruments like tradable permits, tradable quotas, and environmental taxes. These are all cost-effective instruments, but the mechanisms behind differ, and so do the practical implementation problems. The scope for Joint Implementation is discussed in relation to liberalised energy markets and increased international trade. The project focuses on how agents' incentives to react will be under a system with Joint Implementation. It attempts to design institutional frameworks for Joint Implementation which cope with the undesirable incentives and the monitoring and control problems. As part of the project, it is analysed whether Joint Implementation with countries without fixed reduction targets give these countries a negative incentive to make later commitments to fixed reduction targets.

The main issues treated by the European project include: (a) methodologies for the accounting of emissions reduction of a JI project; (b) accreditation of this reduction; and (c) how equity considerations may be included in JI project assessment. Especially accounting issues have been analysed in detail in the project with emphasis on how to treat uncertainties related to baseline development.

The project has examined the implications of different types of approaches to the assessment of emission reduction of greenhouse gases using actual JI projects in the energy sector in Eastern Europe. The analysis has concentrated on the environmental efficiency of the approaches and looked in detail at the inherent uncertainties and how to minimise them with a package of measures including a simplified approach to baseline construction. The analysis points the way for possible options for implementing JI as a fair and efficient means of reducing emissions of greenhouse gases.

As the largest single source of uncertainty in accounting for emissions reductions, the project points to the counterfactuality of the baseline, where the main sources of uncertainty tend to be the choice of technology and timing of its introduction. Analyses show that significant simplifications in baseline construction can be made without compromising the environmental

Figure 1
The Avedøre power plant in Denmark.

objectives of the United Nations Framework Convention on Climate Change. Energy Analyses and Forecasts Study.

The Protocol of Kyoto demands an active climate change policy of the EU and its member states with radical changes in the political choices and energy market structures. The commitment to reduce the six greenhouse gases by 8% until 2008-12 requires an analysis of the economic trade-off between the six greenhouse gases. And the burden sharing among EU member states will need further analysis and further decisions.

Risø participates in a consortium of 9 European institutes for a project for the European Commission, DG XVII (Energy) on a common framework of energy analysis and modelling. It concerns EU-wide issues important for energy policy, putting particular emphasis on strategic energy policy responses to the Kyoto process. The project pursues the following major objectives:

- to design a common framework of energy analysis (the shared approach to energy analysis).
- to analyse generic EU-wide issues important for energy policy and for future energy demand and production.

The contribution of Risø shall focus on energy conservation, CHP, and biomass as instruments to meet the Kyoto targets within the liberalised European energy market.

Publications in 1998: 29, 96
Poul Erik Grohnheit, Poul Erik Morthorst, and Lise Nielsen

Energy Systems Analysis

Analysis of renewable energy technologies in the energy system

Since the late 70s renewable energy technologies have developed from being almost non-existent in the Danish energy system to becoming an important element in the government's attempt to reduce pollution and especially stabilise and cut down the emissions of greenhouse gases, as recently shown in the latest energy plan, Energy21. In the last year Risø has been involved in a number of projects on renewable energy, especially those that analyse such issues as the technical and economic development, and how these renewable technologies might perform under liberalised market conditions.

The system integration of wind power on a liberalised Northern European electricity market has been analysed in a study carried out by Risø National Laboratory in collaboration with the Danish electric utilities Eltra, Elsam, and Elkraft. Risø's contribution has been financed by the Danish Energy Agency.

A main objective of the study has been to analyse the value of fluctuating electricity production, especially wind power, in the context of a liberalised electricity market. Spot market prices and power regulation costs on the market have been estimated and related to the uncertainty associated with predicting wind power production. The consequences of the prediction accuracy and the market strategy on the market value of wind-generated electricity are treated in the study.

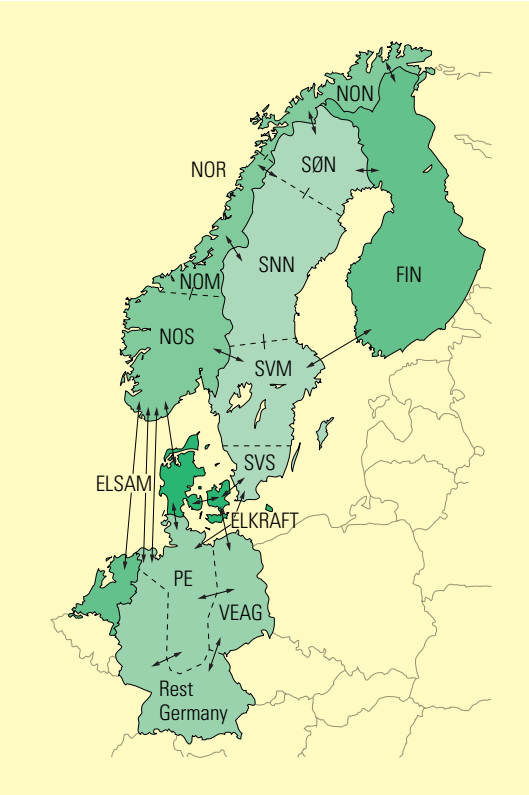


Figure 1
Extent of the electricity market analysed.

A second objective of the study has been to analyse the consequences of introducing technologies that are able to provide power regulation and improve the utilisation of large capacities of wind power in the Danish and Northern European electricity system. Potential contributors, electricity suppliers, and consumers, who are able to increase the power regulation capability on the market are addressed in the study. The Danish energy plan Energy21 forms the starting point of the analysis, and main emphasis is put on the system aspects in years 2005 and 2015.

An essential part of the work has been to set up a baseline market for the sale and purchase of electricity in Northern Europe for year 2005 (Fig.1). The baseline market comprises a spot and balance market for electricity. Detailed model calculations on the Northern European electricity production system, and data from the existing Nord Pool electricity market, form the basis for this baseline market. Uncertainties due to variations in the Scandinavian hydropower production caused by changes in annual precipitation, and the consequences of CO_2-taxation are reflected in the analysis. The ability of decentralised CHP-systems to offer active power regulation on the balance market has been analysed for cases in which heat stores and/or heat pumps are included to increase the flexibility of the CHP-system. Furthermore, load management options offered by electric vehicles have been studied relative to the electricity market. Simulation of these systems interacting with the baseline power exchange set up shows that such technologies or system modifications can increase the supply of power regulation on the market at prices on a level with the balance market. Thus, if large quantities of fluctuating electricity production (e.g. wind power) stress the balance market, such technologies can form backstop prices on this market.

A main result from the study is that the market will be able to provide the necessary power regulation which could be required in 2005 as a consequence of the expected wind power capacity extension, according to the Danish energy plan Energy21.

The consequences of the prediction accuracy of the wind energy, marketed on the average sales price are shown in Figure 2. The prediction level termed 'Correct' on the figure includes no power regulation premium, and thus shows the average spot

market prices in cases of dry, normal, and wet years in the Scandinavian hydropower system.

As seen from Figure 2, the average sales price for wind-generated electricity on the market is less than the average spot market price. This is due to provision of power regulation to balance the unpredictability of the wind power. As the prediction accuracy increases, the average sales price of wind-generated electricity rises. Compared to the spot market prices, the reduction in the market value of wind-generated electricity, at the present level of prediction accuracy, has been calculated as 1.3-2.7 EUR/MWh.

In 1998 Risø carried out an analysis of *the economic and technical development of renewable energy technologies* in relation to the programme for Socio-Economic Research on Fusion (SERF), initiated by the EU-commission in autumn 1997. The programme includes a number of different tasks and subtasks, all related to the long-term development of fusion. This includes the development of long-term energy/economy scenarios, status and perspectives for the technical development of fusion and alternative technologies, and the evaluation of externalities related to these technologies. Finally, a number of sociologically related topics are treated in the programme. Risø has participated in this programme, contributing to the development of long-term scenarios, and by evaluating alternative technologies, namely, wind power and photovoltaics, including related externalities .

For *wind power* two trends have in general dominated the development for grid-connected turbines until now: The average size of the turbines sold at the market place has increased substantially, and at the same time the efficiency of turbine electricity production has risen steadily. Together these trends have increased the cost-effectiveness of wind power by almost 45% over the past decade.

Looking at long-term perspectives, a substantial cut in wind power cost per kWh can be expected to continue over the next 20-30 years. A survey has been made of a number of long-term forecasts for wind power technology in general and shows a decrease in the production costs of 2–2.5% p.a.. This implies that the cost of wind-generated electricity would be expected to be halved by 2030, probably making it fully competitive with conventional fossil-fuel based electricity production.

For *solar photovoltaics* (PV), the annual increase in the total global sales reached 43% in 1997, with a production of 127 MW. Until

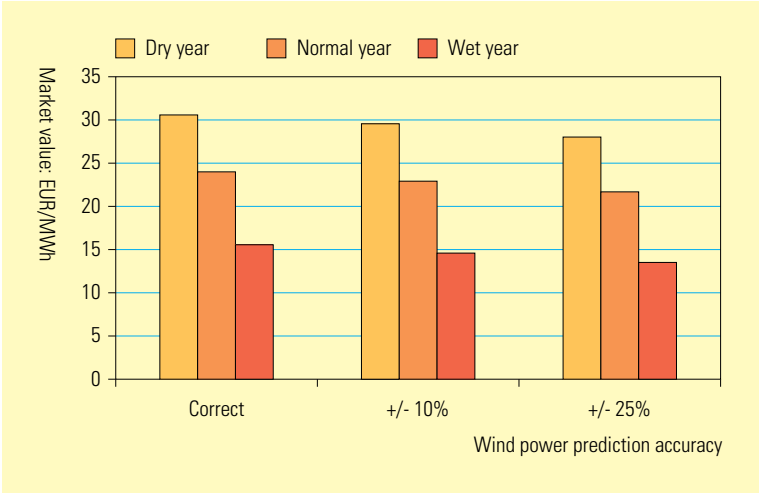


Figure 2
Average sales prices of wind-generated electricity on a North European electricity market, depending on the prediction accuracy for wind power.
1 EUR = 7.44 DKK used.

now off-grid installations have dominated the solar PV market, since they are already economically competitive. However, often the financial mechanisms and necessary organisational set-up are missing. But now the main growth area is on-grid installations in developed countries, where extensive programmes are running in, e.g. Japan (5000 MW in 2010) and the U.S. (3000 MW in 2010).

Status and perspectives for production costs for PV until 2050 have been analysed. The growth of the market that will enable an annual production of 2000 MW to be reached by that year will lead to production plants of the scale necessary to bring the present cost of 4.2 US$/W sharply down to 1 US$/W. It is expected that the PV industry will make decisive investments in these large-size plants in the period 2005-2010.

In relation to the above-mentioned SERF-analysis, *external costs* have been assessed for two wind farms (on land 0.8-1.2 EUR/MWh, off shore 1.0-1.6 EUR/MWh) and a photovoltaic plant (3.5-6.0 EUR/MWh). In all cases the production of materials for the renewable plants has proven to be the most important issue, when considering external costs. The reason for this is the amount of fossil fuel needed to produce and manufacture the renewable installations themselves. The range indicates the large uncertainty in calculating the CO_2 damages. The low value is based on a CO_2 price of 3.8 EUR/ton CO_2, while the high value is based on 139 EUR/ton CO_2.

Publications in 1998: 54, 64, 68, 71
Poul Erik Morthorst, Jørgen Fenhann, Lars Henrik Nielsen, and Lotte Schleisner

Energy Systems Analysis

Equivalent network models for district heating systems

District heating (DH) systems provide an efficient way to heat buildings and have become increasingly common in recent years, especially in connection with combined heat and power (CHP) plants. It has been shown that such systems have a potential for optimising the way they are operated, in order to conserve energy and minimise the costs of supplying heat from production plants to the DH customers.

In order to perform operational optimisation, an adequately accurate mathematical model of the DH system is developed, which can be used to simulate the real system and reflect the operational costs. The simulation model, along with an optimisation algorithm, can eventually be implemented on a computer and then used to find optimal operational strategies for production.

