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Chalmers EnergiCentrum – CEC

System analysis for energy transition

A mapping of methodologies, co-operation and critical issues in energy systems studies at Chalmers

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Report - CEC 2008:2
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CHALMERS TEKNISKA HÖGSKOLA
Göteborg, May 2008

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Björn A. Sandén

Environmental Systems Analysis,

Department of Energy and Environment

Simon Harvey

Heat and Power Technology,

Department of Energy and Environment

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Project financing: CEC (special grant from the President of Chalmers)

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Simon Harvey

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Chalmers Energy Centre (CEC)
Chalmers University of Technology
Chalmers Teknikpark
SE-412 88 Göteborg
Telephone: +46 (0)31-772 10 00
http://www.cec.chalmers.se
Contact: info@cec.chalmers.se

ISSN 1653-3569

Chalmers Energy Centre (CEC)

The Chalmers Energy Centre is a joint forum for research groups working on energy-related issues at Chalmers University of Technology and it will help Chalmers to stay at the international cutting edge of research, education and innovation when it comes to the development of energy systems for a sustainable society. The CEC will act as an interesting meeting place for leading national and international research groups and will be perceived by research financiers, agencies and the EU, as well as players in Swedish and international trade and industry, as a competent force in the initiation and implementation of complex research projects focusing on energy.

The CEC's business philosophy is to co-ordinate and, in national and international networks, develop energy-related programmes at Chalmers designed to develop sustainable energy systems.

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1 Background and scope

In April 2007, the Dept of Energy and Environment, in collaboration with other research groups from Architecture and Göteborg University, proposed a research project theme to be submitted by Chalmers to Vetenskapliga rådet (VR)[1] for Linné Funding. The proposed research consisted in creation of a Centre for methodology development for analyses of transitions to sustainable energy systems. The basis for the proposal was the observation that many of the currently available scientific reports and system studies handle emerging issues regarding long-term societal changes in different and sometimes contradictory ways. The idea for the proposed centre was to systematically build up new knowledge not only regarding new methods, but also regarding relationships between methods, and degree of intervention in ongoing processes of change. The proposal was judged to be too applied by Chalmers Foundation, and thus not suitable for VR that primarily funds fundamental research, and was therefore rejected. Chalmers Foundation did however consider that the idea was worthy of consideration for future co-funding collaboration between Chalmers Foundation, VINNOVA and the Swedish Energy Agency.

In the ensuing discussions it became clear that there was not only an external need for a structure that could better collect and analyse results from ongoing research projects, but that there was also an internal need for increased understanding about ongoing research, i.e. what type of research, conducted by whom, how different types of system studies relate to each other, and how increased exchange of ideas, experience and methods could be consolidated and lead to increased production of knowledge. There is a general agreement that Chalmers is strong within the area of energy systems studies, but there is more uncertainty regarding how this strength can be defined and how it can be further developed. General systems analysis has been established as an academic discipline for over 50 years, and it is felt that individual researchers active within the field of energy systems analysis could gain substantially from a better understanding about how, when and why research results can or should contribute to an increasingly intense public debate in the energy area.

Objective

In order to create a solid basis for future research activities and increased creative interdisciplinarity, this project was initiated.[2] In view of time and funding limitations, the project was limited to the following two issues:

[1] "Centre for methodology development for analyses of transitions to sustainable energy systems"
[2] The study was financed by CEC and conducted in the period 2007-09-01 - 2008-03-31

a) Which types of energy system analysis studies are currently conducted at Chalmers?[3] This involves addressing the following questions: what is done a lot, what is done in several places, what is not done at all, what should be done that is not currently done?

b) Who collaborates with whom and in what way? Collaboration can occur in a variety of different ways, from common publications to common undergraduate courses.

Procedure

The basis for the study was primarily interviews with the following researchers active within the field of energy systems related studies at Chalmers:

Department of Energy and Environment:

- Thore Berntsson, Division of Heat and Power Technology
- Anne-Marie Tillman, Division of Environmental Systems Analysis
- Filip Johnsson, Division of Energy Technology
- Per Fahlén, Division of Building Services Engineering
- Ola Carlson, Division of Electric Power Engineering
- Kristian Lindgren, Division of Physical Resource Theory

Department of Architecture (Built Environment and Sustainable Development research group)

- Björn Malbert
- Mikael Edén

The interview guidelines are included in the Appendix section of this report (Appendix A).

It is important to note that due to time and resource limitations we have not interviewed all groups at Chalmers that perform research or teaching within the here defined field of socio-technical systems related to energy. Nor have we been able to interview groups active at Göteborg University. Our efforts have been restricted to the Dept of Energy and Environment and the Dept of Architecture (Built Environment and Sustainable Development research group). There is thus plenty of scope for further inventory work of this kind at Chalmers. Examples of groups that were not included in our study include the Chemical Environmental Science group in the Dept of Chemical and Biological Engineering, the Water Environment Technology group in the Dept of Civil and Environmental Engineering, etc.

The results from the interviews were analysed on the basis of the authors' own experience within the field of systems analysis. The report also includes statistical results from a bibliometric study that was conducted by the authors that aimed at measuring the number of energy system studies published by researchers from Chalmers, as well as the degree of joint publication within the Dept of Energy and Environment at Chalmers.

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[3] Studies can be classified according to objective formulation, choice of technical system, choice of system boundary, system level, mechanisms considered (complexity level), qualitative/quantitative aspects, handling of goal conflicts, data collection methods, results dissemination and system intervention.

