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Planning of sustainable energy distribution systems

Executive Summary

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RESULT (summary)

The SEDS project, running from 2003 to the end of 2007 includes many activities, and also many participants have contributed to the results which are summarized in this report.

The results from the project can be categorized as follows:

- 3 PhDs
- 4 Technical reports, including the Executive Summary
- A web site called 'Energy Planning Toolbox'
- A list of international publications in journals and conference proceedings
- Presentations at seminars and workshops
- A tutorial on Risk Analysis and Multi-Criteria models prepared by recognized international experts
- Numerous student projects and Master theses

These results summarize the project and mark the end of the project period. On the other hand, it can be a starting point for continued activities and for building knew knowledge in the field of Energy Planning. The objective of the 'Energy Planning Toolbox' that has been developed in this project is to provide a framework for building, collecting and presenting such knowledge. Currently, the toolbox is an instrument to view information and results from the SEDS project and to learn a bit about the methods developed so far, through a couple of examples.

The project team recommends the toolbox as an instrument in future energy planning projects, to be extended, enhanced and supplied with more knowledge and tools. It can thus develop to a very useful tool for students, researchers and teachers, as well as for energy companies, authorities and other entities involved with energy planning.

KEYWORDS

SELECTED BY AUTHOR(S)	Local Energy Planning	Multiple Energy Carriers
	Planning Methodology	Planning Tools

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1 INTRODUCTION

This report represents the executive summary of the results from the R&D project ‘SEDS – Sustainable energy distribution systems: Planning methods and models’ for the project period 2002 – 2007. The main partners within SEDS have been:

- Department of Electric Power Engineering, Norwegian University of Science and Technology (NTNU)
- Department of Energy and Process Engineering, NTNU
- Department of Energy Systems, SINTEF Energy Research
- Department of Energy Processes, SINTEF Energy Research

The project has been funded by the Research Council of Norway, StatoilHydro, Statkraft alliance (Statkraft SF, Trondheim Energi, BKK), Lyse Energi and Hafslund Nett, while Norwegian Water Resources and Energy Directorate (NVE) has been a co-operating partner. Our international partners have been University of Porto and INESC Porto in Portugal, Helsinki University of Technology and VTT in Finland as well as Argonne National Laboratory in USA and Swiss Federal Institute of Technology (ETH) in Switzerland.

The main objectives of the SEDS project, as stated in the original project plan have been the two following:

1. Develop methods and models that allow several energy sources and carriers to be optimally integrated with the existing electric power system.
   Particular emphasis is placed on distribution systems and integration of distributed energy sources, from a technical, economic and environmental point of view.
2. Develop a scientific knowledge base built on a consistent framework of terminology and concepts for mixed energy systems, in the field of planning methods and models.
   This will be a cornerstone for the curriculum ‘Energy and environment’ at NTNU.

Mixed energy distribution systems are illustrated in Figure 1. A mixed energy distribution system means (in this context) a local energy system with different energy carriers (electricity, district heating, natural gas, hydrogen) and a mix of distributed energy sources and end-uses.

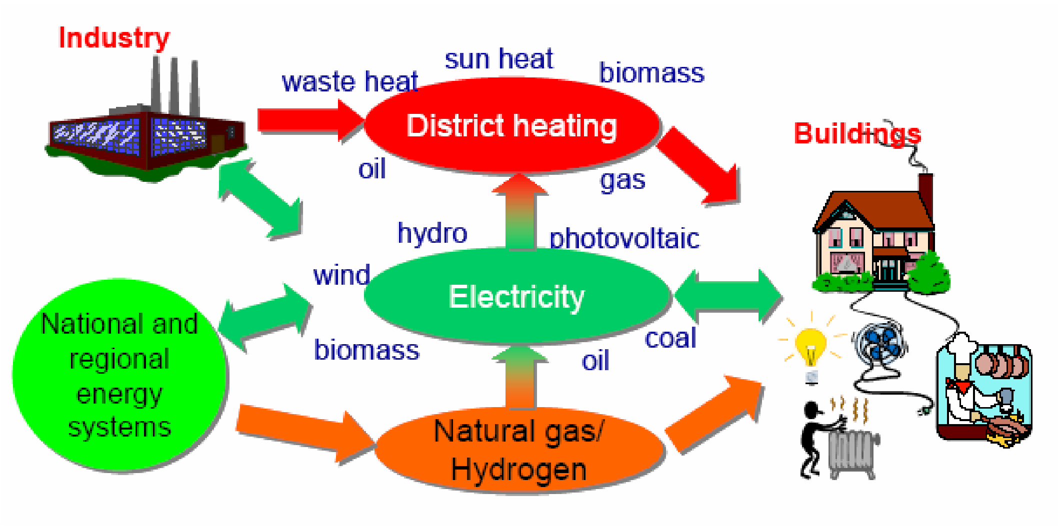

Figure 1 A mixed energy distribution system.

Thus, it is the scientific based methods and models for planning mixed energy distribution systems which are focused in the SEDS project. The term sustainable in the project name should be interpreted in this context. Sustainability relates to all aspects of the recommended planning objective: Economy, quality, security, safety, reputation, contractual aspects and environment. Hence, different energy distribution system alternatives should be characterized with respect to all these objectives, and the planning process should clearly quantify and make these parameters visible and understandable to decision makers and stakeholders, enabling the decision makers to choose sustainable system solutions.

<u>The first objective</u> has been realized through PhD-studies within the following three areas:

- Load and customer modelling of combined end-use (heating, cooling, electricity)
- Quality and reliability of supply in mixed energy systems
- Multiple criteria decision methods for planning of mixed energy distribution systems

In addition an initial study has been performed focusing on environmental impacts using a life cycle assessment (LCA) perspective in planning of local energy systems.

The project has also funded a post doctoral fellowship in multi-criteria decision aid and risk based methodology, and a tutorial given by our partners at University of Porto about risk analysis and multi-criteria decision making.

<u>The second objective</u> has been grouped in two parts:

- Development of a consistent planning framework for mixed energy distribution systems (terminology, concepts, socio-economic principles, general methodology etc)
- Development of a software toolbox environment (web-site) for decision support, visualization and demonstration of methodologies and technologies

For this part SEDS has co-operated with the eTransport project at SINTEF Energy Research [1], where a new tool for planning of energy systems is developed, considering several energy carriers and technologies for transmission and conversion.

The main products from the SEDS project are:

- Technical reports: "Planning of sustainable energy distribution systems" in four parts
- Web-site for energy planning methods and tools
- Three PhD candidates
- Publications in international journals and conference papers
- Presentations at workshops and seminars
- Numerous student project reports and Master theses

These results are made possible by the following contributors:

- Arne T. Holen (Project responsible)
- Gerd H. Kjølle (Project manager 2003, 2006 – 2007)
- Einar Jordanger (Project manager 2004 – 2005)
- Rolf Ulseth
- Eivind Solvang
- Kjell Sand
- Maria D. Catrinu
- Linda Pedersen
- Espen Løken
- Arild Helseth
- Audun Botterud
- Anne S. R. Risnes
- Øyvind Vessia
- Inger M. Lundhaug
- Hege Størseth

The SEDS results constitute a scientific knowledge base for the curriculum Energy and environment at NTNU as well as for energy distribution companies, energy authorities like NVE and governmental agencies like Enova and other stakeholders interested in local energy planning.

[1] eTransport-report: Energy 32 (2007), Elsevier

2 WHY COORDINATED ENERGY SYSTEM PLANNING?

In many countries local energy planners are currently confronted with new challenges. The restructuring of the energy sector and the development of different energy markets are adding complexity to the decision making process. In addition, the widely discussed environmental problems and the continuous depletion of non renewable energy resources are giving new dimensions to the planning problem in the medium and long run. In order to deal with the increased complexity in a systematic way and to include the environmental and resource aspects, there is a need to revisit the traditional planning methods and to look for enhancements.

A typical planning task is characterized by:

- Mixed energy sources and carriers
- A multi-criteria decision type of problem
- Several decision makers and stakeholders involved

In Norway, electric power has been, and still is the dominating energy carrier in energy distribution systems. However, district heating is expanding, and in some areas also natural gas networks are growing. Obviously, there is a need for coordinated planning of local energy distribution systems. Traditionally, utilities responsible for power distribution systems, district heating or gas networks did separate planning and optimization, which probably resulted in sub-optimised solutions. The increased focus on distributed generation and renewable energy sources clearly shows the need to analyse and evaluate alternative energy carriers in mutual combination.

New regulations from authorities and increased public attention and concern regarding both visual impact and emissions have led to more difficulties and restrictions related to implementation of energy infrastructure projects. Hence, the need for formally documented processes and decisions has increased. Therefore, a multi-criteria approach to the decision making process seems to be appropriate. It is generally called multi-criteria decision making (MCDM).

More participants with different objectives and criteria are involved in decision processes (commercial companies, authorities, investors, interest organisations etc). An MCDM approach will support such an environment. Additionally, uncertainty aspects have to be included in the decision making process.