The behaviour of a DH network often involves both time-dependent changes in flows and temperatures, as well as heat losses from the pipe network. Simulation of such changes can be performed to various degrees of accuracy, but since DH networks are often rather large with thousands of pipes, this results in much computational work. This implies a rather long computational time for the optimisation, often hours or days, and it is therefore relevant to find ways to reduce this time in some way. Here, a method is presented in which a complete model of a DH network is replaced by a simplified one, with the purpose of reducing simulation time. This work is part of the project *Equivalent models of DH systems for on-line minimisation of operational costs of the complete DH system*, financed by the Danish Energy Research Programme, and a Ph.D. project financed by the Nordic Council of Ministers.

The simplified network model, referred to as an equivalent network, is generated by gradually reducing the topological complexity of the original network. During this reduction, the relevant model parameters of the network are transformed in a way such that the dynamic behaviour of the equivalent network will resemble the original one. Primarily, these parameters involve the number and dimensions of the DH pipes.

In order to validate the reduction method, simulation tests are performed on an original as well as equivalent network, using a real DH network as a reference case. For this purpose, a general simulation tool for DH networks has been developed. The reference network used is located at the town of Hvalsø in Denmark. A complete model of this network has been generated, consisting of 1090 pipes and 535 consumers. In the simulations, the heat load at each customer is assumed to vary proportionally to a measured load for the whole system, using the customer's yearly heat consumption as a scaling factor. This is necessary since there are no measurements available of the time-varying heat load of the individual customers.

Figure 1 shows how the accuracy of the equivalent network model is gradually reduced when the number of pipes is reduced. It is however observed that the accuracy is slightly poorer for the highest number of pipes, due to special properties of the mathematical model. The accuracy here is defined as the standard deviation of the error in the return temperature at the plant, when a sudden change is made in the supply temperature some time before. The error is generated by simulating a model for the whole network and using the result as a base case where errors are assumed to be zero. Then the error can be computed by subtracting a result from a reduced model from this base case.

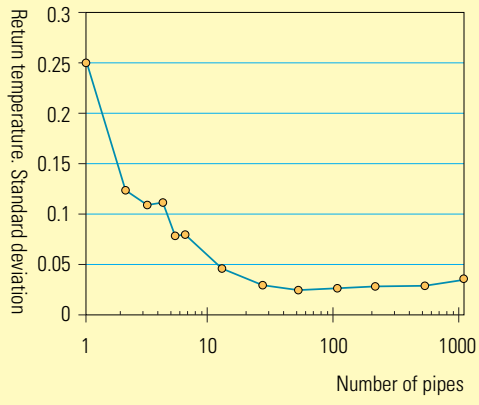


Figure 1
Simulation error in return temperature at the production plant as function of number of pipes.

It is concluded that a simple equivalent network can maintain most of the dynamic characteristics of the original one, but with some loss of accuracy in different situations. When applied to a real network, it is observed that a considerable network reduction is possible without introducing significant errors, which results in a good potential for a reduction of simulation time. Since the simulation time varies in proportion to the number of pipes, it is apparent that using equivalent network models can drastically reduce the computational effort in connection with an operational optimisation.

Helge V. Larsen and Halldor Pálsson

Energy Systems Analysis

Electric vehicles and CO_2 reduction

Energy system consequences of large-scale utilisation of electric vehicles are analysed in an ongoing project carried out by Risø National Laboratory in collaboration with the Technical University of Denmark. The project is supported by the Danish Energy Research Programme and focuses mainly on electric vehicles (EVs) based on batteries or fuel cells on hydrogen. The project aims to analyse energetic, environmental, and economic consequences of an increased use of electric vehicles in the Danish energy system. Also analysed will be the potential synergistic interplay between the utilisation of electric vehicles and a large-scale utilisation of fluctuating renewable energy supplies (wind and solar power) in the Danish power and CHP supply system. The analyses are carried out in the context of a liberalised Northern European electricity market. The Danish energy plan Energy21 forms basic assumptions for the analysis. Due to the low rate of vehicle replacement in the transport sector, the analysis includes the long-term aspects in the two years 2015 and 2030. The project addresses the synergistic effects related to CO_2-emissions reduction in the power and transport sectors, which may arise as a consequence of a potential future large-scale utilisation of electric- and hydrogen-powered vehicles. The large-scale introduction of these vehicles in the transportation sector can significantly reduce the emissions of pollutants in local and urban areas. Through the EVs, developments in the power sector may have direct implications for road transport emissions. Flexibility and options concerning the integration of renewables and reduction of CO_2-emissions in the power sector become options for the transportation sector as well. The CO_2-emissions related to the EV operation, of course, depends on the type of electricity supply system in question as well as the EV power train efficiency. Based on the two extremes, electricity from coal-fired condensing plants and electricity from renewables, the corresponding CO_2-emissions from EVs today may vary, respectively, from about 90% to 0% of the emissions from a conventional comparable size gasoline vehicle. Electricity-based vehicles form new CO_2 reduction options in the transport sector, even with the present fuel mix for power generation. However in addition, these vehicles increase the flexibility of the overall power system due to the substantial load management potential they offer. In the power sector such increased load flexibility increases the ability of the system to integrate fluctuating electricity production, e.g. from renewables such as wind power and photo-voltaic. Thus, concurrent CO_2 reductions in both the transport and power supply sectors can be achieved.

Typically EVs charge batteries during the night, a time when fortunately electricity prices are low due to low loads. However, to benefit fully from the varying electricity spot market prices, which customers may have direct access to in the future, domestic electricity metering on an hourly basis is required. This enables EV owners to suspend charging until favourable low electricity prices are in effect. As future EV battery packs are expected to increasingly prolong the driving range per charge (and thus increase the market for EVs) battery recharge may no longer be required on a daily basis. Full recharge may actually be required only once or twice a week. Simulations of EVs interacting with a liberal spot market for electricity show that the load flexibility of the EV can be used to lower the purchasing costs of electricity (excluding tax) by about 5% relative to an expected Northern European average spot market price in year 2005. Furthermore, calculations show that an increase in battery pack capacity of the EV (to about 200 km/charge) may enable owners to purchase a substantial part of the electricity needed from the electricity balance market, and savings of 10% may well be achieved.

POLFOTO/Jens Dresling

Figure 1
Toyota RAV4.
Electric vehicle.

Thus, future EVs that are able to offer their load management capability on the electricity balance market can gain from this. As a consequence, a development towards increased utilisation of EVs for transport has the potential to increase the supply of active power regulation capability on a future balance market. The capability of the overall electricity system to integrate fluctuating electricity production that requires power regulation, such as wind power, therefore increases. The power regulation potential from EVs may become substantial, and even a few percent of EVs in the transport vehicle fleet can constitute an important player on the electricity balance market.

Publication in 1998: 68

Lars Henrik Nielsen

Energy, Environment, and Development Planning
Centre activities and UNEP support

The Energy, Environment, and Development Planning Programme entered into its fourth contract period as a UNEP Collaborating Centre in 1998. The core function of the centre remains to provide substantive support to UNEP's programme activities on energy and increasingly also on climate change, trade, and economics, and, on a more general level, support to UNEP in its function as implementing agency of the Global Environment Facility.

The centre is a collaborative activity between UNEP, Danida, and Risø and is governed by a Management and Policy Committee (MPC) with representatives from the three organisations. In addition, the centre has an international Scientific Advisory Committee (SAP) with high-level experts from all developing regions and selected international institutions.

The centre implements an increasing number of projects for UNEP and Danida, and has, in addition, expanded its contract activities mainly with other multi- and bilateral development agencies. In order to manage the expansion, an informal programme structure has been established in consultation with the SAP comprising the following issues:

- Climate Change mitigation analysis
- Environmental and development economics
- National and international policy instruments
- Energy sector reform
- Energy efficiency & IRP
- Renewable Energy Supply
- Transport

The programme structure shows the present priority areas, but it must be noted that many projects are covering several programmes and that capacity building is an important cross-cutting theme, which is a priority in all programmes.

Activities in 1998 showed a further increase in the collaborative links with UNEP, reflecting several new important developments in UNEP itself. The major event for UNEP was the arrival of the new Executive Director, Dr. Klaus Töpfer, who joined UNEP in February. Already in the Governing Council in May, Dr. Töpfer presented a new set of priorities for UNEP's programmes and a completely new organisational structure, which is being implemented.

Responsibility for energy activities remains in the Paris office, but is now part of an Energy and Ozone Action Unit in the newly created Technology, Industry, and Economics Division (TIED). The Head of the division represents UNEP on the MPC, and as the new TIED comprises programmes covering energy, economics, and climate change mitigation, the new structure means a clear strengthening of the centre's support role.

On the international environment scene, the establishment of the Kyoto Protocol in December 1997 has generally provided a new impetus to climate change mitigation. The so-called Kyoto Mechanisms – Joint Implementation (JI), emissions trading and the Clean Development Mechanism (CDM) have opened up new important activity areas for the centre, building on its long experience with mitigation issues.

The specific centre activities in this area are described in detail in a later chapter. But it is evident that the further elaboration and implementation of the CDM, with its dual aim of promoting sustainable development, while ensuring certifiable GHG (greenhouse gas) emission reductions, represent a logical extension of many of the centre's activities. These activities relate to climate change mitigation, policy instruments, and sustainable energy development. Activities relating to CDM generally build on the existing UNEP and centre strengths, and focus on methodology development, awareness raising, and capacity building.

CDM activities cannot be seen in isolation from the other Kyoto Mechanisms or the general financial mechanism (GEF) of the Framework Convention on Climate Change (FCCC). New activities have therefore also been initiated to examine the modalities for emissions trading and JI, and special focus is placed on the possible interlinkages and interactions between the different mechanisms. On the capacity building side, emphasis is placed similarly on enabling national experts to choose among the different instruments in order to obtain the best opportunities for project financing.

While the importance of these new activity areas are expected to increase gradually, the most important work in 1998 has been the finalisation of the guidelines for national mitigation analysis and the completion of the fifteen national studies. This was done along with two regional studies undertaken with support from the Global Environment Facility (GEF) and Danida. The main results and achievements are presented in the next chapter.

In parallel with the guideline development, the centre has worked jointly with UNEP and the Intergovernmental Panel on Climate

Change (IPCC) on a report on *Mitigation and Adaptation Costs Assessment – Concepts, Methods and Appropriate Use*. The report has been prepared by an international team of experts convened by centre staff together with colleagues and the Lawrence Berkeley National Laboratory. A first draft was discussed at a workshop in 1997 at Risø co-sponsored by IPCC. The revised version was subjected to a full IPCC scientific review early 1998, and, after inclusion of the review comments, it was professionally edited with support from Environment Canada. It was then published by UNEP as part of its methodological subprogramme supported by the Conventions Subsidiary Body on Technological and Scientific Advice (SBSTA). The report was subsequently presented to SBSTA in a session held during the fourth meeting of the Conference of Parties (COP IV) in Buenos Aires.

This represents an example of the way centre activities provide input to the political side of the convention implementation. Equally important is the centre staff involvement directly in the work of the IPCC as the scientific body of the convention process.

While the centre has worked with the IPCC for several years, 1998 represented a significant increase in IPCC-related activities. Most significantly, the new developing country co-chair of Working Group III (WG III) under the Third Assessment Report (TAR), Ogunlade Davidson from Sierra Leone, worked at the Centre for ten months as a visiting professor. This led to a strong involvement of the centre in the preparation of the TAR. In addition, three staff members have been selected as lead authors for the TAR, and staff also participate as lead authors in the on-going preparation of two IPCC special reports on Emission Scenarios and Methodological and Technological Issues in Technology Transfer.

The centre, in addition, co-organised an IPCC workshop in Zimbabwe on Integrated Assessment in Africa and has started the preparations with the Danish Energy Agency to organise an IPCC workshop on stabilisation scenarios, which will take place in 1999.

While the results and experiences of the on-going work in these ways are contributing to the work of both the political and scientific bodies of the FCCC, the centre has been given new challenges to expand activities both in the areas of methodology development and capacity development.