2 Energy systems studies at Chalmers

Various types of energy systems studies are carried out in several research groups at Chalmers. One can define energy systems in many ways. In this report we focus on higher order systems to be able to exclude a diverse flora of technology research. By higher order we mean systems that contain elements of human action as well as technical machinery. Moreover, we are mainly concerned with systems containing many humans and many technical artefacts, not systems of one person running one machine. We may thus say that we concentrate on *socio-technical systems related to energy*. The balance between the social and the technical varies a lot between research groups. In some cases the social element is small, but then instead the artefacts, such as houses and electricity systems, are composed of many levels of subsystems.

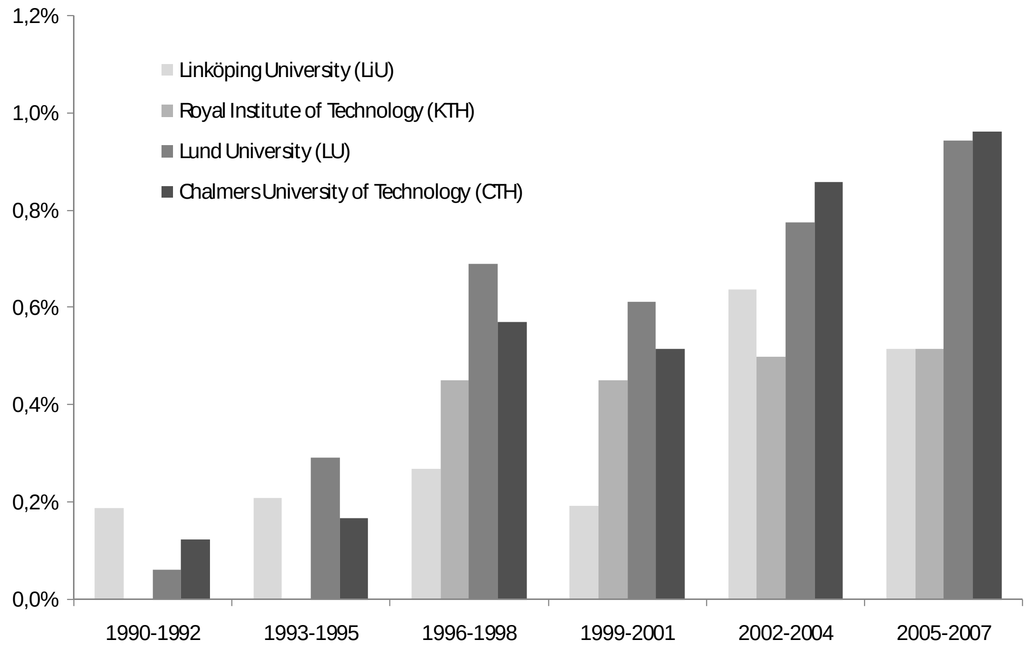

Figure 1 Number of journal publications in 16 reference journals in the field of energy and environmental systems studies, scaled by total volume of articles in these journals.

2.1 Chalmers in a Swedish context

To get an overview of how the field of systems studies related to energy is developing at Chalmers we conducted a minor bibliographical investigation. We searched for publications in 16 scientific journals[4] related to energy, energy policy, and systems analysis in the database Scopus. The selection is based on a search for all papers for which the title, keywords or abstract contains the words ‘energy’ and ‘systems’ followed by an exclusion of journals dealing with purely technical or natural science content. Also journals targeting specific technologies or energy sources were excluded. We do not claim that this list of journals is exhaustive or the best possible sample, but we do think it is representative enough to indicate some trends. The number of publications authored by Chalmers scholars was compared to publications from Linköping University, Lund University and the Royal Institute of Technology in Stockholm (KTH). The results were scaled by the total number of papers in the 16 journals. The Swedish presence in these journals increased substantially from below 1% in the early 1990s to more than 4% today. Figure 1 indicates that Chalmers scholars have done well in relative terms (in this sample), particularly after 2000. The bars for Lund and Linköping are not fully comparable to the Chalmers and KTH bars since the former also include research from non-technical faculties. Figure 2 compares cities (the same journals). The time series for Göteborg (including Chalmers, Göteborg University and some institutes such as SIK and IVL) shows a strong growth trend. One should not jump to far-reaching conclusions from this kind of shallow investigation, but we think it fair to say that energy systems research appears to be strong at Chalmers and in Göteborg at large, and the trend is positive.

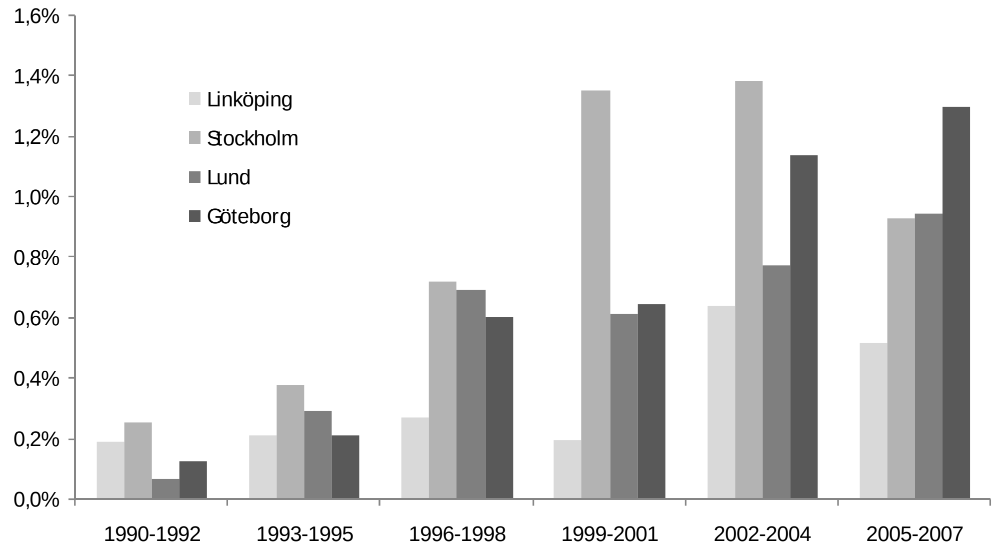

Figure 2 Number of journal publications in 16 reference journals in the field of energy and environmental systems studies, scaled by total volume of articles in these journals.