The SEDS project has focused on local energy supply limited to supply for stationary use. Therefore, electric power grids, district heating and natural gas supply by pipelines are the main infrastructure facilities that have been analysed. There is a distinct difference in costs between these fixed infrastructures: cables, overhead lines, pipelines for hot water and gas on one side and the discontinuous transport by trucks and boats on the other side. Initial investment costs for the fixed infrastructures are very high and normally irreversible, resulting in low marginal costs compared to average unit costs, until reaching capacity limits. The fixed infrastructures are therefore regarded and defined as ‘natural monopolies’. They are under monopoly regulation and need concession from the responsible authority.

It is important to make sound and robust decisions when investment costs are high and the decisions in practice are irreversible. The SEDS project has focused on this type of decisions, and the scope can be summarized as follows:

- Planning of infrastructure for local energy distribution for stationary use (from bulk supply point to aggregated load points, see example in Figure 2)
- Fixed infrastructures (networks) that can be regarded as natural monopolies
- Integration of local energy sources as well as end-user equipment and demand side management is considered
- Medium and long term development of the local energy system
- Planning based on socio-economic principles including technical, economical and environmental aspects
- The main decision makers focused: Distribution companies, regulators, authorities

Apart from particular methods developed within the PhD projects, SEDS has not focused on development of software tools to support planning of mixed energy systems. However, in a 'sister' project called 'eTransport' a tool has been developed, particularly focusing on the competition and interaction between energy sources and carriers. This tool has been applied in SEDS in order to demonstrate how results from eTransport can be used in MCDM. These applications are found on the web-site called 'Energy Planning Toolbox', see description in Chapter 5.

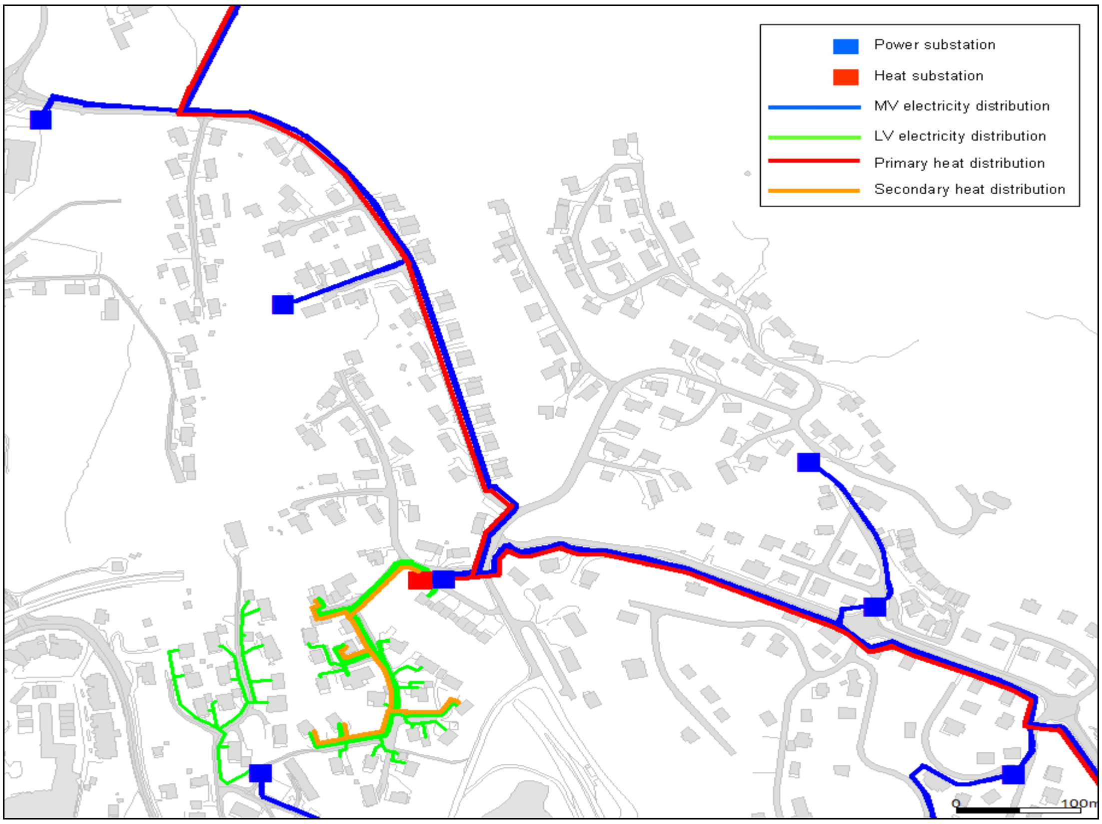

Figure 2 Example of infrastructures for electricity distribution and district heating.

3 OVERVIEW OF MAIN RESULTS

According to the stated objective: To describe a planning framework for sustainable energy distribution systems, technical reports have been worked out and organized under a common headline: ‘Planning of Sustainable Energy Distribution Systems’ and divided in four parts dealing with different aspects of the planning problem. This executive summary represents the first part, while the others are as follows:

- Problem definition and planning principles [1]
- Planning methodology and tools [2]
- A life cycle assessment perspective [3]

A summary of these reports are given in subsequent chapters. A web-site: ’Energy Planning Toolbox’ [4] has been developed and is described in the report about methodology and tools [2].

There are three doctoral (PhD) theses being part of SEDS. By December 2007 two PhDs have been completed. A third PhD is planned to be completed before end of May 2008. A summary of the theses is given in the following.

3.1 LOAD MODELLING OF BUILDINGS IN MIXED ENERGY DISTRIBUTION SYSTEMS, DOCTORAL THESIS AT NTNU, 2007:78, FEBRUARY 2007

Candidate: Linda Pedersen

Objectives

The thesis states: ‘The objective of this thesis was to develop a method that estimates simultaneous heat and electricity load profiles primarily for design conditions, yearly load profiles, load duration profiles and yearly energy demand for different building categories.

Developing an approach to load modelling of buildings in mixed energy distribution systems meant devising a method based on a defined methodology to estimate the future heat and electricity load profiles and yearly energy demands for a specific planning area. A planning area may include a residential housing area or the size of a small Norwegian town. For the purpose of this work, buildings have been divided into different categories, such as single family houses and apartment blocks, office buildings, educational buildings, hospital buildings, and hotels and restaurants’.

Specific contributions

Some specific contributions:

- A new method to estimate heat and electricity load profiles for various buildings based on the building’s hourly simultaneous district heat and electricity measurements.
- A new procedure to determine the change-point temperature for dividing temperature-dependent and temperature-independent heat consumption such as space heating, ventilation heating and hot tap water.

- Development of new and generalised heat and electricity profiles for various building categories.
    - Identification of specific load and energy indicators
    - Procedure for estimating yearly load profiles and load duration profiles
- Development of a method for load aggregation to estimate design load profiles, yearly profiles, load duration profiles and yearly energy demand for a specified planning area, divided into heat and electricity purposes.

3.2 MULTI-CRITERIA PLANNING OF LOCAL ENERGY SYSTEMS WITH MULTIPLE ENERGY CARRIERS, DOCTORAL THESIS AT NTNU, 2007:79, APRIL 2007

Candidate: Espen Løken

Objectives

The thesis states: ‘The main objective has been to propose how a multi-criteria based approach can be applied to discrete investment planning in local energy systems with multiple energy carriers. The proposal is based on two experimental case studies’.

These two are the so-called ‘Hylkje-case’ and the ‘Lyse-case’. The first one is also used as the demonstration example in the web-site ‘Energy Planning Toolbox’.

Specific contributions

The main contributions are:

- A requirement specification for Multi-Criteria Decision Analysis (MCDA) based planning framework, including the elements
    - Easy to use and with transparent logic
    - Results presented in a way easily understood by decision makers (DMs)
    - Able to elicit and aggregate consistently DMs’ preferences
    - Consistent handling of uncertainties
- A description of planning framework with elements
    - Identification and structuring of the problem
    - Building of impact (energy system) model(s)
    - Impact assessment
    - Preference elicitation and aggregation
    - Decision making and implementation
- Experimental testing of two MCDA methods, Multi Attribute Utility Theory (MAUT) and Analytical Hierarchy Process (AHP) on a local energy planning problem: the case studies.
- Demonstration and evaluation of the Equivalent Attribute Technique (EAT) as an instrument to compare alternatives.

- Providing case based experience that demonstrates the importance of close interaction and understanding between the analyst and the decision makers, specifically emphasizing:
  - Problem structuring and identification
  - Selection of criteria and attributes
  - Use of proxy criteria
  - Interpretation of results

3.3 MODELLING RELIABILITY OF SUPPLY IN MULTI-CARRIER ENERGY DISTRIBUTION SYSTEMS

Candidate: Arild Helseth

This doctoral work is planned to be completed in 2008, and therefore the title, objectives and contributions are preliminary. Under the umbrella of the preliminary title the work has been focused towards three sub-areas and so far presented in several publications at conferences and in journals (see reference list in Chapter 8).

- Optimal allocation of switchgear in constrained electricity distribution networks, particularly considering different categories of end-uses and associated interruption costs. The relevant categories of end-uses to consider here are specific electricity end-use as compared to flexible end-use, i.e. which can be covered by alternative energy carrier, such as space heating. The assumption under investigation is that when end-uses currently being covered by electricity are being switched to other energy carrier this may have an effect on the optimal level of switchgear, remote control and automation.
- Methods and techniques for reliability assessment of natural gas distribution networks as compared with techniques used for electricity networks. A special feature with natural gas networks, particularly on transmission level, is the ability of storage due to compressibility of the gas, called line pack.
- Vulnerability of mixed energy distribution systems to failures or combination of failures. The case study being implemented is mixed supply by electricity and district heating, and the focus of the study is to identify events where initial faults in the electricity network cause failure to hot water supply in the district heating network.