The World Bank has requested the centre to develop global overlay guidelines for integrating climate change concerns in its transport sector projects. This challenging project was initiated in 1998 with a number of international partners and will be completed in 1999.

Figure 1
Lake Baringo, Kenya.

Another challenging new activity is the centre's involvement in the "National Communications Support Programme", which is implemented by UNDP in collaboration with UNEP. It receives funding by the GEF and several bilateral donors. This programme aims to enhance the capacity of non-Annex I Parties to prepare their national communications to the FCCC, improve the quality, comprehensiveness, and timeliness of the communications, and ensure timely and cost-effective implementation of the GEF climate change enabling activity projects to be initiated. The centre will provide technical advice to countries in specific areas such as information, tools, analytical support, and scientific assessment studies. It will support both agencies on the organisation of thematic training and regional exchange workshops as well as provide or facilitate direct technical assistance to requesting countries.

While preparations for the meeting of the Commission on Sustainable Development (CSD) in 2001 on Sustainable Energy will officially commence in 1999, a number of related activities have been initiated in 1998. The centre has started several new activities especially in the area of renewable energy, as described in a later chapter. Several other activities are under discussion, including a new very interesting initiative by UNEP to promote energy efficiency and renewable energy technologies in the lending portfolio of the regional development banks. While these new initiatives support the CSD process, it is important to emphasise that the objectives aim directly at sustainable economic development in the collaborating countries by promoting investments in energy efficient and renewable energy technologies.

Publications in 1998: 7,8
John M. Christensen

Energy, Environment, and Development Planning

Mitigation analysis and national and regional studies: Economics of Greenhouse Gas Limitations

Over the last two years, the centre has been implementing the UNEP/GEF project "Economics of Greenhouse Gas Limitations". The objectives of the project are to develop national capacity for making climate change mitigation studies and support the development of a methodology, an implementing framework, and a reporting system, which countries can use in establishing national climate change policies and meeting their likely future reporting obligations under the FCCC. The project has developed methodological guidelines, which have been applied and tested in 11 countries (Argentina, Ecuador, Botswana, Mauritius, Senegal, Tanzania, Zambia, Indonesia, Vietnam, Estonia, and Hungary). The Global Environmental Facility has financed the methodology development and eight of the country studies, while Danida has provided financial support for the country studies of Botswana, Tanzania, and Zambia. Teams in Peru, funded by Danida, and in Egypt, Jordan, and Lebanon, funded by UNDP/GEF, have also used the methodological guidelines and have participated in project workshops. The methodological guidelines developed under the project cover key economic concepts, scenario building, modelling tools, and common assumptions applied to GHG emissions reduction policies in the energy sector, forestry, agriculture, industry, and waste management. In addition to the national studies, the project has also included two subregional studies. Although this is a different level of analysis, many aspects of the methodological approach can be applied.

Development objectives and GHG limitation

In the methodological framework, climate change mitigation is analysed within the context of general development programmes in the countries. This is done in order to reflect how global environmental goals can be met in accordance with national social, economic, and political priorities. The methodological framework emphasises the establishment of a comprehensive overview of linkages between national development plans and future expectations, as well as potential GHG limitation policies. The national teams have assessed these general policy issues in collaboration with relevant national planning authorities. The studies show that a future growth of more than 3.0 % per year in CO_2 emissions is to be expected for the developing countries during the next 30 years (as shown in Table 1), if no limitation policy is initiated. The two participating countries from Eastern Europe, Estonia and Hungary, expect decreasing or nearly stable CO_2 emissions during this period, primarily because these countries currently have very carbon-intensive energy systems that operate at a low efficiency.

Table 1. Projected annual growth rates of GDP, primary energy consumption, and CO_2 emissions until 2030, if no GHG limitation policies are implemented.

	GDP	Primary Energy	CO_2 emissions
Argentina	4.4	3.5	3.5
Ecuador	4.5	3.3	4.0
Botswana	4.6	2.8	3.3
Senegal	2.5	5.6	5.6
Zambia	5.1	3.0	4.7
Indonesia	5.9	5.6	6.6
Vietnam	7.7	6.8	8.4
Estonia	2.5	0.1	-0.8
Hungary	2.6	0.6	0.2

In many of the countries, the expected growth rates of CO_2 emission appear to exceed the corresponding growth in primary energy consumption. This is due to the expected dominance of commercial fossil fuels in future large energy investment projects in the developing countries. The studies have, subsequently, assessed how the objectives of GHG limitations, if supported by additional finance, could decrease future growth in GHG emissions in the countries.

Assessing the costs of GHG limitation

The studies have focused on direct as well as indirect costs and benefits of implementing GHG limitation policies. Direct costs and benefits reflect the resources required to introduce new technologies or to improve the efficiency of energy systems, forestry or agricultural practices. However, such policies can also have significant impacts on important social and environmental issues such as poverty alleviation, employment, environmental health damages, etc. and in some of the country studies, these impacts have been assessed as indirect costs and benefits of GHG limitation policies. A common result of the studies is that there is a large potential for low-cost GHG limitation in the countries measured by direct costs and benefits. This can, for example, be illustrated in so-called mitigation cost curves, where the marginal costs of emission reductions are depicted in ranking order in relation to reduction targets. Mitigation cost curves for Ecuador, Botswana, Zambia, Vietnam, Estonia, and Hungary are shown in Figure 1. An interesting similarity of the cost curves shown in Figure 1 is that they all have a large potential for emission reductions in 2030, where 25% and in some cases up to 30% emission reduction can

be achieved at a cost below US$ 25 per tonne CO_2 . The options on this part of the cost curves include energy efficiency improvements in the household and industrial sectors, and efficiency improvements or the introduction of more efficient production facilities in conventional power plants. Some of the countries such as Zambia and Botswana also have some options with large potential benefits (negative costs), including vehicle maintenance programmes and other transportation options. Most of the studies have also included the introduction of renewable energy technologies, such as wind turbines, solar water systems or photovoltaics. The more advanced of these technologies have a tendency to have medium-to-high costs in comparison to the above-mentioned low-cost options. A detailed overview of these results is given in the individual country study reports.

Adding broader social and environmental issues

One of the most critical questions that can be asked in relation to the large assessed potentials for low-cost mitigation options in the country studies is, how these measures can be implemented in practice? The answer could be found, at least partially, if we were able to explain in a better way what the more specific impact of these measures would be on the population and on the national development needs. These issues are part of what must be considered when the assessment is expanded to include indirect costs and benefits of policies. The project has developed a methodological framework for assessing indirect costs and benefits specifically dealing with macroeconomic impacts, employment, income distribution, broader environmental impacts, and sustainability issues. This framework is presented both in the methodological guidelines and in a special handbook report.

Selected results of national studies:

The country study of Ecuador assumed a high degree of energy efficiency improvements in the baseline case to be achieved in particular as a result of the penetration of highly efficient electrical appliances and cooking devices. The CO_2 emissions, however, are expected to increase significantly as a consequence of increasing carbon intensity of power production, where fuel oil is expected to dominate new constructed production facilities. The mitigation scenario has assessed in total a reduction potential amounting to 23 % reduction of the expected CO_2 emissions in 2030. Most of this potential has been assessed to cost below $27 per tonne CO_2. The options include electricity savings in households, industry, and the service sector, as well as efficient industrial

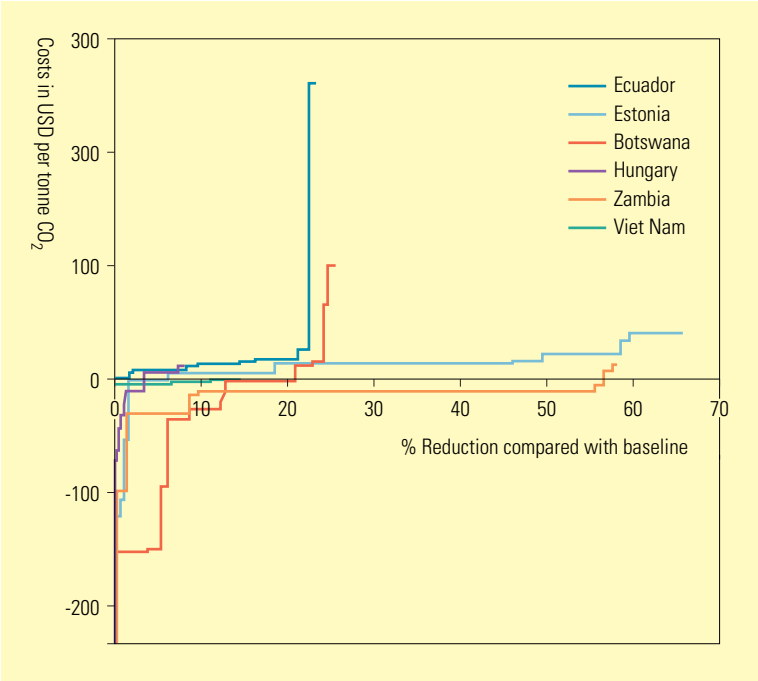


Figure 1
Cost curves for selected countries.

motors, and a number of renewable power production technologies such as wind turbines, hydro- and geothermal power.

In Zambia, a large part of the energy demand is supplied by biomass energy in the form of firewood and charcoal. Although Zambia is at present a net sink of CO_2 (i.e. the country absorbs more CO_2 than it emits, because of the large forest area) there are places where deforestation is taking place. As a consequence of this, the situation may change in the future so that Zambia will eventually become a net emitter of greenhouse gases. Reduction of CO_2 emission can be achieved by substitution away from non-sustainable biomass energy use, for example, to electricity, and by encouraging more efficient production and consumption methods so that the biomass use becomes sustainable. Electricity use in Zambia is essentially CO_2-free, since almost all power is supplied by hydropower. CO_2 reduction can also be achieved by restricting the use of fossil fuels. Figure 2 shows the reduction in CO2 originating from fossil fuel consumption that may be achieved in the mitigation scenario. The Zambian cost curve for CO2 emission reduction, from both biomass and fossil fuel sources, is included in Figure 1.

Regional Studies

Climate Change Mitigation studies have mainly been carried out at the national level. This is a natural consequence of the signatories

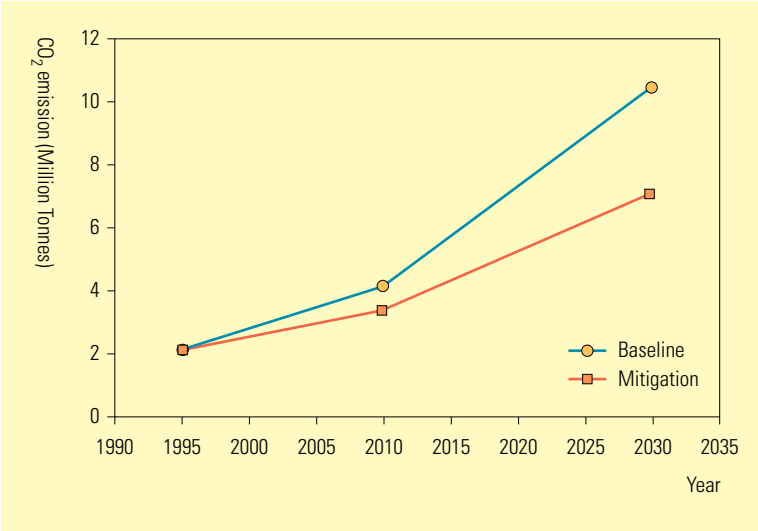


Figure 2
Projected CO_2 emission from fossil fuel sources in Zambia – Baseline and mitigation scenarios

to the Climate Convention being sovereign nations. However, co-operation between regional groupings could provide additional or less-expensive options for reducing GHG emissions. The two regional studies included in the UNEP/GEF project set out to make an initial attempt to explore these issues and possibilities. Two regions were selected: the Andean Group in South America and the SADC (the Southern African Development Community) countries in southern Africa. The SADC regional study focused mainly on power sector options, with a few regional transport intervention options included for illustrative purposes. The power sector options involved, in particular, the displacement of coal-fired generation in South Africa by exploitation of the considerable additional potential for hydropower in the north of the region, in Zimbabwe, Zambia, and the Democratic Republic of the Congo. This study confirmed that regional options to mitigate climate change do indeed exist in southern Africa. Some are of significant size, in terms of the quantity of carbon dioxide abated, and may also be realisable at a competitive 'price'. Nevertheless, considerable barriers exist, particularly institutional and political ones, which make the implementation of such options difficult. The Andean Group study focused on power sector co-operation, and in particular explored the consequences of greater integration in energy markets within the region. The countries of the Andean Group (Bolivia, Colombia, Ecuador, Peru, and Venezuela) include both fossil fuel exporters and importers, and the electricity grids are not fully integrated in a power pool as in the southern African case. There are, therefore, significant differences from the SADC case. The two regional studies thus complement each other in highlighting different aspects of regional mitigation possibilities.