[4] Applied Energy, Climate Policy, Climatic change, Ecological Economics, Energy, Energy and Environment, Energy Conversion and Management, Energy Journal, Energy Policy, International Journal of Energy Research, International Journal of Energy Technology and Policy, International Journal of Global Energy Issues, International Journal of Life Cycle Assessment, Journal of Cleaner Production, Journal of Industrial Ecology, Renewable Energy, Resources Conservation and Recycling

2.2 Research groups

There are a number of research groups dealing with system studies related to energy. The six divisions of the Department of Energy and Environment (Electric Power Engineering, Energy Technology, Physical Resource Theory, Building Services Engineering, Environmental Systems Analysis, and Heat and Power Technology) constitute a natural centre for energy related system studies. At the Department of Architecture, researchers within the Built Environment and Sustainable Development group adopt a socio-technical systems approach and pay great attention to environmental issues, energy issues included. At the Division of Chemical Environmental Science at the Department of Chemical and Biological Engineering environmental and energy system studies are carried out as well. System studies with clear energy content have also been conducted at the Division of Logistics and Transportation at the Department of Technology Management and Economics. Moreover, at the Department of Civil and Environmental Engineering there are systems oriented research that touch upon energy issues and technology research that is closely related to higher order energy systems.

2.3 Types of system studies

The research groups listed above conduct a number of different types of systems studies related to energy systems in transition. At the outcome of the interviews we asked the interviewees to provide us with a list of key references published by their respective research groups. The specifications for these references were that they should provide a good description and illustration of the group’s system study activities and methodologies. The resulting list of key references is provided in the Appendix section of this report (Appendix B).

One observation that we can make after having analysed the results of the interviews is that methodological overlaps exist between groups but there is also clear evidence of ‘division of labour’ and different research environments focus on different methodologies, have different styles when applying similar methodologies or use similar methodologies for studying different socio-technical systems. A more theoretical approach to methodological delineation will follow in Section 4. Here we make a rough subdivision of studies into ten categories, based upon the results of our interviews.

1. *Techno-economic simulation and optimisation studies* of complex but in a socio-technical perspective more limited technical systems such as heating and ventilation systems in houses, industrial plants and electricity systems.

2. *LCA type of assessments* that in contrast to category 1 take into account effects in various surrounding technical systems, in particular environmental impact effects. This category includes studies of industrial plants/houses/heating systems as well as more typical LCA studies of products and their production chains. The starting point is one unit of a particular service (functional unit).

3. *Resource assessments and material flow analyses* are not based on delivered services but are based rather on an analysis of the resource side, and assess magnitudes of resource availability and the allocation of resources in society.

4. *Techno-economic trend analysis* is used to establish historical records of specific parameters and to identify relationships between parameters. (This is obviously a more positivistic than systemic approach but the selection of parameters requires a systems perspective and the findings are used as input in other systems studies.)

5. *Energy systems models* are used to analyse how resources, technologies and services can be combined under different conditions. Such models are often linear and based upon cost minimisation as a mechanism for simulation and optimisation.

6. *Spatial models* of cities and traffic can be used to simulate changes of energy use due to new transport patterns.

7. *Technological innovation system models* are used to study growth of new socio-technical systems and the diffusion of new energy technologies. The focus is on emergence, rather than selection, and hence positive feed-back and path-dependency is emphasized. Experiments are also made with future studies based on the same model (socio-technical scenarios).

8. *Research by design* is used particularly in architecture where optimisation in a classical sense is impossible or meaningless due to the multitude of parallel services that are provided by a complex product such as a house and the vast number of possible designs. Many designs are produced and selection is made by humans in a psychological and social process.

9. *Process handling methodologies* based on critical choice theory are used to facilitate processes in systems were conflicting interests are present (optimisation depends on perspective) and the number of stakeholders is small enough to allow for a managed process. This is typically used in city planning processes.

10. *A group of modelling tools that could incorporate multiple goals and conflict and/or dynamic and path-dependent features* are under development but yet not applied in the field of energy systems at Chalmers. Examples are Agent based modelling and Systems dynamics.

3 Current level of interaction

In this Section we discuss current levels of interaction within the field of energy systems at Chalmers. The results are based partly upon information gathered during the interviews, and partly upon a bibliographical study conducted using Chalmers CPL publication record database.

In the remainder of this report, the following abbreviations are used to denote different Departments at Chalmers:

- A: Dept of Architecture (Arkitektur)
- BoM: Department of Civil and Environmental Engineering (Bygg- och miljöteknik)
- EoM: Department of Energy and Environment (Energi och miljö)
- TF: Department of Applied Physics
- KB: Dept of Chemical and Biological Engineering (Kemi- och bioteknik)
- I: Department of Technology Management and Economics (Teknikens ekonomi och organisation)
- MoT: Dept of Materials and Manufacturing Technology (Material- och tillverkningsteknik)
- PPU: Dept of Product and Production Development (Produkt- och produktionsutveckling)
- S2: Dept of Signals and Systems (Signal och system)

The following abbreviations are used to denote the different research groups (divisions) within the Dept of Energy and Environment (EoM):

- EnTek: Division of Energy Technology (Energiteknik)
- FRT: Division of Physical Resource Theory (Fysisk resursteori)
- InstTek: Division of Building Services Engineering (Installationsteknik)
- VOM: Division of Heat and Power Technology (Värmeteknik och maskinlära)
- MSA: Division of Environmental Systems Analysis (Miljösystemanalys)
- ELTek: Division of Electric Power Engineering (Elteknik)

3.1 Research interaction

All interviewees were eager to stress the significant amount of research collaboration with other groups at Chalmers. Hereafter follows a brief synthesis of results from the interview process, organised per research group. For an explanation of the acronyms used to denote the different departments and research groups, see Section 3.2.