4 PROBLEM DEFINITION AND PLANNING PRINCIPLES

Energy system planning is a complex and multi dimensional task due to a number of assets and work processes, decision makers, stakeholders and supply options, environmental impact and a wide span in time horizon from microseconds to many years. It is impossible to solve the total planning problem in one large operation due to this complexity. Hence, energy system planning calls for structured system analysis, simplifications and decompositions. The following levels can be identified:

1. International level
2. National level
3. Regional (county) level
4. Municipal/ concession area level
5. Part(s) of the municipal level — Local energy system level
6. End user level

4.1 STRUCTURE AND DEFINITIONS

Long term planning of **local** energy systems:

- Long term is here defined as a planning horizon of 10-50 years.
- Long term planning is here defined as planning of energy system infrastructure development (investment planning)
- Local energy systems means energy systems on a municipal or concession area level or less

Planning phases can be grouped into:

1. Stakeholder identification
2. Problem formulation - establishment of principles, premises and criteria to be used
3. Definition of system boundaries – limiting the planning area
4. Collection of relevant data related to existing infrastructure, demand forecast, available energy options and technologies, costs, restrictions etc.
5. Analyses of relevant alternatives (simulation/estimation of technical, economical, environmental and reputation impact)
6. Decision making (evaluation, negotiation, acceptance etc)

Main stakeholders:

- Energy distribution companies
- Energy authorities
- Energy providers
- End users

Main planning objectives:

- Economy
- Environmental impact
- Quality and reliability of supply
- Reputation

4.2 SYSTEM BOUNDARIES

As stationary energy systems might be very large, it is often necessary to limit the planning problem to a manageable size as planning resources (money and time) are limited. An important motivation for problem size reduction and hence model reduction, is to reduce data volume and to improve data quality. Result interpretation might also be difficult when the models are very large.

It is hence essential that the planning problem formulation and delimitation is carefully considered when the actual planning process is initiated. To reduce model size, system decomposition is a well known technique. The following figure illustrates the principle.

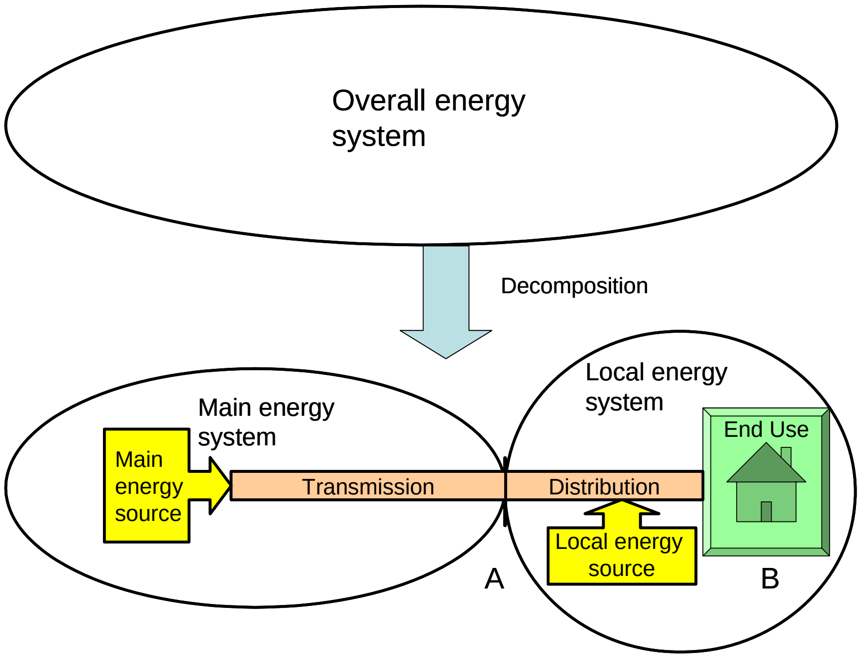

Figure 3 Planning problem decomposition – model reduction.

The overall energy system is divided into two subsystems: The **main energy system** and the **local energy system**. The main energy system is **not** represented in any detail while the local energy system is modelled to the level of detail that the study requires. The main energy system might be the "national" energy system while the local energy system might be a small part of the system that should be evaluated.

The decomposition can be performed along several axes:

- Geographical/spatial and technical system boundary
- Energy source – carrier (e.g. separate optimization of the local district heating system from the local electricity distribution system)
- Along the life-cycle (time base) of a project (investment)
- Along the value chain of the energy system (generation, transmission, conversion, distribution, end-use – upstream versus downstream)
- Level of detail (e.g. optimization of transformer size or cross-section of cables or pipes)

Decomposition: An illustration

From a local energy planning perspective a boiler metaphor can be used to illustrate the decomposed energy system, see Figure 4 and 5.

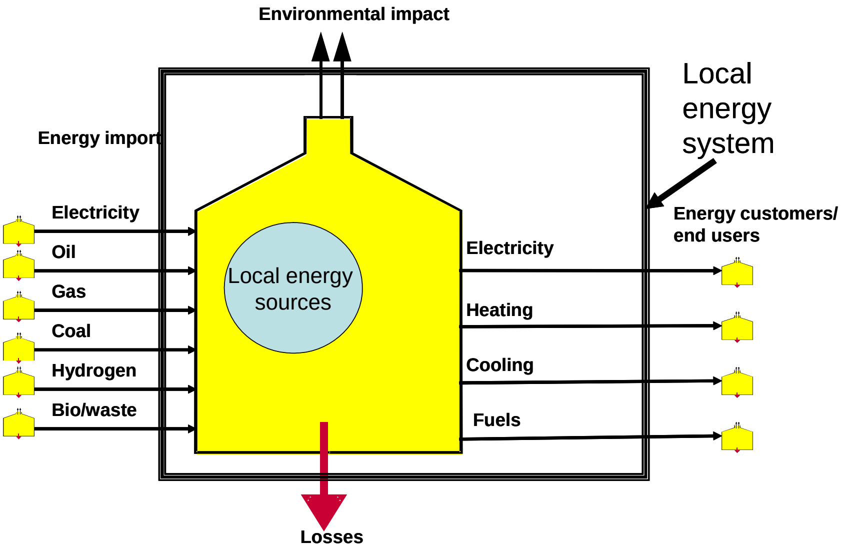

Figure 4 Decomposition – excluding end-users.

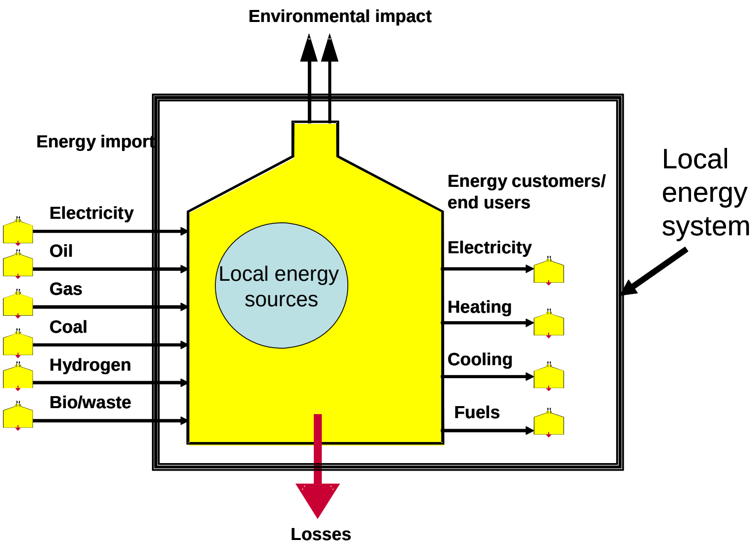

Figure 5 Decomposition – including customer energy processes.

Cost at system boundary
System boundaries i.e. where to place the borders between the main energy system and the local energy system is a task that should be carefully considered so that **all relevant effects in the problem formulation are included in the model – and avoiding double accounting of effects.**

Let us consider the following example:

If the electricity producers have to pay for green house gas emissions and this cost is included in the electricity import price, this environmental impact should not be included as an extra environmental cost in the local energy planning problem. One could argue that the market price does not necessarily reflect the real costs and actual emissions, particularly when several countries are involved, but even in an imperfect market there is probably no better estimate.

In general, from a socio-economic point of view, costs and emissions occurring as a result of decisions made within the system boundaries should be included in the optimisation process. The reasoning above regarding attributes associated with imported energy carriers also applies to considerations regarding the demand side. This means that the infrastructure for different energy carriers on the demand side (end-users premises) has to be included in a socio-economic optimisation.

In a socio-economic approach, it is a prerequisite that the decisions should be the same as if the whole energy system was owned by one single party. The use of long term or short term marginal costs play an important role in system decomposition.

A very simple model of the main energy system in Figure 3 above is to represent it by the costs of delivering energy at the connection point A. This energy cost should be the **marginal** costs of producing and transporting energy to point A. The resource allocation (the planning decisions) will then be the same as if the planner undertook the job of modelling the complete energy system.