Capacity building and awareness raising

Strengthening national capacity for mitigation analysis has been one of the main objectives of the project and has been pursued throughout the process. This has involved training the national teams both in-country, and through joint workshops for all national teams, which also facilitated the exchange of expertise and cross country links. Teams have, in addition, had access to technical assistance from national, regional or international experts, as well as an opportunity for team members to work either at the centre or at another relevant international centre of excellence.

To disseminate results and experiences, the centre organised four regional workshops in May 1998. The conferences gave national teams an opportunity to present their final results and discuss these in a wider context. Participants came from a large number of countries in the regions and from international organisations. Information on the workshops is summarised in the table below:

The results of the activities have in addition been presented in a number of international fora, as can be seen in the list of publications and presentations.

Regional Conference	**Place and date**	**Participants**
Africa	Victoria Falls, Zimbabwe	22 African countries, international organisations and donors
(co-sponsored by Danida)	18-20 May 1998	63 participants
Latin America	Quito, Ecuador	23 Latin American countries, international organisations and donors
(co-sponsored by Danida)	21-22 May 1998	110 participants
Asia	Goa, India	11 Asian countries international organisations and donors
	4-6 May 1998	35 participants
Eastern Europe	Eger, Hungary	10 Eastern European countries, international organisations and donors
(Countries with Economies in Transition)	21-22 May 1998	30 participants

Lessons learned

The project has been successful in conducting a very valuable dialogue between national and international experts about methodological issues related to the application of the guidelines in the various geographical, economic, scientific, and political settings, which have been represented by the teams who have undertaken the project. This has implied that a general consensus about analytical structure, concepts, and critical assumptions has been established, which provides an important basis for enabling cross-cutting international discussions to take place. Another result is that many of the experts in the project already now in their personal capacity in various international fora like IPCC and the Conference of the Parties are using important parts of the material produced by this project.

Publications in 1998: 14, 22, 23, 39, 42
Kirsten Halsnæs, Henrik Meyer, Jørgen Fenhann, and Gordon Mackenzie

Energy, Environment, and Development Planning
The Clean Development Mechanism

The Kyoto Protocol to the Framework Convention on Climate Change (FCCC) introduces several new mechanisms to assist Parties in achieving their greenhouse gas emission reduction targets. Among these, the Clean Development Mechanism (CDM) is intended to enable developing countries to achieve sustainable development while facilitating the overall aim of the climate convention. It does this by allowing industrialised countries to claim credit for emissions reductions achieved in a host developing country.

The CDM is generating a great deal of interest among signatories to the FCCC, but raises many difficult methodological issues. The UNEP Centre is currently undertaking a Danida-funded pilot project in collaboration with the Ministry of Transport and Energy and the Southern Centre for Energy and Environment, Zimbabwe. The project investigates the potential relevance and implications of using the CDM for financing projects in Zimbabwe. It will describe how specific projects that have been proposed, but not funded, could be marketed, evaluated, financed, and implemented under the CDM, as well as through other existing sources, including multi-lateral, bi-lateral agencies and the Global Environment Facility (GEF). The purpose of doing this is two-fold: first, to assist the private and public sectors to better understand what may be needed to participate in the CDM, as opposed to operating under existing funding mechanisms; and second, to enable Zimbabwe to fully participate in the discussions about the CDM on the global level, and formulate domestic policies related to future involvement in it.

From the perspective of developing countries, the CDM is a tool for achieving national sustainable development goals. Since its structure and function is as yet unclear, the project will consider hypothetical CDM mechanisms to determine which type of CDM arrangement would be most desirable from Zimbabwe's point of view.

Preliminary results of the project were presented at the workshop *New Partnerships for Sustainable Development: The Clean Development Mechanism under the Kyoto Protocol, Accra, Ghana, September 21 to 24.* This workshop was organised by the UNEP Centre in collaboration with the Environmental Protection Agency, Ghana, the International Energy Agency (IEA), the United Nations Development Programme (UNDP), the United Nations Conference on Trade and Development (UNCTAD), and the Stockholm Environment Institute (SEI). The Workshop's sponsors were Danida, UNDP, and UNEP.

The specific objectives of the workshop were:

- To develop a common understanding of the CDM as it applies to African countries;
- To identify critical political, institutional, and methodological issues relating to the operation of the CDM and;
- To develop an African perspective on key issues regarding the implementation of the CDM.

Over the four-day period, 80 experts, officials from universities, research institutions, industries and non-governmental organisations, climate change negotiators from Africa, and experts from other global regions and international organisations met these objectives by means of presentations on the various aspects of the CDM, coupled with plenary discussions. The report of the workshop was presented at the fourth Conference of the Parties to the Climate Convention (COP IV), where it received considerable attention. The main points of the report were also presented by the Ghanaian Minister for Environment to a meeting of the African Ministerial Conference of the Environment (AMCEN), and later formed part of the basis for a AMCEN decision on the CDM. Directly preceding COP IV, the UNEP Centre co-sponsored a *Consultation Meeting on the CDM* in Barbados organised by the Commonwealth Science and Research Council and the Barbados-based Caribbean Planning for Adaptation to Global Climate Change (CPACC). The seminar was aimed at the community of Small Island and Developing States with a view of identifying the potential and issues that need to be addressed in the region in this context. Around 20 experts from the Caribbean, mainly from governmental organisations, participated in the meeting. Following COP IV in Buenos Aires, the UNEP Centre will continue and deepen its work on the CDM of the Kyoto Protocol in a wider UNEP programme aimed at developing methodological guidance and building capacity for CDM in developing countries.

Figure 1
Scenery from Barbados.

Publication in 1998: 48
Cassandra Brooke and Fanny Missfeldt

Energy, Environment, and Development Planning
Sustainable energy development

The centre has a broad set of activities to promote sustainable energy development in support of UNEP's energy programme, which is operationalised through information dissemination and capacity building in the areas of energy-efficient technologies, renewable energy resources, energy planning and policy making. Decisionmakers in governments, the private sector, and NGOs are target audiences for this. These activities are also linked to the centre's activities related to climate change mitigation and adaptation policies.

Energy Efficiency

The main centre activity related to energy efficiency has been the dissemination and application of the manual on "Tools and Methods for Integrated Resource Planning: Improving Energy Efficiency and Protecting the Environment", which was published at the end of 1997. The manual was used as the basis for the training in the South African regional workshop on "Integrated Resource Planning- Tools and Methods", held in Cape Town in May 1998. The manual has, in addition, been disseminated widely and, for example, been used as basis for training of relevant project managers in the World Bank and later disseminated to several of their national offices. On the energy supply side, special efforts were made to promote the increased use of renewable energy resources. In 1998, the centre has been active in a number of project activities in this area covering the assessment of specific technologies and their potential, analysis of implementation barriers, and specific policy instruments to overcome part of the barriers. Project activities are noted below.

Renewable Energy Technologies

A state of the art book on wind energy is being written in response to a request by the UN Committee on New and Renewable Sources of Energy and Energy for development (UNCNRSEED) and planned to be published in 1999. The book discusses wind energy technology, economics, finance, competitive power markets, environmental impacts, policy, and other issues. A short 16-page report on wind energy prepared by the authors of the book was published by the UN as the report of the United Nations Secretary General in February 1998.

The centre worked on a Government of Thailand project entitled "Investigation of Pricing Incentives in a Renewable Energy Strategy". The project was financed by Danced and implemented by the Thai National Energy Policy Organization. The centre worked with a number of Danish and Thai institutions and was in charge of analysing international experiences with pricing incentives to promote Renewable Energy Technologies (RETs) and the use of externality assessment for policy design.

The centre has initiated a Danida-sponsored UNEP/UNDP project that seeks to identify barriers to the implementation of renewable energy technologies and measures to overcome the identified barriers. The project covers three country case studies, viz., Egypt, Ghana, and Zimbabwe, which will be carried out in collaboration with national institutions in these countries. The experiences from the case studies will be generalised for dissemination and use in promoting RETs. The project was begun in November 1998 and is planned to be completed in 18 months. In addition to the direct results of the national studies, the project aims to provide input to the preparatory process of the Commission for Sustainable Development (CSD) in its ninth session in 2001. A small centre project has also been initiated in India to identify the barriers related to renewable energy. The project collaborates with Indira Gandhi Institute of Development Research, Mumbai, and takes up a case study of the State of Maharashtra, India.

Energy Planning

The centre has been involved since 1997, in collaboration with the Danish Energy Agency, in building capacity in the new Energy Agency in Ouagadougou in Burkina Faso. The main focus of centre involvement has been in general capacity building, establishment of an energy database for the country, construction of an electricity planning model, and development of an electrification plan for Burkina Faso. A model was constructed allowing for choice of different supply sources and used to make projections of the electricity demand and the supply structure until 2014. The electrification plan has now been finished, involving both urban and rural areas.

The centre, along with UNEP, UNDP, and other organisations, supported a meeting convened by the Latin American Energy Organisation (OLADE) in October 1998 in Trinidad and Tobago to discuss and approve a Caribbean Action Program (CEAP) for the Insular Caribbean Nation States, Belize, Guyana, and Suriname. The CEAP will be implemented in the modules comprising information systems, energy policy, training, legislation, energy efficiency, renewable energy, and project formulation and financing.

Publications in 1998: 31, 46, 47

J.P. Painuly

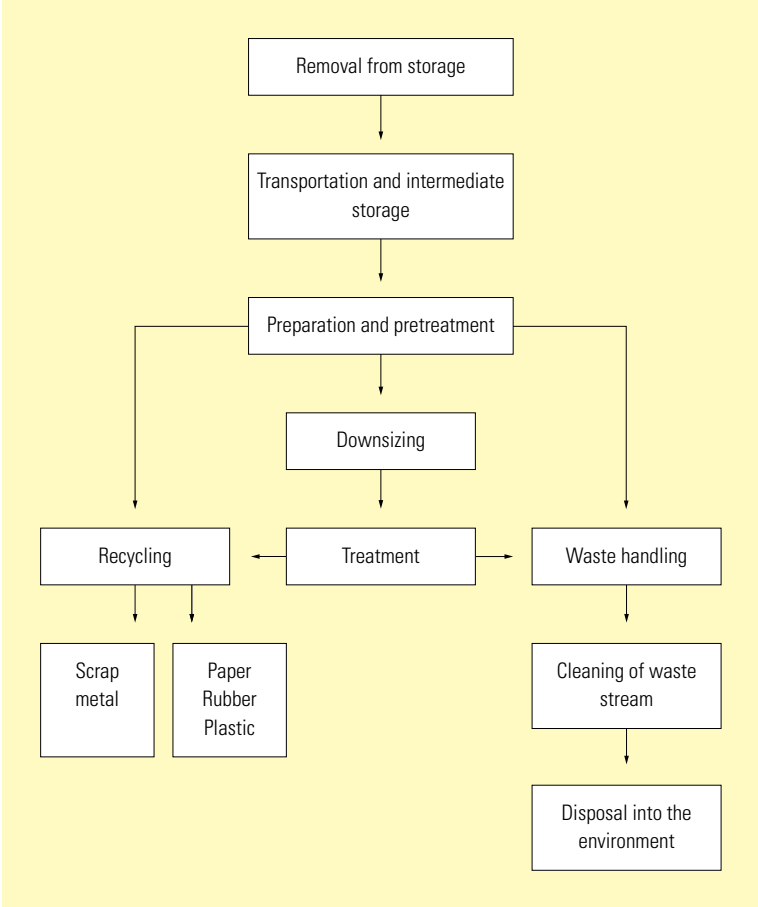
Industrial Safety and Reliability

Assessment of technologies for environmentally acceptable disposal of explosive waste

Risø contributes to a project funded by the EU-LIFE programme on disposal technologies for discarded ammunition. DEMEX Consultants coordinate the project, and the Danish Ammunitionsarsenalet, the Danish waste-processing industry KommuneKemi and the Dutch research institute TNO-PML participate also. The project is divided into 10 separate tasks, to be carried out between 1997 and 2000. One of Risø's responsibilities is the assessment of the environmental and safety impacts of alternative disposal techniques. The Preliminary Impact Assessment (Task 2 in the project) was concluded and reported in 1998.