Energy Technology: Significant collaboration with many groups within the framework of the Alliance for Global Sustainability (AGS) Pathways project. Has well established research collaboration with FRT and, more recently, with VOM. Is currently working on establishing collaboration with ELTek within the area of Wind Power. Ongoing collaboration with the GU Business School within the field of investment decision processes.

Environmental Systems Analysis: Collaboration within EoM, with FRT and starting up collaboration with VOM and EnTek. Ongoing or newly initiated collaboration with BoM, A, I, PPU, KB, TF and with several departments at GU, e.g. Chemistry, Biology, Political Science, Sociology, Business Economics and Economic History.

Physical Resource Theory: Significant collaboration within EoM, primarily with MSA and EnTek. Even more collaboration, however, with research groups at GU.

Heat and Power Technology: ongoing research collaboration within EoM with EnTek and, more recently, with MSA: Significant collaboration with other groups within the KB department (in particular the Forest Products and Chemical Engineering group). Ongoing collaboration with the GU Business School within the field of investment decision processes.

Building Services Engineering: research collaboration within EoM: primarily with ELTek.

Electric Power Engineering: relatively low level of research collaboration. Examples include collaboration with InstTek and with the Automatic Control, Automation and Mechatronics group within the S2 Dept.

Dept of Architecture: the Built Environment and Sustainable Development research group has limited collaboration with EoM/MSA.

3.2 Joint publication interaction

During the interviews, most interviewees emphasized their positive attitude to the idea of common publications with other groups at Chalmers active in the field of energy systems. However, a number of interviewees admitted that co-publication had not in fact occurred to any great extent in the past. With this in mind we decided to examine the complete list of publications for the Dept of Energy and Environment (EoM) for the period 2005-01-01 through 2008-04-01, as available through the Chalmers Publication Library (CPL) database. The start date 2005-01-01 was selected since as of this date it became compulsory to register all Chalmers publications in CPL. This date also corresponds to the formal administrative date for start of the department at Chalmers within the framework of a general reorganisation of all departments at Chalmers. The complete list of publications was then analysed with a view to identifying papers published with authors from at least two different groups within EoM. A more extended analysis was also conducted so as to identify papers co-published by groups within EoM and other groups within other departments at Chalmers or at Göteborg University (GU). The total number of publications was assessed as well as the number of publications in refereed journals.

Table 1 presents an inventory of the number of publications co-authored by researchers from at least two research groups within the Dept of Energy and Environment (EoM) for the period 2005-01-01 through 2008-04-01.

Co-publication within EoM		
	Total	**Refereed Jnls**
EnTek+MSA	2	2
FRT+EnTek	1	1
FRT+MSA	1	1
InstTek+ELTek	1	0
InstTek+EnTek	1	0
InstTek+EnTek+ELTek	1	0
VOM+FRT+EnTek	2	0
VOM+FRT+EnTek+InstTek	2	0
TOTAL	**11**	**4**
Total number of publications during sample period: 826		

Table 1 Inventory of number of publications co-authored by researchers from at least two research groups within the Dept of Energy and Environment (EoM) for period 2005-01-01 through 2008-04-01

The numbers presented in Table 1 essentially confirm the results of the interviews, i.e. that the extent of co-publication between different groups with EoM at Chalmers is very limited. 11 publications were co-authored by researchers from at least two research groups within EoM, compared to a total publication volume of 826 for the sample period. Furthermore the number of joint publications in refereed journals is almost non-existent (4 publications during the sample period). Many of the joint publications are other types of publication, particularly reports written under the auspices of Chalmers Energy Centre (CEC). It can furthermore be noted that 3 out of 4 of the publications in refereed journals are co-authored by researchers who belong to different research groups in the current EoM department structure, but who have belonged to the same research group at some point prior to January 1st, 2005. In other words, it can be argued that these publications reflect collaboration that was initiated by researchers within the same research group, and cannot be considered to reflect research collaboration over research group boundaries within EoM.

In addition to inventory of joint publications within EoM, we also elected to take inventory of joint publications authored by at least one researcher within EoM and at least one researcher within another department at Chalmers or GU. The same CPL sample list was used. The results are presented in Table 2.

Co-publications with other CTH depts and GU		
	Total	**Refereed Jnls**
ELTek+MoT	1	0
ELTek+S2	2	1
EnTek+BoM	1	0
EnTek+KB	28	23
EnTek+KB+GU	1	1
FRT+GU	3	0
FRT+I	2	0
InstTek+A+BoM	1	0
InstTek+BoM	2	2
InstTek+EnTek+BoM+KB	1	0
InstTek+S2	4	2
MSA+A+BoM	2	0
MSA+BoM	1	0
MSA+GU	2	1
MSA+I	1	0
MSA+PPU	3	1
VOM+KB	3	0
VOM+PPU	1	0
TOTAL	**56**	**30**
Total number of publications during sample period: 826		

Table 2 Inventory of number of publications co-authored by researchers from at least one research group within the Dept of Energy and Environment (EoM) and one researcher from another department at Chalmers or Göteborg University (GU) for period 2005-01-01 through 2008-04-01

The results presented in Table 2 show that the extent of joint publication between researchers within EoM and other research groups at Chalmers and GU is significantly greater than within EoM, even though the number of co-authored publications is still relatively small compared to the total publication volume. It should furthermore be noted that these results are very much dominated by joint publications between the Energy Technology group and the Dept of Chemical and Biological Engineering within the framework of well-established research collaboration between these groups working on joint projects within the field of combustion and gasification processes.