From a local planner’s perspective it is convenient if all imports and exports are given in terms of market prices that reflect socio-economic costs. It will be difficult for the local planner to have sufficient insight in all upstream and downstream energy value chains to asses relevant cost factors, environmental factors, quality factors and reputation factors if they are not to a certain degree declared by the market and/or by the supplier. In a perfect market the prices will reflect the real costs and the difference between corporate and social economy does not exist, i.e. in a perfect market the socio-economic costs will equal the market price. But in practice this is not always true and should hence be addressed in the specific planning case.

4.3 SOCIO-ECONOMIC PRINCIPLES AND MARGINAL COSTS

The planning objective stated in the Norwegian Energy Act [2] is as follows:

§1.2
The act is intended to ensure that generation, conversion, transmission, trading and distribution of energy are rationally carried out for the benefit of society, having regard to the public and private interests affected.

The underlying regulations state that a socio-economic planning approach is relevant to achieve a nation's energy objectives. The planning principles should hence be based on the energy system's contribution to maximize the 'welfare of the society'. In energy planning the main objective is to develop, operate and maintain a socio-economic efficient energy system.

Marginal cost signals are useful tools to optimise energy systems that are owned by different stakeholders. The stakeholders might be energy producers, energy transporters and/or energy users. Marginal costs can be defined in several ways, but the two most important are

- STMC: Short Term Marginal Cost – the cost of loading existing system with an extra unit **without considering** system reinforcement.
- LTMC: Long Term Marginal Cost – the cost of loading the existing system with an extra unit **considering** system reinforcement.

Figure 6 illustrates the total energy system costs and the marginal costs as a function of peak power demand.

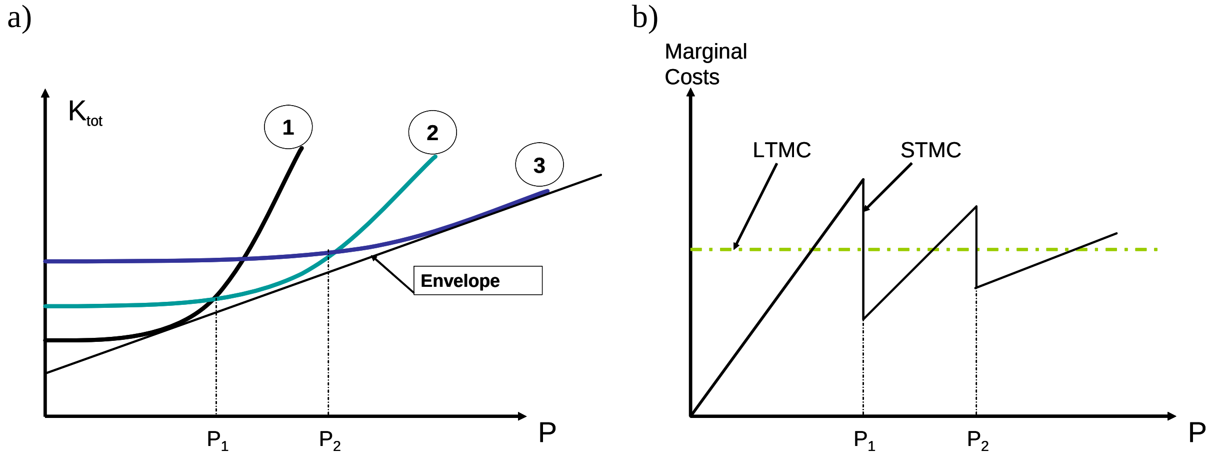

Figure 6 a) Total Energy System Costs as a function of the Peak Power Demand for three different transport capacities.
b) STMC and LTMC as a function of Peak Power Demand.

Traditionally, the marginal cost signals have been applied to expanding systems, but the principle is equally applicable to non-expanding systems or even in declining systems.

[2] REG.no.959 of 7 December 1990

5 PLANNING METHODOLOGY AND TOOLS

The main objectives for the planning process are as follows:

- To cover supply duties with acceptable quality of supply and to contribute to effective energy markets
- Design infrastructure and mix of energy sources and carriers to minimum cost and acceptable environmental impact
- Optimise interplay between the infrastructure and demand side management

5.1 THE PLANNING PROCESS

The sequence of tasks involved in local energy planning is illustrated in the flowchart in Figure 7. In the report [2] a description and explanation of these tasks is found together with references and links to supplemental material.

Even if this flowchart is quite general, in terms of terminology and content, it serves as a reference and guideline for local energy planning. As a supplement to the flowchart some important aspects regarding the planning problem are elaborated in the following.

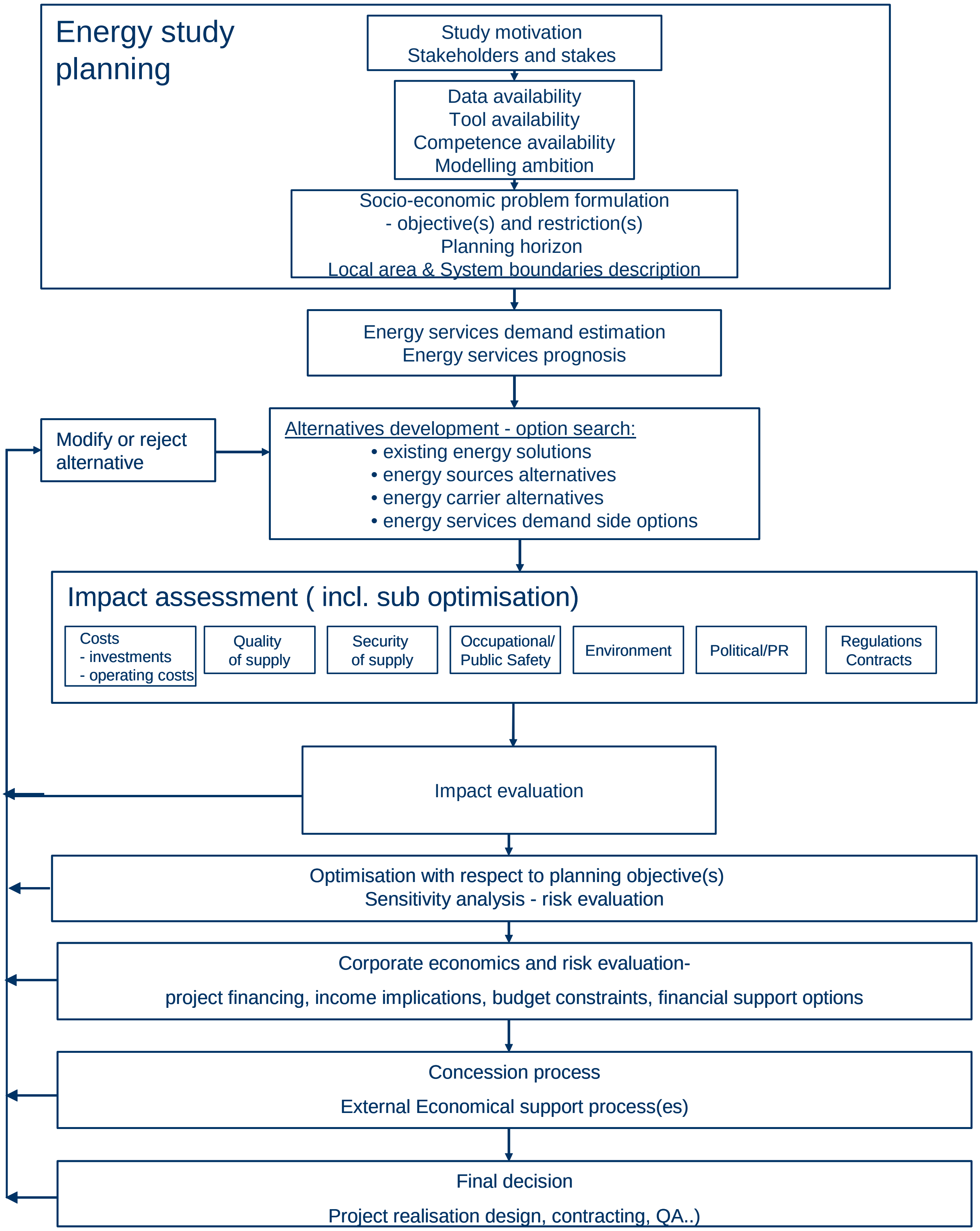

Figure 7 Local Energy Planning Flowchart.

5.2 DECISION MAKERS, STAKEHOLDERS AND STAKES

The report on planning methodology gives an overview of planning problems and tasks as well as challenges for the most important groups of decision makers in the planning of local energy system. The discussions are focusing on examples form the Norwegian energy sector. In general, four important groups of decision makers have been identified as relevant for the SEDS project:

- Energy distribution companies
- The Regulator: The Norwegian Water Resources and Energy Directorate (NVE)
- Enova: Governmental agency. Enova's main role is to promote and fund energy solutions according to the energy policy of its owner, the Royal Norwegian Ministry of Petroleum and Energy.
- Local and regional governments (municipalities and counties)

Tasks and related challenges are described in the report for the four groups of decision makers [2].