Ammunitions include a large variety of different types and blends of propellants, explosives, pyrotechnic materials, and containers or shells. The environmental impact of obsolete munitions originates from the original chemicals, from degradation products that are formed over time, and from the combustion products and residues. These are very diverse and complex and depend on the specific blend of chemicals and the disposal technique.

Figure 1
Schedule of the typical sequences of treatment and disposal of discarded ammunition.



The activities in a demilitarisation operation are presented in the schedule. All activities in the schedule will lead to impacts on the environment. These impacts are emissions of pollutants to air, water, soil, and also noise, vibrations, use of resources like land-use and energy, and exposure to hazards. The impacts affect our cultural heritage, natural heritage, the climate, vegetation, animal welfare, and human health and welfare. We distinguish between emissions during normal operation and those during distortions in operation (incidents and accidents). Both the *consequences* of the emissions and the *probability* that the emissions will occur characterise accidents. In other words, accidental emissions have an additional dimension. One can define a one-dimensional characteristic called "risk" as the product of the probability and the consequences of the accident. However, it should be kept in mind that "risk" is a simplification of these two independent factors.

In order to select the "best" disposal technology, Multi-Criteria Decision Analysis is used. Such an MCDA will also include economic factors. In order to apply MCDA, a hierarchy of objectives and criteria has been defined. By evaluating to what extent the alternative technologies fulfil these objectives, the alternatives can be compared and the "best" one selected. The Impact Assessment for Environment, Health and Safety includes the following aspects, classified according to 4 so-called meta-objectives:

- Minimise the environmental impact
- Minimise risks to human life and health and accidental environmental damage
- Minimise the use of natural resources
- Minimise economic costs

The meta-objectives are subdivided into detailed objectives. Defining the set of detailed objectives for an MCDA requires consideration of completeness and redundancy. The total set of objectives needs to be *complete* in order to represent the total impact of the alternatives. On the other hand, it needs to be also *non-redundant* in order to avoid the possibility that dependent or related issues are counted twice in the evaluation. As an example, the detailed objectives for minimising risks for human life and health are discussed below:

Minimise the Potential Loss of Life (PLL). This objective covers both personnel as well as the general population. Previous studies have indicated that minimisation of PLL is a formulation of the objective

to increase safety, but some additional goals or boundary conditions based on Individual Risk or Societal Risk can be added. It may be appropriate to add objectives with other end points than fatality, e.g. severe injury, but there is little experience in using these other end points.

Minimise the risk of diseases at work. This objective addresses specifically occupational health. An objective measure can be the number of cases that should be reported under the various Acts on Occupational Health in the EU member states. Aspects especially relevant for this objective are the possibilities of exposure to toxic substances either through the skin, the respiratory system or the digestive system.

A preliminary screening of disposal technologies has been made, based on a qualitative assessment of the basic technologies and the giving of high/low marks to the list of objectives. The results of this screening have been analysed by two methods of weighing the marks, viz. using the reference point method and obtaining subjective weights from a questionnaire that had been circulated among the partners.

The imaginary technology that includes all desired positive effects (i.e. having high marks for all objectives) is called the "reference point". One can try to find the (real) technology that is "closest" to the reference point. "Closest" can be defined as "having the shortest distance" in the n-dimensional space of objectives. This method is known as the reference point method. Note that this method implicitly assumes that all criteria are equally important!

In order to derive the "subjective weighing", representatives from the project participants (DEMEX, Risø, TNO, Ammunitionsarsenalet and Kommunekemi) filled out a questionnaire with questions about their personal attitude towards the importance of the different objectives. The answers were transformed to weighting factors. There is unanimous agreement that health and safety factors, especially loss of life, are the most important, followed by purely environmental issues. Natural resources and economic considerations are weighted equally.

The chart shows the results of the preliminary screening. Each technology has obtained two scores, one using the reference point method and the other using subjective weighing. The higher the score, the more the technology satisfies the objectives.

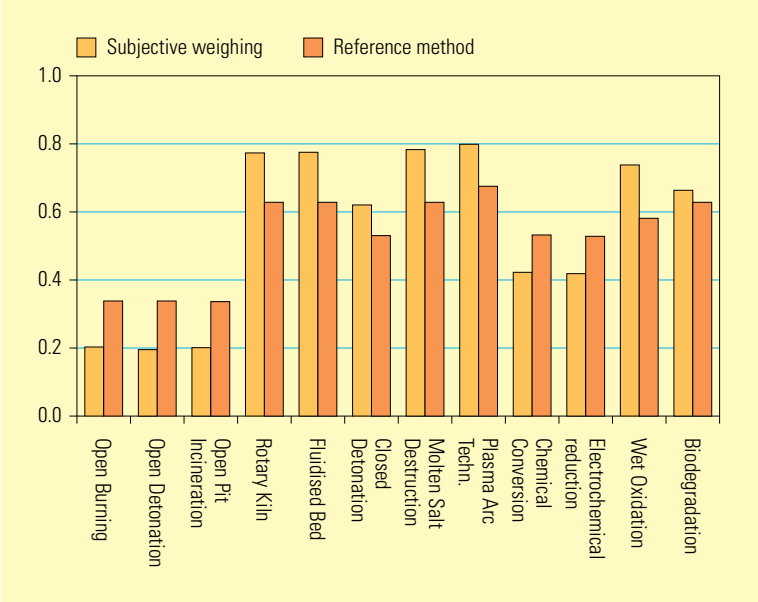


Figure 2
Results of the preliminary screening of disposal technologies for discarded ammunition, showing scores derived from subjective weighing (yellow) and the reference method (orange).

As economic costs are considered of lesser importance by the panel of representatives, subjective weighing acts in favour of expensive, advanced methods. These could be Plasma Arc technology and Molten Salt Destruction, closely followed by the "proven technology", namely, controlled incineration in Rotary Kilns or Fluidised Beds.

The result of the Preliminary Impact Assessment is a detailed framework of methods and objectives to be used during the final assessment at the end of the project. MCDA is demonstrated as a useful methodology for selecting the "best" removal technology. It confirmed also the importance of further development of controlled incineration in the project.

Publication in 1998: 53
Nijs Jan Duijm

Industrial Safety and Reliability
Statistical properties of plumes

Assessing the consequences of an industrial accident often involves predicting the atmospheric dispersion of a contaminant plume. Real clouds are formed by turbulence and acquire extremely irregular and basically irreproducible shapes, which no model can predict in detail. Both models and experimental studies of plumes, therefore, belong in a statistical framework aiming at establishing statistical properties. The typical practical tool available for analysing an accidental release is a model that predicts the mean concentration at a given position relative to the point of release. Although an important statistics, the mean concentration is not always adequate, because real concentrations are characterised by large fluctuations. Concentration fluctuations are, for example, important in evaluating the flammability of a cloud or acute toxic effects. For such applications standard deviations of the concentration can be just as important as mean values.
Despite the need for error bars around dispersion predictions, present models have, unfortunately, little to offer. The main reason for this has been the lack of experimental data to back up theoretical developments.

The COFIN (Concentration fluctuations in industrial releases) is an EU-sponsored project under the fourth framework programme and has been initiated in 1998. The project is carried out in collaboration with the Department of Wind Energy and Atmospheric Physics and aims at developing methods to quantify statistical properties of clouds, for example, by assigning proper error bars to predicted mean values.

COFIN is based on the analysis of a series of high-resolution plume experiments carried out over the recent years by Risø.
The experiments were made in flat terrain with a smoke machine producing a passive plume. The heart of the experiments is a lidar – a device similar to a radar, but based on the back-scatter of an infrared light laser beam instead of radio waves. The lidar can provide instantaneous cross-plume concentration profiles (here only ground level concentrations along a line across the plume will be considered). The database is unique and was made available to the project by the Department of Wind Energy and Atmospheric Physics.

A few preliminary results are given below. They concern mainly the plume width, which is somewhat simpler to discuss than the concentration. The average plume width is defined in terms of the second central moment of the average cross-plume concentration profile. Two such profiles are shown in figure 1. Plume width and concentration are strongly correlated (narrow plumes tend to be more concentrated). The average plume width is a measure of the width of the area that the plume 'visits' during the averaging time. It can be shown that the plume width always increases when the averaging time is increased. Figure 2 shows plots of average plume widths against averaging time for two different experiments. These experiments were done on the same day, one shortly after another, and the meteorology parameters characterising the two releases are in fact so similar that models would predict almost identical plume widths. Nevertheless, the two curves are quite different. Both curves are increasing, but one seems to reach a constant level while the other continues to rise. The reason for this is simply that the wind direction was rather steady during the first release, while it turned slowly during the second release (which in fact ended prematurely as the plume came out of sight of the lidar). Both types of behaviour seem to be common.
The plume width predicted by a typical model would correspond to the concentration profile, which is obtained from averaging over an ensemble of repetitions of the experiment. It is worth noting that the mean profile is unaffected by time averaging and should, in theory, be equal to the average profile in the limit of infinite averaging time. With real data the averaging time is limited and it is impossible to make repetitions with identical meteorology. In addition, and contrary to model assumptions, the weather is always in a state of transition, hence averages over long periods are difficult to establish unambiguously. The present example indicates that there is no universal behaviour of plumes for long averaging times.

It is interesting to note that for short averaging times the plume widths for the two experiments approach each other, indicating a more universal behaviour. The shorter averaging times are obtained by chopping up the data in time blocks and treating each block as separate experiments. Thus, for zero averaging a block consists of just one instantaneous profile. The corresponding mean profile cannot be assigned to an absolute spatial location, since it represents the mean concentration field in a co-ordinate system that follows the meandering plume centre. Therefore, using zero averaging time is referred to as 'moving frame analysis', while using the long averaging time limit is designated 'fixed frame analysis'. The fixed frame plume width is a measure of the width of the area likely to be affected by a release of long duration and is relevant for the assessment of cumulative effects. The moving frame is more relevant in the discussion of acute effects such as an explosion. It is worth noting the substantial difference between the plume widths in the two types of data analysis.