3.3 Interaction for Undergraduate Education (BSc and MSc levels)

Interaction between groups active in the field of energy systems at Chalmers for undergraduate education activities is well-developed. All interviewees report collaboration between research groups (both within EoM and with other groups/depts/programmes at Chalmers and GU) in the form of guest lectures, parts of courses, joint supervision of master thesis projects, MSc programme development, etc. A brief overview of these joint activities is presented below, presented on a research group basis:

Energy Technology: participation in a number of courses offered by other groups (e.g. FRT, and MSA). Participation in development of the Sustainable Energy Systems (MPSES) MSc programme. Responsible for two courses within the MPSES programme (MEN120 - Heat and Power Systems Engineering and MEN031 - Combustion Engineering). Joint responsibility with FRT for the course “Miljö och energiteknik ENM030” in M3.

Environmental Systems Analysis: significant collaboration for undergraduate education. The following list is indicative but by no means exhaustive. Responsible for the “Environmental Measurements and Assessments” MSc programme (MPEMA). Significant collaboration (including full responsibility for several courses) with FRT and others within the MSc programme “Industrial Ecology” (MPECO). Responsible for course “Technological change & industrial transformation” (IDY040) within MSc programmes MPECO and “Management and Economics of Innovation” (MPMEI). Responsible for the course “LBT625 - Environmental Engineering” within the Building and Civil Engg (TIBYL) programme (grade 3).

Physical Resource Theory: responsible for the MPECO programme. Responsible for two compulsory courses within the MPSES programme (FFR160 “Sustainable Development” and FFR170 “Sustainable Energy Futures”). Responsible for three courses within the “Complex Adaptive Systems MSc programme” (MPCAS). Responsible for a number of courses at the BSc level within the Physics, Mechanical Engineering at Chalmers and other programmes at GU. Joint responsibility with Energy Technology for the course “Miljö och energiteknik ENM030” in M3.

Heat and Power Technology: responsible for coordination of the MPSES programme. Responsible for 2 courses (KVM013 – Industrial Energy Systems and KVM071 - Design of Industrial Energy Equipment) offered within the MPSES and “Innovative and Sustainable Chemical Engineering” (MPISC) programmes. Responsible for the compulsory course KVM033 (Energiteknik och miljö) for K2 & Kf2 students, in collaboration with the Forest Products & Chemical Engineering group (KB dept). Responsible for the compulsory course KVM090 (Thermodynamics) for K2 & Kf2 students, in collaboration with the Physical Chemistry group (KB dept). Significant contribution to two other courses at BSc level within K/Kf programmes: KAA146 - Introductory Chemical Engineering (in collaboration with the Chemical Engineering Design group in the KB Dept) and KSK070 - Processes and Products from a Sustainability Perspective in collaboration with the Forest Products & Chemical Engineering group (KB dept). Collaboration with the Forest Products & Chemical Engineering group for the course KSK061 – “Sustainable process performance indicators” offered within the MPISC MSc programme.

Building Services Engineering: Participation in development of the MPSES programme. Responsible for two courses within the MPSES programme (ENM045 - Heating, Ventilation and Air Conditioning Systems Engg. and ENM080 - Air-Conditioning, Refrigeration and Heat Pump Technology). Responsible for a number of courses offered within the “Structural Engineering and Building Performance Design” (MPSTR) programme (in collaboration with BoM and A Depts).

Electric Power Engineering: responsible for the “Electric Power Engineering” (MPEPE) programme. Significant collaboration with other departments for courses at the BSc level within the E and Z programmes, as follows: ENM011 (Miljöteknik och elenergi Z) in Z2, FSP025 (Teknisk kommunikation), Project course in E1, EEK136 (Miljö- och elteknik) in E2, EEK231 (Miljövänliga energikällor) in E1, and ENM095 “Sustainable power production and transportation”, a new course developed for the MPEPO MSc programme.

Dept of Architecture: The Built Environment and Sustainable Development group is responsible for the MSc programme “Design for Sustainable Development” (MPDSD). Significant collaboration with BoM and the Division of Building Services Engineering.

3.4 Interaction for Postgraduate Education (PhD level)

Interaction within EoM for education activities at the postgraduate (PhD) level is so far extremely limited. One explanation for this is that creation of the Department of Energy and Environment in January 2005 coincided with Chalmers decision to fully restructure undergraduate education so as to fulfil the requirements of the Bologna structure. Hence, most teacher time resources available for development of new activities have been dedicated almost exclusively to implementation of the new MSc programmes at Chalmers. Very few postgraduate courses aimed at a target student group broader than a single research group have thus been developed with EoM. One exception was a PhD course in *Engineering Thermodynamics* offered during the Spring 2007 term, with participants from a number of different EoM divisions. Another exception was a course covering methods and systems for energy and environmental systems analysis offered by the MSA division during the Spring 2007 term. It is intended that this course should be further developed in collaboration with researchers from several research groups within EoM and offered on a regular basis to all PhD students within the department.

Other postgraduate course activities involving collaboration between EoM research groups and other departments within Chalmers appear to have also been limited, according to information provided by Jan-Olof Dalenbäck, responsible for EoM’s graduate research school. Jan-Olof was only aware of one such course offered since January 2005, namely a PhD student course offered in collaboration between InstTek and the BoM department.

4 Some critical aspects of system studies and potential for improvement

The list of methodologies in Section 2.3 demonstrates intellectual richness but also indicates that there is plenty of room for confusion. In this Section we will point out some issues where there is potential for development through cross-learning between research groups, new methodological combinations or possibly development or import of tools that are lacking.

We will first turn to the more contextual issues and then turn to the more internal issues of the architecture of assessments.