5.3 LOAD MODELLING

Essential in local energy planning in short term (operation) or in long term (expansion planning involving substantial irreversible investment decisions) is to estimate present and future demand for energy services, such as:

- Light
- Mechanical work
- Heating (space heating, cooking, hot water..)
- Cooling (air condition, refrigeration..)
- Electronics (PC, TV, stereo…)

The different services can be characterised with respect to whether the services can be performed by different energy carriers/sources or not. For example, space heating might be supported by several energy technologies and carriers (hot water, electricity, biomass, etc.) – alone or in combination – while for electronics, electricity is the only upstream technology that can be used.

In the context of energy infrastructure planning, the estimation of end-use energy demand resumes however to the estimation of the demand for those energy carriers for which distribution infrastructures (pipes, electrical grids) are necessary. It is essential to be able to model for example the system's maximum for heat and electricity as well as load duration profiles.

Load models can be used to forecast the energy demand both in short term operation of an energy system and in long term expansion planning involving substantial irreversible investment decisions. Load modelling can be defined as aggregation of spatial, individual energy demand specified in time. In practice this is done by establishing representative load profiles for defined customer categories with similar demand. The doctoral work about load modelling in SEDS as described in chapter 3, made specific contributions applicable for mixed energy distribution systems.

5.4 MULTI-CRITERIA DECISION AID FOR ENERGY PLANNING

The description of this topic is extracted from two PhD studies carried out at NTNU: one is part of the SEDS project, described in chapter 3, and the other was part of the 'sister' project eTransport.

Multi-Criteria Decision Analysis (MCDA) is the discipline that studies methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process. The use of MCDA in energy systems planning is justified by the simple fact that not all aspects that matter (and must be considered) in distribution system asset management can easily be given a monetary value. When using MCDA light can be shed on what tradeoffs, uncertainties and value judgments are crucial to the decision and what issues do not matter. MCDA is a process which seeks to help decision makers (DMs) learn about and better understand the problem they face, their own values and priorities and the different perspectives of other stakeholders.

It is important, however, to stress the fact that MCDA does not provide 'the right answer', as some mathematical or engineering methods would be expected to do. Instead it provides recommendations or advice regarding which decision to make based on the information available in a given decision situation. Practice has shown that MCDA's recommendations are often at least as good as the choices based on intuition (as most decisions are made).

There are two types of modelling for MCDA: the modelling of consequences (impacts) each decision may have in terms of the relevant goals and the modelling of decision-makers' preferences regarding their options (decision alternatives) with respect to the chosen goals. In energy planning advanced decision aid can be achieved by combining:

- Energy system models –for impact modelling
- Multi criteria decision analysis models – for preference modelling.

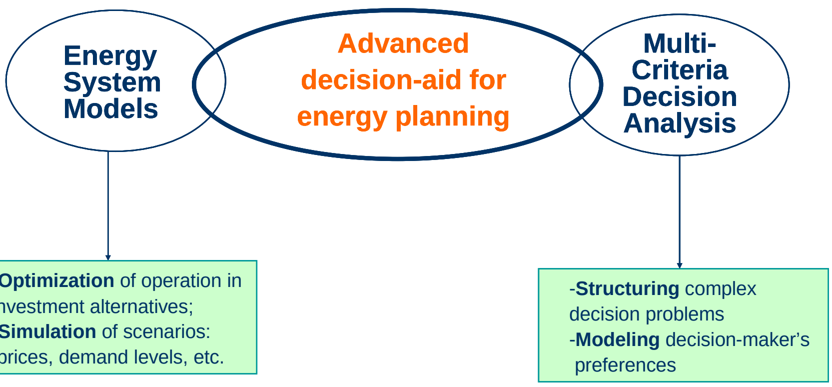

Figure 8 Decision-aid for energy planning, combining Energy System Models with Multi-Criteria Decision Analysis (MCDA).

In SEDS the eTransport model has been applied for impact modelling (Energy system model in Figure 8). eTransport has been developed to provide support for the planning of local or regional mixed energy distribution systems. It is a deterministic linear model, and it describes in sufficient detail various energy sources and –carriers, including topological/geographical infrastructure and energy conversion options. End-use, i.e. load profiles for daily, weekly and seasonal variations are also modelled in detail. The model determines the cheapest way, from a socio-economic point of view, to satisfy end-use energy demand.

The multi-criteria decision analysis part is based on the above mentioned doctoral theses. An example is found in the web-site: ‘Energy Planning Toolbox’ [4].

5.5 UNCERTAINTY

Uncertainty is becoming increasingly more important in the planning process. Uncertainty means that there is a risk of making a decision that one will regret later on, because the future situation became different from what was assumed when the decision was made. Dealing with uncertainty involves identification of the various sources and classes of uncertainty, to understand and structure these classes and to model and make them part of the decision process.

Usually, uncertainties are grouped in two main classes:

- External uncertainty: events that are outside control of the decision maker.
- Internal uncertainty: uncertainty or imprecision in the process of identification, structuring or analysis of the decision problem, for example in identification of decision maker preferences.

External uncertainties are modelled with the impact model, and internal uncertainty and imprecision can be resolved with preference modelling.

The report further explains and expands on these two classes of uncertainty [2].

5.6 CASE STUDIES

The first two case-studies are examples of energy planning problems, seen from the perspective of different types of decision-makers:

- An energy distribution company reinforcing supply to an expanding local area, looking at alternative supply options.
- The governmental energy agency Enova evaluating the socio-economic aspects of a project where alternative solutions for heat and hot water supply to a local town are compared.

Each example is structured so that the main challenges for planning (identifying system boundaries, alternatives and criteria for analysis) will be first revealed, and then different tools to support the final decision are discussed.

The third case-study is about forecasting energy demand. This is in fact an example demonstrating how results from the PhD on load modelling can be applied to find specifically the type of load profiles that are being used in energy system modelling (impact models).

5.7 PLANNING TOOLS

The report [2] also describes the content and organization of a software toolbox environment for decision support and demonstration, implemented on the web-site called ‘Energy Planning Toolbox’, see Figure 9 [4].

The **main objective** of the toolbox is to provide support for the analyses and decisions that are required during the planning process, and it is designed for educational, research and development purposes. It aims at closing the gap between the availability of scientific solutions and their use in practice.

Currently, the toolbox includes main results found in the technical reports from the SEDS project. It can be used to view these results through a couple of examples, looking at the planning tasks involved with these examples and the corresponding tools. It is emphasized that the current content is a preliminary version.

The toolbox is, however, structured according to the recommended general planning methodology described in the reports and attempts to give a comprehensive picture of the planning process. The vision is that the content of the toolbox is going to be expanded with more examples and more tools and then be a useful instrument. In particular:

- *Students* will be able to:
    - learn methods and theory applied to practical problems
    - carry through projects and theses work: perform analyses, further development of methodology etc.
- *Researchers and teachers* at the Energy and environment curriculum will find support for:
    - teaching 'energy planning' and for carrying out of students work
    - accessing data and specific case-studies
    - testing of new models and methods
    - demonstration of the influence of new technologies on the supply or demand side
    - visualisation and demonstration of planning aspects, mechanisms and ideas
    - carrying out analyses in energy planning projects
- *Energy companies*, *authorities* and other entities involved in local energy planning will:
    - get easy access to useful methodologies and tools for decision analysis and support that will supplement the existing planning routines
    - gain a broader knowledge of the planning process