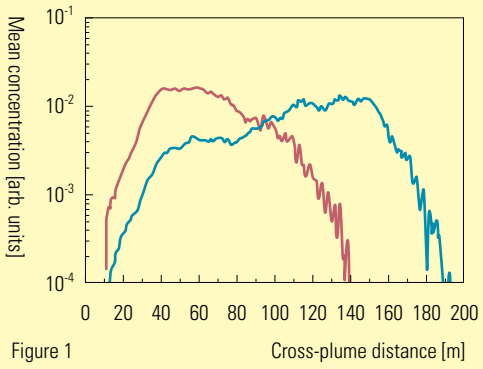


Figure 1

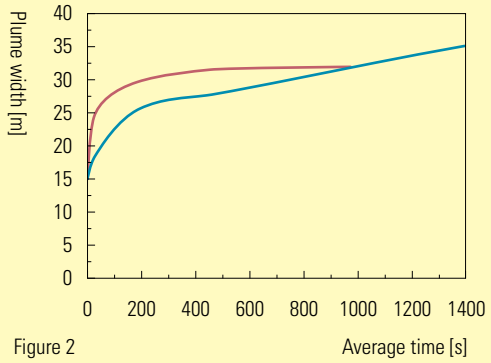


Figure 2

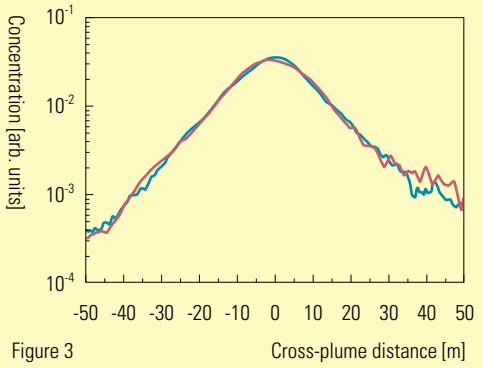


Figure 3

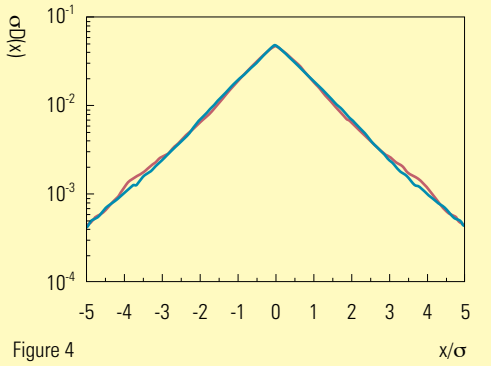


Figure 4

Figure 1
'Fixed frame' concentration profiles for long averaging times (20 minutes) obtained from two very similar experiments distinguished by separate colours.

Figure 2
Plume width dependence on averaging time.

Figure 3
'Moving frame' concentration profiles.

Figure 4
Distance-neighbour functions.

Figure 3 shows the (normalised) moving frame profiles of the two experiments in a semi-logarithmic plot. In this plot a Gaussian would appear as a parabola, while an exponential would be a wedge consisting of two straight lines. Both experimental curves are well represented by a single universal curve, which is rounded near the centre like Gaussian curves and has exponential tails. This behaviour has been observed for all experiments analysed so far. The corresponding fixed frame profiles in figure 1 are far less regular.

Figure 4 shows a plot of the (non-dimensional) distance-neighbour function for the same two experiments. The distance-neighbour function is an alternative to characterising the instantaneous plume. Technically it is defined as the mean spatial two-point concentration correlation function. One can think of the distance-neighbour function as the probability of observing concentrations simultaneously at two positions separated by a certain distance. From figure 4 it appears that the distance-neighbour function is universal and well represented by a simple exponential. The distance-neighbour function and the moving frame average profile both determine the moving frame plume width, but the distance-neighbour function, in addition, determines the variance of the plume width. In other words, the distance-neighbour function yields the moving frame plume width including error bars.

Classical theory for homogeneous, isotropic turbulence based on Kolmogorov scaling predicts a different, non-exponential distance-neighbour. It also predicts that the plume width grows proportionally to the travel time raised to the power 3/2, while data for ground level plumes, on the other hand, are consistent with a linear growth. The reason for the observed deviations from classical theory could be that plume dimensions exceed the inertial range (the realm of Kolmogorov scaling). It has been found that replacing Kolmogorov scaling with surface layer scaling leads to an exponential distance-neighbour function as well as a linear growth of the plume width. Similar ideas have been applied to the moving frame profile in order to explain its Gaussian centre and exponential tails.

Søren Ott

Industrial Safety and Reliability

Repeated system identification as a means for on-line fault diagnosis for process control equipment

Within the framework of the collaboration agreement between the OECD Halden Reactor Project and Risø National Laboratory a common interest in on-line monitoring in nuclear power plants was identified. The final aim is to facilitate early warnings to plant operators of incipient failures in the control systems of the plant.

Electronic control normally involves the inclusion of stabilising feedback mechanisms. An unwanted side effect of this stabilisation is that component degradation will be hidden, making monitoring difficult to achieve. The method investigated will overcome this difficulty by repeatedly establishing a parametric model without interfering with the process. The model will make the identification by means of the time series measurements of the basically stable, but weakly fluctuating input- and output signals. Degradation will be indicated by differences between the parameters of the initial and current identification processes.

Traditional measurements of response functions may disturb the current process, and this cannot be tolerated for safety-critical equipment. The method used here facilitates identification with a very low degree of process disturbance.

General aspects of monitoring

A full-scale monitoring of all instrumentation resources in a distributed process control system presents a considerable challenge to the designer of the system. The superior task is to monitor the co-operative functions carried out by the integrated system, while each piece of control equipment will have to be monitored separately as well. A traditional way of solving this problem would be a straightforward full-time monitoring of all control equipment combined with a checking that all main parameters of the complete system lie within their defined operating limits. In order to detect changes early enough to avoid critical situations, some kind of monitoring of the control equipment is useful as the first step towards facilitating operator warning and initiating a fault diagnosis.

The first step in the design of monitors is the creation of a suitable model for the equipment to be monitored. The model is described by means of some characteristic parameters. Monitoring will then consist of the comparison of some or all of these parameters to values measured over the operating period.

In some cases a physical model can be established, but for complex equipment a so-called identification process has to be carried out to establish a parametric description. The method of monitoring being investigated consists here of making repeated identifications and comparisons between identified parameters and originally specified and initially checked system parameters.

Monitoring control loops

The control loop as considered here will control a process by means of a single parameter and will enable the process to be controlled by means of a sensor and a controller with its reference, an actuator, and a negative feedback mechanism. Because of this feedback, the loop has an inherent capability to hide changes in the system performance as long as the equipment stays within its design envelope. If the transfer function, defined as the ratio of the output to the input signal values of the open control loop, is G, a change in G will affect the controlled output variable only by a factor of 1/(1+G) in the closed loop. G is a function of the frequency in complex notation.

Although a modern controller is the least failure prone part of a control loop, this investigation has taken a special interest in this component. For valves and sensors adequate models including failure modes are available, whereas the controller in both diagnosis and failure analyses is often handled as a black box component without suitable information on failure modes.
This interest also reflects the special conditions for safety-related circuits, where measurements on-line are not allowed to disturb the process.

Identification methods

A number of methods are available for the identification process. The traditional method for estimating transfer function models is based on measurements of the system reaction to deterministic perturbations of the input, such as step, pulse, or sinusoidal changes. The “modern” statistical approach to signal handling, as introduced by N. Wiener and C. E. Shannon, has prepared the ground for other methods, such as correlation analysis, Fourier analysis, auto-regression, and wavelets. A key issue in the investigation reported here is being able to establish an engineering knowledge of the sensitivities of these methods.

There are intrinsic noise signals in the controller, and all over the system for that matter. Under certain favourable circumstances, the process can be described as linear and stationary. Then its noise

can be modelled, and means can be provided for estimating the frequency characteristic without disturbing the process. This physical noise is complementary to the so-called white noise driving of an auto-regression process. A measurement based on this estimate will result in a set of time series from which an assessment of the frequency response of the controller can be made.

Figure 1
High-pressure heaters of an ASEA-ATOM Boiling Water Reactor.

Auto-regression system identification

In using auto-regression models, we do not anticipate any knowledge of the physical system under investigation. Instead, we aim only at giving a mathematical expression for the prediction of a limited number of process variable values, based on knowledge of a historic time series for system variables. The models are all based on the stochastic concept of auto-regression analysis. These models can be handled if the process can be anticipated to be linear and time invariant, i.e. there is a linear dependency between system output and input, and the response to a given input signal is independent from the pre-history of signals and equipment.

Mathematical tools are available for such analyses. By means of sets of time-identical measurement values, an equation for making a general estimate of the monitored values can be constructed by means of auto-regression and expressed in the form of a set of equations. Auto-regression expresses one value in a discrete time series as a function of all other values in the series. This enables an estimate to be made of the step function responses and of the frequency domain transfer functions of the measurement parameters.

The general notation for the auto-regression with one independent variable may be written:

$$y(k) = \sum_{m=1}^{p} a(m)y(k-m) + v(k) \qquad (1)$$

where y(k) for k=1,2,...,N is the time series set of data, v(k) is the white noise driving the process, and p is the auto-regressive model order; a(m) for m=1,2,...,p are the model coefficients. These coefficients may be found by solving the over-determined system of equations formed by inserting the time series values successively into (1). As the k-intervals represent equally spaced time divisions, (1) is actually a description of the time-dependencies in the dynamic system under consideration. Methods are available for making a best fit of the a-values, most often by least-square procedures.

The a(m)-coefficients may be the target for the monitoring, but estimates of more physically relevant parameters, such as the pulse response or the frequency characteristics, can be derived from (1).

This auto-regressive notation can be extended to be valid for many-parameter models by making the "y" a vector and the "a" a matrix. In this way, models for control systems, e.g. systems with a single input and a single output can be treated.

Experimental work

In 1999 experiments will be carried out on a selected control loop from a nuclear power generating station, e.g. the control loop for the water-steam ratio in the high-pressure heaters. The regression analysis can be performed with commercially available software tools.

The outcome of the experiments is expected to provide an indication of the quality and sensitivity of the modelling of feedback systems.

Palle Christensen

Man/Machine Interaction

Centre for Human-Machine Interaction

Early in 1998 the Danish National Research Foundation approved a joint proposal from Risø, University of Aarhus, Technical University of Denmark, Danish Maritime Institute, and Danfoss A/S to establish a Danish centre for research into theoretical and methodological issues connected with the analysis and design of complex human-machine systems.

The research agenda adopted by the new Centre for Human-Machine Interaction (CHMI) has background in the fact that information and communication systems have become the standard interface between people and their work in many professions. These technological changes, which have taken place in recent years, in addition to having made human work more diversified, changeable and intellectually demanding, have given birth to dynamically evolving individual and co-operative work patterns, as well as interactions with non-human agents. The intention with the centre is to create a forum for scientific approaches to the analysis of human behaviour in dynamically changing, co-operative work situations. Furthermore, the centre will use this forum as a platform for developing novel principles for the design of interfaces that visualise the content of complex work domains in a transparent way. The associated need for compatible and complementary theories, methods, models, and empirical knowledge has been met by gathering a team of around twenty researchers in computer science, the humanities, and various engineering disciplines. Among the important objectives for the centre activities are collaboration with researchers abroad, international dissemination of research results, and training of PhD students.

CHMI (http://www.chmi.dk) has Risø as its host institution and includes the following partners:

- Systems Analysis Department, Risø National Laboratory
- Department of Information and Media Science (IMV), University of Aarhus
- Department of Computer Science (DAIMI), University of Aarhus
- Department of Automation (IAU), Technical University of Denmark
- Department of Control and Engineering Design (IKS), Technical University of Denmark
- Division of Simulation & Information Technology, Danish Maritime Institute (DMI)
- Danfoss A/S.

The joint research is directed and co-ordinated by Annelise Mark Pejtersen in collaboration with Peter Bøgh Andersen, IMV, and Susanne Bødker, DAIMI. It is organised into four projects of which the three first ones are strongly empirically oriented and related to a particular set of concepts, methodological approaches, and work domains. These projects are: (1) *Ecological Systems* (Risø, IKS, and Danfoss Information Centre), which addresses the support of information seeking and knowledge exploration in industrial product development; (2) *Elastic Systems* (IMV, IAU, and DMI), which is concerned with new flexible interfaces and their application for instrumentation of ship bridges and training of maritime operations; and (3) *Common Information Spaces* (DAIMI and Danfoss User-Centred Design Group), which focuses on technology that helps multiple users co-ordinate and integrate distributed activities. In the fourth project, *Development of Theoretical Foundations,* all of the partners work together with the aim of synthesising theories, methods, models, and empirical findings into a common framework.