4.1 Identifying core activities and the main message in system studies

What is the most important activity in a systems study? Or to put it differently, where is the main message? To explicate what we want to capture with this broad question we suggest that activities related to system studies can be divided into four groups: (1) problem selection; (2) system design; (3) assessment, and (4) intervention.

The analytical core of system studies is the *assessment* of something. One view is that the main result of a systems study is the explicit result of an assessment: “Technology X is better than Y”, or “when policy Z is implemented emission W will increase”. This somewhat simplistic view could be contested.

Some would argue that the *problem selection* is of equal importance. What problems, technologies, policies etc are worth a study costing millions of SEK and several years in a PhD student’s life? Selecting a certain problem for study doubtlessly sends a strong signal to society.

Further, assessments require some kind of system model. Models need to be designed. But *system design* can also be a goal in itself, a construction and demonstration of novel configurations that work. In some disciplines, such as architecture, it is obvious that the designs are central outcomes. It has been observed that design is a more important outcome than what is often assumed also in other types of systems studies. System design that spans a wide range from design of ventilation systems and houses to global energy mixes can, in themselves, become mental models or frames that guide thinking and action.

We here use the term ‘*intervention*’ instead of the weaker ‘dissemination of results’ to capture a broader range of activities. From the interviews we found out that action and intervention by researchers is sometimes but not always considered an integral part of the system studies done at Chalmers. However, some argue that the main result is in the action, in an interactive learning process where the systems scientist’s role is to mediate and inspire, and the analytical results are of less importance for actual socio-technical change.

We don’t think there is one answer to the question posed here but we think that it can be a starting point for reflection and discussion.

4.2 Dissemination of results and styles of intervention

There are reasons why the issue of intervention is of special importance in system studies.

Results from system studies seldom have the same general applicability as results from natural science research. Natural laws derived in one scientific field can be used in other fields or in technical development without knowing the mechanisms behind the laws. The laws as results provide a fairly complete and general interface between the studies providing them and activities using them. Simple technical artefacts also provide more or less complete interfaces. To use a washing machine you don’t need to know how it was made or its internal mechanics and electronics. You only need to understand the interface. On the other hand, the functioning of socio-technical systems such as energy systems cannot be tested by single persons within short time periods in the same way as technical artefacts and systems of lower order. An implication of this is that results from system studies do not in themselves provide a simple interface between the study and actions that can be taken based on the study. When you want to use the result of a systems study, you can never be sure of the outcome.

System studies do not provide answers that can be tested but rather arguments that are open for debate, and their relevance is dependent on the specific context. This implies that the boundary between the study and the use of results is not well-defined and needs to be crossed from one side or the other. As a consequence systems researchers at Chalmers often take part in some kind of action (learning or decision-making processes) outside the university. Likewise, users of the results (commissioners, practitioners, decision-makers) sometimes take an active part in studies. At the Department of Architecture scholars have turned this ‘problem’ of system studies into a method. The academic scholars function as facilitators or mediators in a process where different stakeholders take part in problem formulation and solving. In this way the university provides an arena for communication. Inspiration comes from Strategic choice theory and Research by design. We have also met this idea of systems studies as a neutral arena and meeting place for stakeholders in other research groups at Chalmers (Heat and Power Technology). Some research groups do not take it as far as this but explicitly state the importance of stakeholder involvement and stress the importance of the relation between research results and user context (Building Services Engineering, Environmental Systems Analysis).

However, in all cases it has been observed that it is insufficient that academics only serve as mediators. They also need to be a kind of avant-garde, suggesting novel solutions and contesting old conceptions.

Broadening the view of the learning process, most systems researchers at Chalmers, as mentioned above, do interact with society in multiple ways, and thus take part in a society wide learning-process, acting as an avant-garde critically examining current practices and suggesting new designs (of houses, electrical systems and societies).

In conclusion, we observe an interesting diversity of intervention strategies, which to some extent could be explained by the different questions dealt with. Nevertheless, we think there is a potential in sharing of experiences and cross-testing of procedures.

4.3 Problem selection in context

A related contextual issue is how problems are selected. As noted in Section 4.1 the selection as such is of fundamental importance. Following from this, it is probably worth thinking about how that selection is done. In the interviews there seemed to be a consensus about that research funders do not generally interfere in problem selection and system design in a problematic way. There appears to be a reasonable amount of academic freedom. This was also the case when funding was provided by firms. On the other hand, it was noted that some areas are trendier than others, demonstrating the trivial fact that what you can get research funding for is limited. Hence, researchers select problems that have a fair chance to get funding. It was observed that in the field of energy and environment, there is risk to 'go with flow', and 'run with the pack'. One interviewee made the observation that current energy and environmental systems research is driven almost exclusively by CO_2 emissions reduction considerations. It is harder to find money for empirical issues that could become important later on but are less in focus at the moment, and for more fundamental methodological and theoretical studies. Thus we see a risk that the position as avant-garde in the societal debate on sustainability could be undermined over time. Possibly, in the long term this trend may change as more people with a systemic academic background populate various funding organisations. This trend can also be counteracted more directly by dedicating internal funding to methodological work.

On the other hand, it was also stressed by many of the interviewees that it is important to deal with problems that are perceived as relevant by decision-makers (in firms, policy etc). Thus there could be a trade-off between avant-garde and usefulness in some situations. This clearly is a variant of the basic-versus-applied-science debate. There is no solution to this somewhat eternal question. But there could be a need for reflection and an awareness of the choices made in individual cases.