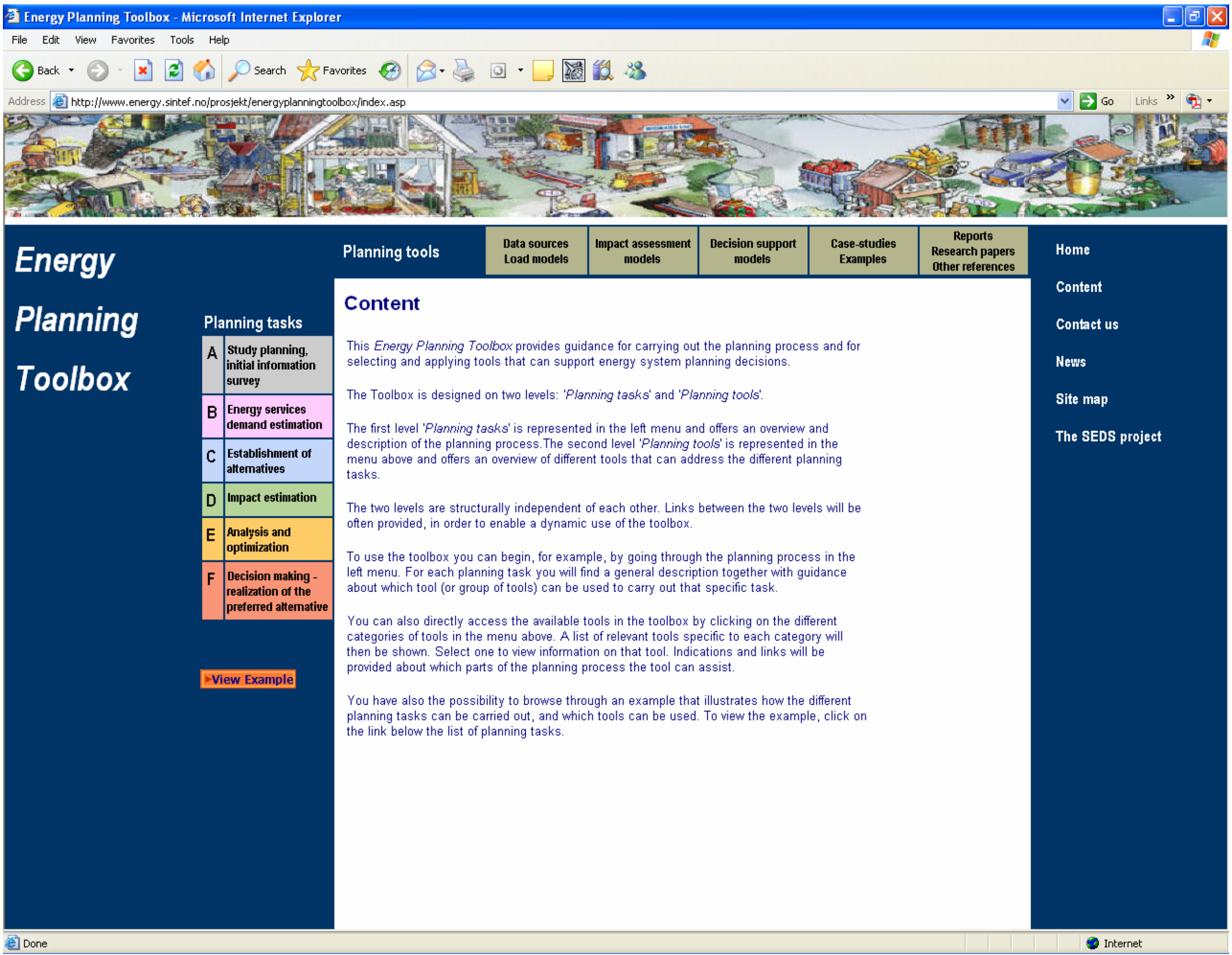

Figure 9 Main organization of the Energy Planning Toolbox.

Further details about the toolbox are found in the report [2].

6 A LIFE CYCLE ASSESSMENT PERSPECTIVE

An introduction to Life Cycle Assessment (LCA) in the context of energy planning is provided by the report [3]. The report tries to point out the major differences between emission accounting and a broader LCA perspective. LCA is a holistic approach accounting for all environmental impacts occurring from the system's "cradle" to the "grave", together with all related activities throughout the lifetime of the system. The study presents a broad range of different LCA studies, thus providing a starting point for further studies of LCA of energy systems. The LCA perspective is found to be useful and necessary for sound environmental planning of energy systems, aiming at socio-economic optimal energy systems.

The LCA thus introduces two new important dimensions of analysis of an energy system; energy flow activities from extraction of fuel to utilisation in e.g. a power plant, together with the up and downstream processes related to any process associated with the energy service. In the context of SEDS it is important to analyse the importance of these two dimensions, to find out whether the additional information is crucial for the overall environmental impact. It is important to be aware of the limitations of a traditional emission accounting analysis, which only counts for operational (stack) emissions. Different environmental loads occur at different phases of the energy system's life cycle.

Examples where traditional emission accounting fails are e.g.:

- The burning of biomass if it is transported long distance by truck and need considerably amounts of fertilizer.
- The installation of a photovoltaic (PV) panel when more energy is used during production of the PV panel than will ever be produced during its lifetime.

These two examples show that operational emission accounting can produce misleading answers when related upstream processes are neglected. When analysing energy systems using LCA, there are two major areas of interest:

- Detection of the most harming processes located in the energy system being analysed, serving as basis for system optimization.
- Comparison between different energy system options in order to make a well informed decision.

The observation and main conclusion from this rather brief overview and introduction to LCA as a tool in local energy planning, is that for design and construction of grids for electricity or district heating the LCA does not add significant new information to the decision process. What can be observed also from an LCA perspective is the well recognized fact that transmission losses have to be compensated by increased up-stream generation and possible up-stream network expansion. Such expansions have environmental impact. By careful definition of system boundaries for the current analysis this will be observed and included in the impact analysis as described in Chapter 5.

However, in general an LCA perspective is useful and necessary for sound environmental planning of energy systems, particularly to avoid forgetting environmental impacts outside the system boundary defined for the case being studied.

7 TUTORIAL, WORKSHOPS AND SEMINARS/CONFERENCES

7.1 TUTORIAL: 'APPLICATION OF RISK ANALYSIS AND MULTICRITERIA MODELS IN ENERGY SYSTEMS PLANNING'

The tutorial was given in October 2003 (2003-10-06 to 10) by two specialists from our international project partner: Inesc Porto and University of Porto, Portugal. This tutorial was instrumental for development and progress for the two PhDs within multicriteria decision making (MCDM): one within the SEDS project and the other within the eTransport project. Results from these PhDs have been implemented in the web-site. In addition to the teachers the tutorial had other international participants: two PhD students from ETH, Zürich, Switzerland. It became the starting point of a close PhD cooperation between ETH and NTNU in the area of mixed energy distribution systems.

The topics covered by the tutorial were as follows:

- Basic concepts and definitions
- Decision support systems
- Review of typical problems
- Multiattribute problems
- Multiobjective problems
- Meta- heuristics
- Decisions under uncertainty
- Decision trees
- Simulation
- Application to planning problems

7.2 WORKSHOPS

The following workshops have been organized by SEDS:

- **'Planning process, methods and tools', 2003-05-28**
  This was the first workshop, discussing problem definition and planning principles. The workshop included presentation of four master theses applied to specific planning tasks in Norwegian energy companies. It is interesting to observe that three of these master students later on became the three PhD students in the SEDS project. Also included in the workshop was a discussion of content, scope and focus of the SEDS project in order to give a fundament for further work.
- **'Load and Customer Modelling', 2004-06-17 and 18**
  This workshop was organized to get an overview of activities and methods relevant to load and customer modelling and particularly to support the doctoral work within this area. The workshop had international participation (VTT/Finland).

- **‘Reliability of Supply in Energy Distribution Networks: Electricity, District Heating and Natural Gas’, 2005-04-19**
  This workshop attempted to focus on methods relevant for mixed energy distribution systems, particularly supporting the doctoral work on reliability. The workshop had international participation, where the PhD students from ETH, Zürich, Switzerland made a presentation of their work under the project: ‘Vision of Future Energy Networks’.
- **‘Socio-economic Principles and System Boundaries. Load Modelling’, 2006-01-19**
  This workshop was organized to discuss particularly the work which has been presented in the technical report ‘Problem Definition and Principles’ [1] and became a part of the basic foundation for the planning methodology. The workshop also included a brief section about load modelling.
- **‘Planning Methodology and Tools’, 2007-03-15**.
  This workshop focused on discussion of the topics which are presented in the technical report ‘Planning Methodology and Tools’[2] and implemented in the web-site ‘Energy Planning Toolbox’.

7.3 SEMINARS

The project team, PhDs and master students have participated in a series of annual conferences about ‘Distributed Energy’ in the period 2003-2006. These conferences have been organized together with related research projects at NTNU and SINTEF Energy Research, and in cooperation with The Research Council of Norway. At these conferences SEDS has contributed by various presentations. The research team of SEDS as well as students have also participated in two national seminars organized by Norwegian Electrotechnical Association (NEF). A selection of presentations are found in the reference list, in the following chapter.

7.4 STUDENT PROJECTS AND MASTER THESES

Numerous student projects and master theses have been completed under the umbrella of SEDS. Projects and theses have mostly been done in the form of case studies of particular planning tasks and scenarios and in close cooperation with Norwegian energy companies. A reference list is found in Chapter 8.

7.5 PUBLICATIONS: JOURNALS AND CONFERENCE PAPERS

An important objective part of the project has been to make international contacts and to contribute through publication of results in journals and at relevant conferences. Particularly, the PhD candidates have been active, but also other researches in the project have made contributions. A complete reference list is found in the following chapter.

8 PUBLICATIONS AND PRESENTATIONS, REFERENCE LISTS

This chapter gives an overview of publications and presentations produced in connection with the SEDS project, the most recent publications from the top of the lists. Some of the publications have been co-authored with the researchers in the eTransport project.

8.1 JOURNALS AND CONFERENCES

Under review
Espen Løken, Audun Botterud, Arne T. Holen: ”Use of Equivalent Attribute Technique in Multicriteria Planning of Local Energy Systems”, Special issue of the European Journal of Operational Research on "Operational Research Models and Methods in the Energy Sector"

Arild Helseth, Gaudenz Koeppel: “"Pipeline Storage and its Impact on Reliability of Supply in Pipeline Energy Systems", Reliability Engineering & System Safety, Elsevier

Published
Arild Helseth, Arne T. Holen: "Impact of Energy End Use and Customer Interruption Cost on Optimal Allocation of Switchgear in Constrained Distribution Networks", IEEE Transactions on Power Delivery, Vol. 23, Issue 1, 2008.