Up to now, the contributions from Risø to the project on Ecological Systems have involved analyses of empirical investigations at Danfoss and Novo Nordisk regarding the activities undertaken by engineers to acquire and seek information. The purpose of these analyses has been to open up our work on the development of principles for designing ecological information systems, supporting information seeking, and exploring knowledge in work domains with autonomous actors, whose work is governed by company strategies, social policies, and actors' intentions. In these domains, actors create, share, seek, store, and maintain heterogeneous information that is used during the co-operation. Previous studies stress the importance of the context in which work is done and call for information systems that take into account the contextual characteristics of information that is applied during knowledge exploration in collaborative work. For information to be useful, the context in which it is brought about must match the one in which it is going to be used. Along with easy access, this seems to be a key item of support for the well-known finding that engineers get most of their information from their colleagues and from internal reports.

The centre has participated in the "Content Organisation and Retrieval" project. This project, which is led by the University of Washington in Seattle, USA, has as its goal to investigate the information-seeking behaviour of engineers when they search for information on the World Wide Web. Furthermore, the objectives

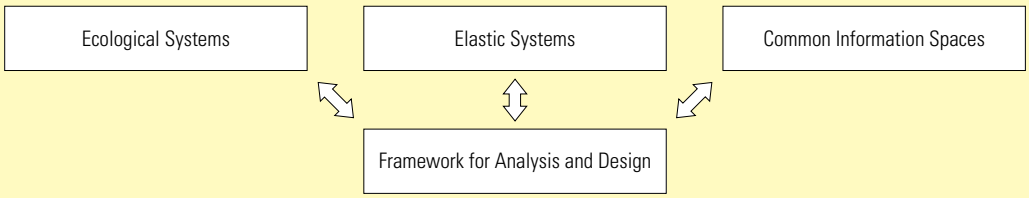


Figure 1
The Centre is organised into three empirical projects and their correspondent theoretical project.

of the project were to create a description of major patterns of Web use, examine the effectiveness of these patterns, and make recommendations for improved system functionality and interface. The adopted method was guided by the conceptual framework developed at Risø for a work-centred evaluation and design of information systems. Although each of the Web searches, which were studied, had its own specific context, some common patterns of searching behaviour emerged. For example, from among the mental strategies available to the searchers, they most frequently selected browsing and the analytical strategy. Also, the most important factors sought for in the information sources were reliability and relevance. If information was not directly accessible, the Web could provide names of people to contact. The project suggests that an improved design of information systems for engineers could be achieved by providing the engineers with support for locating experts and potential collaborators.

These findings correspond to our analyses in the centre, where we have found that the engineers' use of documents reflects the limited ability of documents to include sufficient information about the context in which they were produced. Engineers intertwine their search for relevant documents with that for informed people. Thus, documents, which would otherwise provide the engineers with the needed information directly, are often not read for that purpose. Instead they are used to determine whether the documents can be used as directories of people who may possess the needed information. Only very simplistic systems are available to support engineers with finding people with specific competencies. While information seeking is a well-established field with respect to written information, it seems that searches for informed people have been largely neglected despite their immense importance in engineering work.

The centre has also co-operated with the University of Washington on the analysis of data from a study of the searching behaviour of high school students who use the Web for their homework assignments. The data consisted of observations in class and at the terminal with students thinking out loud, and included interviews with various participants, the director, teacher, and librarian. Students encountered many difficulties with the interface, and met up with problems due to lack of structures in the heterogeneous work content. This emphasises the need for a framework that enables the analysis to encompass the implications for system design of both the work context and the students' Web-searching behaviour. The purpose of this work was to identify problems that arise in using the Internet to support a co-operative work setting with novice users. The study gave rise to a one-day presentation at the ESPRIT MIRA workshop "Evaluation Frameworks for Interactive Multimedia Information Retrieval Applications" held at the University of Grenoble, France, 30 March – 1 April, 1998). Participants were from universities in England, Scotland, Ireland, France, Germany, Switzerland, Italy, and USA.

Future work on the project on Ecological Systems will include detailed empirical studies of how people find information that is capable of answering to their needs. These studies are also intended to lead to principles for designing information systems that incorporate context information, for example by mediating contacts with people who have the relevant work context information. Other approaches to handling context information will also be investigated.

Publication in 1998: 33
Annelise Mark Pejtersen, Leif Løvborg, and Morten Hertzum

Man/Machine Interaction

Human Factors evaluation of a novel aviation training device

The MATE project was one of the 25 projects awarded the European Information Technology Prize 1998.

Whenever airline pilots have to qualify for a new type of aircraft, they undergo a so-called conversion, or type rating course. A considerable part of their initial training in such a course is carried out in a "paper-tiger" – a ply-wood-and-paper mock-up on which is mounted 1:1 size photos of the controls and displays of the aircraft cockpit. Pilots' training of more dynamic tasks, i.e., those that require system feedback, is performed with the use of various types of desktop computer tools or in relatively expensive cockpit-system simulators. Pilots conduct their training in real aircraft and full-mission flight simulators but extensive use of an aircraft of limited availability for training purposes is vulnerable to costly delays of the training course and ineffective use of training time, and for smaller airline companies the cost of buying training time in a full-mission flight simulator may be prohibitively high. There is, therefore, a need for a cost-effective training device that fills the gap between the low fidelity of desktop training-tools and the high fidelity offered by cockpit-system simulators and full-mission flight simulators.

A consortium of European companies and research organisations with joint expertise in aviation, simulator manufacturing, software development, and human-factors evaluation has completed the ESPRIT project MATE (Multi Aircraft Training Environment), begun in 1994. The objective of the project was to develop and test a re-configurable, low-cost training device of medium fidelity that would be sufficient for training such cockpit procedures as going through checklists and starting the engines. This objective has been met through the application of computer graphics technology, in which the instrument panels and manual controls of a cockpit are simulated by means of touch-sensitive display screens. A cockpit simulator of this design makes it possible to accommodate a variety of aircraft types and models. The prototype developed in the project simulates the cockpit of a Saab 340 twin-propeller commuter plane. Its touch-screen panels are mounted in a cockpit mock-up with added paper-tiger parts and demo objects for those parts of the cockpit equipment, which are not simulated with touch screens.

Figure 1
The MATE cockpit involving touch screens with back-projected graphics.

In order that a simulator of this novel concept can be accepted by both the aviation training community and aviation authorities, it has to be demonstrated that the effects of training in a MATE simulator be transferable to the corresponding real cockpit environment. Risø has been the leader of the evaluation efforts of the project. Risø's final and extensive task in the project, which terminated in the autumn of 1998, was to determine whether two-dimensional, touch-sensitive pictures of switches and controls would provide a pilot with the necessary training environment that would enable him or her to operate the switches and controls of a real aircraft cockpit sufficiently smoothly and timely. A literature study and laboratory experiment carried out with non-pilot subjects at Risø earlier in the project indicated that it might be possible to achieve the same effect of training with touch-screen interaction as with hardware controls.

An extensive evaluation experiment was conducted during the last part of 1997 and the first part of 1998 at Arlanda Airport, Sweden, using two groups of pilot trainees, undergoing a type rating course with Skyways airline. One group of pilots (the experimental group) received part of their training in a MATE cockpit, while the other group (the control group) went through a conventional training schedule involving, as a training device, the use of a real aircraft with engines shut off at the airport. The experimental group trained the pre-start checklist and the engine start checklist for a SAAB 340 in the MATE prototype. The control group trained the same procedures using a real SAAB 340 for their training of the pre-start checklists and a desktop computer-tool for training of engine start. The after-training performance shown by the two groups on the pre-start checklist was compared in a formal checkout, which took place in the aircraft. The checkout, which was used to evaluate performance on the engine-start procedure, was carried out in a full-mission flight simulator available at SAS Flight Academy in Arlanda.

Risø staff was stationed at Arlanda during the training courses of the two groups, recording their performance during training and

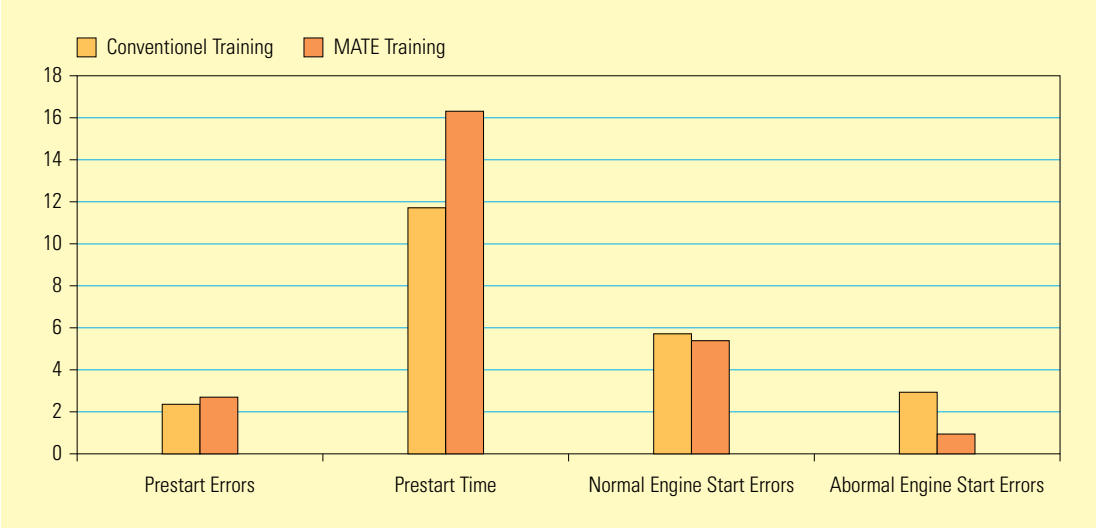


Figure 2
Errors and time during pre-start and errors during normal and abnormal engine starts.

Figure 3 and 4
Close-ups of the MATE cockpit.

checkouts on audio and video and collecting instructors' ratings of trainees' performance. Subsequently, the totality of recordings were analysed with the assistance of DERA (Defence Evaluation and Research Agency) of the UK, a project partner. A comparison of MATE trainees with conventional trainees revealed that when the former were transferred to the real aircraft without any previous familiarisation with the real cockpit environment, they used slightly longer *time* to complete the pre-start checklist. The MATE trainees did not commit a greater number of checklist *errors* than did the conventional trainees, but they seemed to be *less confident* in their performance than conventional trainees, as judged by their instructors. In contrast, when the MATE trainees had become familiar with the real cockpit, no significant differences were observed between the two groups, except for the observation that the MATE trainees displayed a better performance during abnormal engine starts.

Thus, the main conclusions of Risø's evaluation of the training effects of the project demonstration trainer are: (a) that the performance of pilots trained with the new training device is adequate if trainees are given sufficient time to familiarise themselves with the real cockpit environment and controls, and (b) that the new training device seems to produce an enhanced learning effect in the training of dynamic tasks, such as aircraft engine starts.

Steen Weber, Gunnar Hauland, and Henning Boje Andersen

Man/Machine Interaction

Classifying human errors in air traffic control

It is widely accepted that some form of "human error" is the predominant cause of accidents and incidents in safety critical domains such as aviation, maritime navigation, and process control. The same applies to Air Traffic Control (ATC), where various instances of human error are known to have been involved in causing large and tragic accidents.

While a large number of classification schemes and statistical summaries exist for aviation accidents, there are, perhaps surprisingly, no trans-national statistical summaries of the causes of ATC-related accidents and incidents, let alone statistics of the distribution of human errors in such events. In order to advance the state of knowledge about the occurrence and nature of human errors involved in accidents and incidents within air traffic management, EUROCONTROL (the European Organisation for the Safety of Air Navigation) issued a call for tender concerning the first of two phases of a project on taxonomy of human error involved in ATC.

The tender, which was granted to a consortium consisting of Risø and the National Air Traffic Services in the UK, has now resulted in project HERA – running from 1998 to 2000 – which aims at establishing a validated taxonomy of human errors and a prototype database over human error involvement in ATC incidents and accidents in some selected European countries. It is planned that a second phase of the project will seek to categorise a much larger body of incident reports from a larger number of countries belonging to the EATCHIP group of nations (The European Air Traffic Control Harmonisation and Integration Programme – a co-operative programme of the Member States of the European Civil Aviation Conference (ECAC), co-ordinated and managed by EUROCONTROL).