4.4 Empirical pluralism for methodological development

The resource groups included in this investigation differ in one important aspect. Some groups tend to focus on one type of technical system, e.g. industrial process industry or buildings/construction, while others focus on one or a few methodologies to investigate different technical systems in different industries. It has been observed, e.g. at Environmental Systems Analysis, that such empirical pluralism has greatly benefitted methodological development in Life cycle assessment as well as Innovation system studies. On the other hand, large investments are required in order to develop an understanding of an empirical field and to build a useful network. Thus there is a trade-off between breadth and depth. One solution is cooperation. There could be a great potential for methodological development by combining experiences from studies of different technical systems now separated by organizational boundaries.

4.5 Methodological pluralism for complete and qualified assessments

The relation between methodology and empirical domains can also be turned around. It was observed that different methodologies applied to the same empirical domain, generate partially different and sometimes contradictory results. Thus better and more qualified arguments can be reached if many different methodologies are used to tackle the same question. However, no researcher can become an expert within more than a very limited number of methodological frameworks. Hence, once again, some type of cooperation could be valuable. It was observed that that is now done in larger research programs. It was also observed that the trend towards letting researchers organize research programs themselves is due to a lacking capacity for synthesis among users (such as authorities, government agencies, etc). A positive outcome of large programs where many methodologies are applied in parallel is an awareness of the limited value of individual methodologies. This virtue can also be reached through other means, such as methodologically oriented PhD courses, that help the students to find their own methodological position in relation to others and thereby become able to qualify the results they produce in their own studies.

4.6 System level interdependencies

A question related to methodological pluralism that is of specific relevance for system studies is the relation between studies focusing on different system levels. System boundaries need to be drawn, but system boundaries also have an excluding effect. Researchers working at higher system levels could argue that those working at a lower level miss important system effects that occur outside the system boundary of the lower level systems. Optimising a house or a process industry could possibly have adverse effects at the energy system level. Optimising a national energy system could imply neglecting important international mechanisms and so on. A specific kind of sub-optimisation can occur when a studied lower order system is not in itself questioned but taken for granted. For example, biofuel benchmarking normally neglects the option of not having biofuels at all. On the other hand, researchers working at lower system levels could argue that system studies at higher levels lack in detail and miss important possibilities for system integration and multi-functionality at lower levels.

Independently of the system level studied, it is necessary to make assumptions about elements outside the boundary affecting the system (boundary conditions). The problem is normally not total omission but rather oversimplification. In particular, special care is warranted when long time periods are considered. Constraints at higher system levels that could be disregarded in the short run could be of great importance in the longer run. And vice versa, development taking place at lower (micro) system levels could be disregarded in the short run but could radically transform the higher (macro) system in the long run. The development of the internal combustion engine some 100 years ago, and the steam engine 100 years before that, are prime examples of micro level phenomena that had a huge macro level impact in the longer run.

It was pointed out by interviewees that Chalmers has a specific strength since there is a large volume of research being performed at different system levels. Taken jointly this could enable better system assessments and also provide a potential opportunity for further development. Projects could be designed to, on the one hand, methodologically demonstrate how results and recommendations differ depending on system boundary, and on the other, use results from studies on higher and lower system levels to refine assumptions regarding boundary conditions.

4.7 Co-operation with technical, natural and social sciences

Socio-technical systems studies are not only dependent on results from other system studies (see 4.6) but also on assumptions regarding technical parameters, social mechanisms and environmental effects. Also here it was pointed out that there is great opportunity connected to being at a technical university with access to cutting edge technology know-how. Moreover, there seems to be a fair amount of ongoing or planned cooperation with other university faculties including economics, economic history, sociology, psychology, political science, business economics, law, mathematics, and natural sciences. Such cooperation can be further exploited. It was also observed that in many social sciences there is now an increasing interest in systems studies and cooperation with technical faculties. As an example, a GMV systems seminar arranged by us on 15/11 2007 attracted between 50-100 scholars from Chalmers and Göteborg University.

One view put forward by the interviewees was that in-house technical know-how at Chalmers is currently not used in system studies as much as it could be. Another was that, due to the desire to answer critical questions, social science studies are sometimes performed by groups that are traditionally more technically oriented, but who lack the solid experience and required methodological competence to do social science of good quality. We think that the most fruitful way to proceed is not to refrain from tackling interesting questions but rather to develop co-operation and learning networks with technical specialists as well as social and natural scientists and to develop PhD courses targeting methodology.

Looking at the question from the opposite side, large technically oriented research programmes, such as Mistra-programmes, now require a component that captures systemic implications. This does not only create a market for system studies but also result in a two-way communication of data and results between technically oriented research and system studies.

4.8 Two types of assessment and a flexible boundary line

In Section 4.2 we discussed views on the relationship between the analytical task (the assessment), and dissemination of results, or more broadly, intervention in user contexts. We would like to add that the analytical part can incorporate smaller or larger parts of the decision making process depending on how the research question is formulated.

Generally, the assessment projects undertaken at Chalmers can be divided into assessments of technologies and assessments of intervention activities. The former type of studies typically answers questions of the type: “Is technology X good from a (specific) systems perspective?” The latter answers questions of the type: “What happens in the system when system intervention(-s) Y occurs?” and “Is Y an intervention that can be recommended?” Interventions then typically include public policies (such as regulation, taxes and subsidies) and investment decisions in firms and households. Assessments of interventions are closer to the decision making situation and are more complex, since they are bound to involve identification and assessment of non-linear effects emanating from chains of consequences stretching into the future. They incorporate a larger part of the decision making process since they address the result of an action and leave less to the judgement of the decision maker.

This flexible boundary of the assessment in relation to decision-making and its methodological consequences, calls for a clarity that is not always present.

4.9 Historical and future-oriented studies

The natural interest at a technical university is to put together new things or improve the functionality of existing systems. Eyes are fixed upon the future. It is not without reason that Chalmers motto is: ‘Avancez!’ There is a tradition not only to observe but also to construct. Hence, it is probably not controversial to postulate that scientists at technical faculties have less doubt about future studies than colleagues in humanities and social science.