Espen Løken: “Use of Multicriteria Decision Analysis Methods for Energy Planning Problems”, Renewable & Sustainable Energy Reviews, Volume 11, Issue 7, September 2007, pp 1584-1595

Linda Pedersen: “Use of different methodologies for thermal load and energy estimations in buildings including meteorological and sociological input parameters”,
Renewable & Sustainable Energy Reviews, Volume 11, Issue 5, June 2007, pp 998-1007

Arild Helseth, Gaudenz Koeppel: “Storage Potential in Pipelines and its Impact on Reliability of Supply”, ESREL, 2007-06-25/26, Stavanger, Norway

Linda Pedersen, Rolf Ulseth: “Method for Load Modelling of heat and Electricity Demand”, The 10th Symposium on District Heating and Cooling, SHDC 2006, September 3-5, Hanover, Germany

Arild Helseth, Arne T. Holen: “Impact of energy end-use on optimal allocation of switchgear in radial distribution networks”, The 3rd International Symposium on Modern Electric Power, MEPS 2006, September 6-8, Wroclaw, Poland

Espen Løken, Audun Botterud; Arne T. Holen: ”Use of Equivalent Attributes in Multicriteria Planning of Local Energy Systems”, The 19th Mini-Euro Conference, ORMMES 2006, September 6-8, Coimbra, Portugal

Espen Løken, Arne T. Holen: ”Multicriteria Planning of Local Energy Systems with Multiple Energy Sources and Carriers – Why and how?”, The 18th International Conference on Multiple Criteria Decision Making, MCDM 2006, June 19-23, Chania, Greece

Arild Helseth, Arne T. Holen: “Reliability modelling of gas and electric power distribution systems; similarities and differences”, The 9th International Conference on Probabilistic Methods Applied to Power Systems, PMAPS 2006, June 11-15, Stockholm, Sweden

Espen Løken, Audun Botterud, Arne T. Holen: ”Decision Analysis and uncertainties in Planning Local Energy Systems”, The 9th International Conference on Probabilistic Methods Applied to Power Systems, PMAPS 2006, June 11-15, Stockholm, Sweden

Audun Botterud, Maria Catrinu, Ove Wolfgang, Arne T. Holen: “Integrated energy distribution system planning: A multi-criteria approach”, The 15th Power Systems Computation Conference, PSCC 2005, August 22-26, Liège, Belgium

Einar Jordanger, Bjørn H. Bakken, Arne T. Holen, Arild T. Helseth, Audun Botterud: “Energy Distribution System Planning - Methodologies and Tools for Multi-Criteria Decision Analysis”, The 18th International Electricity Distribution Conference & Exhibition, CIRED 2005, June 6-9, Turin, Italy

Espen Løken, Audun Botterud, Arne T. Holen: “Planning of Mixed Local Energy Distribution Systems: A Comparison of Two Multi-Criteria Decision Methods”, The 28th IAEE International Conference, 2005 June 3-6, Taipei, Taiwan

Linda Pedersen, Rolf Ulseth: “Methodology for Estimation of Maximum Load Profiles for Heat and Electricity in Buildings”, The 9th International Symposium on District Heating and Cooling, SDHC 2004, August 30-31, Espoo, Finland

Maria Catrinu, Espen Løken, Audun Botterud, Arne T. Holen: “Constructing A Multicriteria Framework for Local Energy System Planning”, The 18th International Conference on Multiple Criteria Decision Making, MCDM 2006, June 19-23, Chania, Greece, MCDM 2004, 2004-08-06/11, Whistler B.C.

Maria Catrinu, Arne T. Holen: “Modelling local energy systems from a multicriteria perspective”, The 17th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy and Process Systems, ECOS 2004, July 7-9, Guanajuato, Mexico

Bjørn H. Bakken, Arne T. Holen: “New Tool for Optimisation of Integrated Energy Service Systems”, The 15th International Conference on Modelling and Simulation, IASTED2004, March 1 –3, Marina Del Rey, CA, USA

Bjørn H. Bakken, Arne T. Holen: “Energy Service Systems: Integrated Planning Case Studies”, IEEE Power Engineering Society General Meeting, 2004, June, Denver, Colorado USA

8.2 PRESENTATIONS AT SEMINARS

NEF Teknisk Møte 2007 / 07-09 March (In Norwegian)

- Arild Helseth:
  Hvordan bør vi investere i brytere, fjernstyring og automatisering i fordelingsnett når gass eller fjernvarme fortrenger elektrisitet?
- Espen Løken:
  Multikriterieanalyse – et nyttig hjelpemiddel til lokal energiplanlegging?
- Linda Pedersen; Rolf Ulseth:
  Utvikling av en metode for estimering av lastprofiler for elektrisitets- og varmeformål.

Distributed Energy, Mastemyr, 2005 / 15-16 November

- Maria Catrinu; Einar Jordanger; Arne T. Holen:
  Integrated energy distribution planning: A multi-criteria approach
- Arne T. Holen:
  How do we define system boundaries in local energy planning?
- Torbjørn Johnsen:
  Practical experience with mixed energy systems
- Arild Helseth:
  Reliability of mixed energy supply systems
- Linda Pedersen:
  Energy consumption in buildings – Load estimation

Distribuert Energi, Mastemyr, 2004 / 07- 08 September (In Norwegian)

- Rolf Ulseth:
  Fremtidens energisystem: Kan gass og/eller fjernvarme erstatte el?
- Arne T. Holen; Einar Jordanger:
  Parallelle infrastrukturer: Kan det være fornuftig og hvordan finner vi ut av det?
- Linda Pedersen:
  Belastningsfastlegging - eksempel på lastmodellering for varme og el
- Bård Olav Uthus:
  Alternative energisystemer – planlegging i praksis
- Audun Botterud; Espen Løken; Maria Catrinu:
  Beslutningsstøtte for lokale energisystemer: Håndtering av multiple kriterier og usikkerhet

NEF Teknisk Møte, 2004/ 29-31 March (In Norwegian)

- Linda Pedersen; Rolf Ulseth:
  Eksempel på el- og varmelast ved vannbåren varme
- Gerd Kjølle; Arne T. Holen:
  Hvordan planlegge energisystemer med flere energibærere
- Rolf Ulseth; Jacob Stang:
  Hva er sammenhengen mellom ”Energiutredninger”, EPD og forslaget til ny PBL?
- Espen Løken; Alf Idsø; Eivind Solvang:
  Energiplanlegging i Sandnes – alternative løsninger for varme og kjøling

8.3 NORWEGIAN PERIODICALS

- Anne-Lise Aakervik: ”Flermåls beslutningsanalyse. Synsing satt i system, Xergi, 2005-1
- Gerd Kjølle; Arne T. Holen: ”Hvordan planlegge energisystemer med flere energibærere?” , Xergi, 2003-4

8.4 PRESENTATIONS AT WORKSHOPS

Organized at NTNU/SINTEF Energy Research:

- ‘Planning Process, Methods and Tools’, 2003-05-28
- ‘Load and Customer Modelling’, 2004-06-17 and 18
- ‘Reliability of Supply in Energy Distribution Networks: Electricity, District Heating and Natural Gas’, 2005-04-19
- ‘Socio-economic Principles and System Boundaries. Load Modelling’, 2006-01-19
- ‘Planning Methodology and Tools’, 2007-03-15

8.5 TUTORIAL

Organized at NTNU/SINTEF Energy Research:

‘Application of Risk Analysis and Multicriteria Models in Energy Systems Planning’, by Manuel A. Matos and Jorge Pinho de Sousa , Inesc Porto and University of Porto, Portugal, 2003-10-6 to 10.

8.6 DOCTORAL THESES (PHD)

There are three PhDs within the SEDS project. However, the PhD within the eTransport project, completed by Maria Catrinu in 2006 collaborated closely with the SEDS project and particularly with the PhD by Espen Løken and has therefore been referenced here.

eTransport, Completed, 2006

- **Maria D. Catrinu**: 'Decision Aid for Planning Local Energy Systems. Application of Multi-Criteria Decision Analysis.', Doctoral Thesis at NTNU, 2006:62, April 2006.

SEDS, Completed, 2007

- **Linda Pedersen**: 'Load Modelling of Buildings in Mixed Energy Distribution Systems', Doctoral Thesis at NTNU, 2007:78, February 2007
- **Espen Løken**: 'Multi-Criteria Planning of Local Energy Systems with Multiple Energy Carriers', Doctoral Thesis at NTNU, 2007:79, April 2007.

SEDS, To be completed in 2008

- Arild Helseth: 'Modelling Reliability of Supply in Multi-Carrier Energy Distribution Systems' (Preliminary title)

8.7 PROJECT MEMOS

Jordanger, E., Kjølle, G.:
Planning of mixed energy distribution systems. Problem identification and formulation.
Trondheim: SINTEF Energy Research 2005
(AN 04.12.69 / AN 05.12.126)

Risnes, A.S.:
SEDS. Gjennomgang av prosjekt- og masteroppgaver i energiplanlegging.
Trondheim: SINTEF Energy Research 2005
(AN 05.12.55)

Sand, K.:
Socio-economic principles in the planning of mixed energy systems.
Trondheim: SINTEF Energy Research 2006
(AN 05.12.101)

Vessia, Ø.:
SEDS – Life Cycle Assessment of local energy systems.
Trondheim: SINTEF Energy Research 2007
(AN 07.12.46)

Solvang, E., Holen, A.T., Jordanger, E., Catrinu, M.D.:
SEDS Planning methodology.
Trondheim: SINTEF Energy Research 2006
(AN 06.12.92)

Catrinu, M.D.:
Energy system planning toolbox. Content and organization.
Trondheim: SINTEF Energy Research 2007
(AN 05.12.44)

Sand, K.:
SEDS Planning methodology - flowchart
Trondheim: SINTEF Energy Research 2007
(AN 07.12.142)

8.8 STUDENT PROJECTS AND MASTER THESES, NTNU

The list includes master theses and student projects in the period 2003-2007 on topics either directly linked to the SEDS project, on topics related to eTransport project or other topics relevant to local energy planning.