The primary role of Risø in the HERA project (Human Error involved in Air Traffic Management) consists in (a) contributing to the development of the planned human error classification scheme – especially by drawing on experience from other domains, such as process control and marine navigation, and by developing a communication error classification; (b) developing training tools to support the use of the classification scheme; (c) validating the planned human error classification scheme in order to ensure that different incident analysts arrive at the same results when applying the scheme; and (d) developing a prototype database, which allows end-users to query by various types of causal factors involved in incidents.

It is expected that the HERA project will be strengthened by results from two PhD projects in the department focusing on team situation awareness in the ATC environment and on the classification of human errors observed during ATC operations and real time simulations.

Henning Boje Andersen and Thomas Bove

Figure 1 and 2 Human error plays a primary role in accidents and incidents related to Air Traffic Control.

Man/Machine Interaction

Improved skills in image recognition

A new project led by Risø dealing with improved skills in image recognition has been initiated in 1998. An important feature of this project is the working together of people at various locations via a network for obtaining consensus and standardised performance when classifying or in other ways making decisions based on common images. Therefore, the project, which is partly funded by the EU Telematics programme, is based on developing a new software system and strategy for 'Converging Agreement by Networking Telematics for Object Recognition (CANTOR)'.

In a series of industrial, clinical, and scientific processes, the ability to make visual recognition in images, i.e. to classify different types of objects, depends on and will always be partly based on individual evaluation. For example, when a medical doctor evaluates the probability that cancer cells will be present in a tissue, the observations that led to this are based on a personal judgement. Unfortunately, within many healthcare sectors considerable variation exists. In order to demonstrate the possibilities of reducing these variations, and to try out the CANTOR tools on a general basis, two healthcare sectors have been selected: histopathology of oncology and serology of autoimmune analyses.

For the patients it is of the utmost importance that both doctors and lab technicians possess a high level of visual acuity to recognise the objects they are supposed to judge in the diagnostic phase in accordance with the classification criteria of the clinic or of international standards. The CANTOR software system will be able to perform statistical consensus analyses and to compare agreements and disagreements in object classifications carried out in repeated processes by the same person, by several persons, and by groups of persons. Based on the statistical consensus analysis, images may be selected for building up a reference image database and a related knowledge database. Together these databases will include all the important information and notations connected with each image. They will be used for further education and training in consensus making and standardisation within the domain covered by the specific set of databases. Within each of the selected sectors CANTOR aims at demonstrating the use of telematics for four important stages related to visual classification of objects in microscopic images: education, training, quality assurance, and standardisation. Apart from its role as overall co-ordinator of this project, Risø elicits detailed user requirements for all of the four stages mentioned above, and evaluates the validity of the system

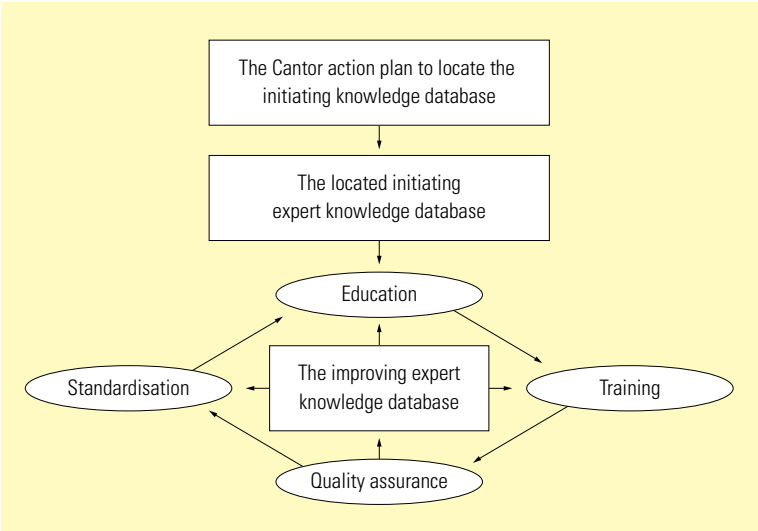


Figure 1
The Cantor strategy.

at the end of the project. During 1998 the elicitation of user requirements has been performed and presented in a 'User Requirements' report. The methods applied in the study leading to this report were based on:

- Interviews (qualitative, semi-structured, unstructured)
- Document inspection (worksheet reports, standards, quality assessment schemes, handbooks, laboratory manuals, classification lists, diagrams, drawings, etc.).
- Observations (activities at the microscope, presentation of labs).

The project is expected to run for two years during which the CANTOR system will be further developed, implemented, evaluated, and demonstrated.

Figure 1 shows the CANTOR strategy, which consists of two parts:

- an action plan to extract the initial expert knowledge related to the images from a group of people, and
- a CANTOR cycle to continuously improve the quality of the knowledge database.

The CANTOR cycle includes the interacting phases: education, training, quality assurance, and standardisation. All phases have two aims in common: to continuously improve the quality of the expert knowledge database and to use this expert knowledge in order to increase the classification agreement among the users and be able to conduct this agreement against the opinion of the ultimate expert.

Verner Andersen

Technology Scenarios

Methodologies for technology foresight and research planning

It is generally acknowledged that the accelerating development of new technologies will have a profound impact on society in the years to come. This opens up a range of challenges and opportunities for society, for industry, and for individuals, but it also gives us a higher level of uncertainty about the future. Hence, technology scenarios and foresight studies have attracted renewed interest in many countries and industries. In response to this, the department in 1998 established a new research programme, Technology Scenarios. Its objective is to analyse commercial, societal, and scientific possibilities, and study consequences in relation to the selection, development, and commercial application of new technologies. By the end of 1998, the programme was fully operational with staff consisting of a head, a research specialist, two senior scientists, and two postdocs. The programme is advised by a Scientific Advisory Panel, with ten experts from Danish and international industry and research organisations.

During its first year, the research programme has concentrated on three activities: 1) conceptualisation of the programme's approach and its most important research themes, 2) initial considerations of Danish needs and models for Technology Foresight studies, and 3) initiation of three pilot cases with the purpose of developing competencies and research methodologies.

The conceptual framework for Technology Scenarios covers four areas: The first area could be labelled technology analysis. Analysing technological scenarios and future possibilities demands a basic understanding of what technology is and of technological innovation and industrial dynamics. This research area draws on theories of technological innovation and techno-economical changes which have been developed during the past few decades, and it includes taxonomies of the technology, systemic complexity and uncertainty, sources of knowledge, science/industry interaction, core competencies, knowledge protection mechanisms, qualitative and quantitative trends, etc. The second area considers technology impact assessment, and includes direct and indirect impacts of the application of a technology on the environment, the economy, society, and other areas. Also included in this area are the public's technology acceptance, and technology perception analysed from a socio-psychological point of view. Technology impact assessment is not based on any well-defined theoretical framework. The impact assessment utilises a number of research methodologies such as environmental impact assessments (i.e. Life Cycle Assessments); risk, reliability and safety impact assessments; macro-economical impact of a new technology; social and behavioural impact; etc.

The third area is technology forecasting and foresight. This area introduces time and change in the framework using innovation theory and methodologies of scenario studies and Delphi studies. The fourth area deals with comparisons and choices of substituting technologies or desired futures. Comparisons of alternatives are based on the technology analyses, the impact assessment, and the present or future possibilities as well as a set of values and objectives. This area is theoretically anchored in elements of decision theory, i.e. multi-criteria analytical (MCA) methods that have been developed and applied for policy making and planning purposes during the last few decades.

Within this conceptual framework of theories and methodologies, the initial considerations in 1998 on the programme's research profile concluded that two themes were of special interest and relevance. The first research theme is developing methodologies for using technology foresight on two levels: on a Danish national level and on the level of industry and research organisations. Our initial studies have indicated that the experiences of other countries on technology foresight can enrich Danish approaches to research and technology planning on a national and industrial level. These experiences cannot be directly translated to a Danish context, however. A Danish approach (taking into account Danish traditions of mutual agenda setting. political consensus, etc.) needs to be developed. Also, our studies have revealed a need for developing a Danish base of knowledge (or a scientific platform) capable of participating in technology foresight processes on a European Union level. The second research theme is developing operational theories and methodologies for embodying forecast and foresight elements in technology/product life-cycle-analyses. This research theme is important because the accelerating technological development might significantly change the physical and economical environment of a product during its lifetime. Planning a nation's electricity supply or a power company's generation capacity portfolio must take into account technologies that are expected to be available 10 or 20 years ahead. Until very recently, life-cycle analyses of products and technologies have not included such technological changes. Life-cycle analyses usually have been based on present-day knowledge (or more likely, on yesterday's knowledge and data).

As mentioned, three test cases have been selected with the purpose of developing research methodologies.

The first case study has been carried out in co-operation with the Danish company *NKT Research Center A/S* and has been

Definitions of some terms

Technology Foresight

The process involved in systematically attempting to look into the longer-term future of sciences, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economical and social benefits (Ben R. Martin, 1995)

Technology Forecasts

Prediction of futures based on extrapolation of current trends using elements of industrial economics theory and innovation theory. This approach to technology futures can be useful for shorter-term predictions.

Technology Scenarios

Technology scenarios can be defined as stories describing different but equally plausible futures. They are developed using techniques that systematise the perceptions of alternative futures. A scenario approach can be used to test technology in future economical or societal settings.

Delphi Studies

Delphi studies are based on questionnaires sent to a selected panel of experts. Such a study can cover the range from a narrow topic to a wide technological foresight enterprise at a national or supranational level. A Delphi process includes typically two to four rounds, where the results from each are communicated to the participants in order to achieve a consensus after the final round regarding the issue under investigation. Delphi studies can be used to predict futures, to come up with new ideas and to provide a mutual agenda setting for industry, science, policy makers and the general public.

concerned with so-called SQUIDs. SQUID is an acronym for *Superconducting QUantum Interference Device*, and appears to be the most sensitive technology for measuring magnetic flux. The primary aim of the project was to achieve a better understanding of industrial and technological dynamics during the development of new technologies, and the creation of new technology-based business opportunities. During the study, the SQUID technology was analysed through the use of traditional technology taxonomies and with a focus on the company's core competencies.

Also, the technology's future perspectives were analysed by means of a technology diffusion analysis and a patenting analysis.

The second pilot case study concerns genetically modified plants. Risø's Plant Biology and Biogeochemistry Department and the company DLF-Trifolium have initiated an ambitious research project to develop a genetically modified high-value ryegrass incapable of producing stems. This automatically reduces the lignin content and thus improves digestibility. Simultaneously, the incapability of producing flowers and seeds avoids the dispersal of transgenes to related plant species. The core of the pilot case study is to develop a holistic life-cycle analysis methodology for comparing this new type of ryegrass with traditional ryegrass taking into account potential business opportunities and risks, environmental risks, public acceptance, etc. Furthermore, scenario-building techniques are used to include long-term societal, commercial, and environmental effects in the analyses. In 1998 the first phase of this quite complex case study was concluded by outlining a research methodology and identifying the major types of empirical information.

The third case study has been also carried out in collaboration with Risø's Plant Biology and Biogeochemistry Department and concerns the production of oat. The aim of the study is to compare conventional and organic agricultural methodologies.

The comparisons are made on a national level and on a corporate level including environmental and commercial issues. The study is based on life-cycle analyses including production, harvesting, processing, transport, consumption, waste treatment, etc. on oat production. During 1998 the research methodology has been outlined and three scenarios have been identified.

Furthermore, in 1998 a small consulting task was carried out for Dantec Measurement Technology A/S in co-operation with Risø's Optics and Fluid Dynamics Department.

In November 1998 a workshop on "Technology Forecast and Technology Scenarios" was arranged with 45 participants from research, governmental bodies, and industry. At the workshop, Risø's activities in the technology scenarios research programme were presented. Speakers from industry, governmental bodies and foreign research organisations gave presentations on the needs for and experiences in technology foresight studies and scenarios.

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