Master theses

- Fra avfall til energi på Sveberg
  Sigrun Kavli Mindeberg, vår 2007
- Nettplanlegging i regionalnett i Trondheim
  Åsmund Wie, vår 2007
- Analyse av fjernvarmeforsyning til ny blokkbebyggelse
  Grete Eikeland, vår 2006
- Long term CO_2 mitigation scenaries for South Africa 2001-2050. Integrated environmental, energy and climatic strategies.
  Øyvind Vessia, vår 2006
- Analyse av samfunnsøkonomi og privatøkonomi ved bygging av parallelle infrastrukturer for elektrisitet og fjernvarme
  Kari Lise Heskestad, vår 2006
- Analyse av samfunnsøkonomi og privatøkonomi ved bygging av parallelle infrastrukturer for elektrisitet og fjernvarme ved ulik varmetetthet
  Jofrid Vestbøstad, vår 2006
- Analyse og optimalisering av et fjernvarmesystem
  Marit Hestnes, vår 2006
- Analyse av distribusjonsnettet i Trysil
  Bjørn Bjørstad Pedersen, vår 2006

- Optimering av vind-hydrogen systemer
  Kristian Rasmussen, vår 2006
- Analyse av samfunnsøkonomi ved bygging av parallelle infrastrukturer for elektrisitet og fjernvarme i områder med lavenergibygninger
  Marianne Riddervold, høst 2005
- Analyse av sentrale faktorer ved planlegging og bygging av nytt fjernvarmeanlegg
  Vegard Sveen, vår 2005
- Hydrogenproduksjon fra vindkraft i svake nett
  Christopher J. Greiner, vår 2005
- Analyse av konsekvenser ved nær-/fjernvarmeforsyning med varierende varmetetthet
  Marius Bergsholm, vår 2005
- Analyse av systemeffektivitet ved forskjellig utførelse av fjernvarme-/nærvarmesystemer
  Kjetil Hoftvedt, vår 2005
- Analyse av energiforsyning til et utbyggingsområde i lokalt og i utvidet perspektiv
  Kjell G. Garpestad & Helge Aa. Tvedt, vår 2005
- Enhetlig metodikk for analyse av parallelle infrastrukturer med fokus på systemgrenser
  Lars Aksnes, vår 2005
- Modellstudie av energitransport basert på biobrensel som grunnlast for varme
  Anne Sofie Ravndal Risnes, vår 2004 (SEDS / E-Transport)
- Analyse av energiforsyning til utbyggingsområder på Hundvåg i Stavanger
  Kjell Tormod Urberg, vår 2004
- El- og varme til lokalt utbyggingsområde i Trondheim
  Alternativt: Fjernvarme/Kogenerering basert på søppelforbrenning
  Arnstein Kvande, vår 2003 (SEDS / E-Transport)
- Forsterkning av elnett sammenlignet med gassbasert kogenerering og fjernvarmenett i Hylkjeområdet
  Alternativt: Lokal energiforsyning: Teknisk-økonomisk sammenligning av alternativer med flere energikilder og –bærere
  Arild Helseth, vår 2003 (SEDS / E-Transport)
- Energiplanlegging i Sandnes
  Espen Løken, vår 2003
- Analyse av energiforsyning til boligområde
  Linda Pedersen, vår 2003
- Analyse av energibehov og alternative fleksible energisystem for Li skole og eksisterende svømme- og idrettshall i Nittedal
  Kaja K. Hartmark, vår 2005
- Energy Planning in Longyearbyen, Svalbard
  Anders L. H. Eide, vår 2004
- Metodikk og planverktøy for lokale energiutredninger og lokale energi- og klimaplaner
  Ida M. Falch, vår 2004

- Local Energy Planning in the Region of Primorsko Goranska, Croatia
  Sigrid Simensen Ilsøy, vår 2003
- Lokal energiplan for Aurskog-Høland kommune
  Alexander Fossgård, vår 2003
- Lokal energiplan for Gran kommune
  Kjetil Kronborg, vår 2003
- Optimal dimensjonering av vind - hydrogen systemer
  Erika Stenvik, vår 2005
- Introduction of Hydrogen in the Energy System of Oslo and Akershus towards 2050
  Karen B. Lindberg, vår 2005
- Systemstudie: Hydrogen - Vind
  Lars N. Grimsmo, vår 2004

Student projects

- Analyser og planlegging av utbygging fjernvarmesystem
  Astrid Gaustad, høst 2006
- Analyse av nærvarmesystem for blokkbebyggelse
  Eskil Selvåg, høst 2006
- Analyse av varmegjenvinning i aluminiumsverk og planlegging av fjernvarmesystem
  Øyvind Solberg, høst 2006
- 60 kV nettet i Trondheim i 15-20 års perspektiv. Luftlinje eller kabel, og hva blir KILE-kostnadene?
  Åsmund Wie, høst 2006
- Aktuelle løsninger for nett og trafostasjoner i Ålgård-området i lys av lastutvikling og mulighet for bruk av gass i kraft-varmeverk
  Vegard Willumsen, høst 2006
- Vannbåren varme i Stjørdal, hvor lønnsomt kan det bli?
  Sigrun Kavli Mindeberg, høst 2006
- Teknisk/økonomisk analyse av energiforsyning ved aktuelle, parallelle infrastrukturer
  Marit Hestnes, høst 2005
- Analyse av samfunnsøkonomiske kostnader ved fjernvarmeforsyning i nytt utbyggingsområde i Trondheim
  Jofrid Vestbøstad, høst 2005
- Helhetlig energiforsyning til utbyggingsområdet
  Grete Eikeland & Kari Lise Heskestad, høst 2005
- Videreutvikling av Energiutredninger til kommunale energi- og klimaplaner
  Kristian Strømmen, høst 2005
- Biofuels from lignocellulosic material - In the Norwegian context 2010 - Technology, potential and costs
  Øyvind Vessia, høst 2005

- Introduksjon av bioenergi i det norske varmemarkedet
  Anders Ettestøl, høst 2005
- Effekt- og energibehovet i nye ”lavenergibygninger” og konsekvenser ved bygging av infrastruktur for energiforsyningen
  Marianne Riddervold, vår 2005
- Alternativ infrastruktur
  Lars Aksnes, høst 2004
- Helhetlig energiforsyning til utbyggingsområdet Tasta i Stavanger
  Kjell G. Garpestad & Helge Aa. Tvedt, høst 2004
- Energi- og varmeplanlegging i kommuner i Norge, Sverige and Danmark
  Solveig Hammerhaug Ulseth, vår 2004
- Energiforsyning til utbyggingsområde på Hundvåg I Stavanger
  Kjell Tormod Urberg, høst 2003
- Energiutredning Melhus kommune
  Anne Sofie Ravndal Risnes, høst 2003 (SEDS / E-Transport)
- Varmeforsyning til leiligheter I blokkbebyggelse
  Kjetil Christiansen, høst 2003
- Energiforsyning til Ila – Vannbåren varme
  Arild Helseth, høst 2002
- Energiforsyning til Ila – Elektrisk nett
  Espen Løken, høst 2002
- Varme- og energiplanlegging i Arendal
  Linda Pedersen, høst 2002
- Lokal energiplan for Lørenskog kommune
  Kaja K. Hartmark, høst 2004
- Lokal energiutredning for Vestby kommune
  Karen B. Lindberg, vår 2004
- Analyse av barrierer for implementering av tiltak i lokale energi og klimaplaner
  Kjetil Kronborg, høst 2002
- Lokal energiplan for Ullensaker kommune
  Sigrid Simensen Ilsøy, høst 2002
- El og hydrogen, kan det bli samspill av slikt
  Erika Stenvik, høst 2004
- Vind and Hydrogen Stand-Alone Power Systems
  Lars N Grimsmo, høst 2003

9 REFERENCES

[1] Sand, K.; Holen, A.T.; Kjølle, G.H.; Ulseth, R.; Jordanger, E.:
Planning of sustainable energy distribution systems.
Part I: Problem definition and planning principles.
Trondheim: NTNU/SINTEF Energiforskning, December 2007
(TR A6557)

[2] Sand, K.; Holen, A.T.; Kjølle, G.H.; Solvang, E.; Ulseth, R.; Jordanger, E., Catrinu, M.D.:
Planning of sustainable energy distribution systems.
Part II: Planning methodology and tools.
Trondheim: NTNU/SINTEF Energiforskning, December 2007
(TR A6558)

[3] Vessia, Ø.:
Planning of sustainable energy distribution systems.
Part III: A life cycle assessment perspective.
Trondheim: NTNU/SINTEF Energiforskning, December 2007
(TR A6560)

[4] Energy Planning Toolbox web-site:
http://www.energy.sintef.no/prosjekt/energyplanningtoolbox/

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