However, models that are said to say something about the future need to be based on observed constants, trends and mechanisms. If everything is assumed there is little science in it. There is a constant need to question the validity of assumptions made. We believe that more cooperation between research groups to some extent could cure blindness to ill-founded assumptions. We also believe it would be worthwhile to test more assumptions and whole models against historical data.

We also observe that models and results do not have to explicitly deal with the future to be interesting for decision makers. A study describing a historical trend (e.g. Category 4 in the list presented in Section 2.3) or a more complicated historical system development (e.g. Category 7 in the list presented in Section 2.3) is sometimes more powerful than models that explore possible future developments. As discussed in Section 4.8 there is a trade-off between number of assumptions and completeness of decision support.

It might also be the case that system studies have something to offer to the discipline of History. Potentially, a fertile area for research is historically oriented system studies with focus on energy and environment. Such research does exist at Chalmers but could be expanded through cooperation with historians and social scientists.

In addition, there might be patterns and processes observed in historical studies that are not currently used in future studies. Here, there could be some room for fruitful experimentation.

A specific area is of course the history of future studies, or more generally, the history of assessments. What did they foretell and recommend, and what did they achieve in a broader societal context? We think this is a subject that at least should be included in a PhD course.

4.10 Optimisation and simulation

A term inherited from technical studies is ‘optimisation’. While optimising a small-scale technical system when a limited number of performance parameters are agreed upon can be done, the situation is different for large-scale socio-technical systems.

One fundamental issue is to establish an objective function. We should note that this is also a problem for more limited technical systems. Performance is always socially constructed and dependent on user demands. It was noted in interviews that acquiring knowledge about user demands and keeping it in focus are central issues for optimisation of systems such as heating and ventilation. There is always a risk of degenerating to optimisation that takes into account a limited set of technical parameters that are not thoroughly motivated. We believe that this is an important lesson also for studies at other system levels. The multi-functionality of systems makes comparison and optimisation more difficult.

An even more fundamental problem for optimisation is the many conflicting goals that are bound to exist in large socio-technical systems. There are no undisputable ranking of performance parameters. There are numerous different social groups and individuals with different agendas. In economic modelling (which could be viewed as a specific branch of system studies) this simple fact is often neglected (utilitarianism), to enable calculations of optima at the societal level. This could be valuable as a thought-provoking academic exercise but perhaps not as a guiding principle for all decision making.

An additional problem for optimisation models of large systems is to prove the sufficiency and relevance of the mechanisms used in the model. As discussed earlier the whole system can never be tested, and mechanisms at the system level can never be thoroughly evaluated. In addition to this general problem there are two specific mechanisms that make it even worse. First, positive feedback introduces the existence of multiple optima and the phenomenon that small events may have large impacts in the longer term. The systems are perhaps not as stable as one would wish. Secondly, when human actions and choice is part of the mechanisms in the model, the making of the model may itself affect the modelled system (sometimes called second order systems where the analyst is included).

In response to these daunting problems with using the term ‘optimisation’ many researchers prefer the term ‘simulation’. Models can be used to simulate possible outcomes given certain premises to demonstrate potential impact from different mechanisms and assumptions. “What-if”-studies are conducted. Optimisation algorithms are then used not as a tool to find an optimum but as simulation mechanism (e.g. what would happen if society would select least cost options). Using models for simulation and learning is probably a fruitful area for development. We will return to this in Section 4.12.

Despite the problems with optimisation, or perhaps due to the same problems, we see an interesting avenue for the use of optimisation studies. Some of the interviewees see a fruitful area for systems studies that investigate conflicts. Conflicts can be highlighted, explained or foreseen by comparing optimisation calculations at different system levels (Section 4.6), in different geographical areas and from the perspective of different actors. This could also be of use when researchers act as mediators in multi-stakeholder processes (Section 4.2).

Studying the effects of using different types of objective functions is also a possibility. Low cost is a very useful objective parameter, but not the only possible one. Comparison of the effect of including different types of mechanisms is a third option. What happens when negative feedback is introduced? What is optimal when positive feedback and path-dependency is introduced? We appreciate that this kind of playfulness is now making headway into systems research at Chalmers.

4.11 Data storage and data sharing

Many systems studies rely on the availability of large data sets. Some are acquired from other researchers and various organisations such as IEA and national statistical agencies. Others are developed through labour intensive collection of individual pieces of data. One important question for Chalmers systems research is how to maintain and update these databases. A second issue of similar importance is how to share data between research groups at Chalmers, i.e. how to develop the research infrastructure. A third issue is to identify the databases that can be shared without restriction with the rest of the world, e.g. through websites. We note that research is very much an individual act, or rather an act of small groups. These individuals and small groups seldom have the routines or resources to maintain and manage large sets of data in a professional way.

4.12 Open access to models and Interactive Games

If ideas of intervention and interaction with users discussed in Sections 4.1 and 4.2 are combined with the ideas of playful use of optimisation and simulation one is lead to start thinking about open access to models and using the new powerful tool Computer Games. One research group at Chalmers is now on the verge of testing open access to a model. Such a website could be used to gather information about the kind of simulations that are performed, and if combined with surveys, information can be collected about what is learnt by using the model.

At Chalmers the use of visualisations and interactive games are now discussed more frequently as tools for simulation and learning. We believe that there could be many fruitful uses of these methodologies and tools in energy systems studies. First, diffusion of systems understanding can be accelerated by the use of accessible and appealing tools. Second, a new type of ‘semi-hard’ models can be developed, that partly takes into account actual human decision making and partly uses mathematical algorithms. Third, data from played games can be gathered to investigate choices made by different actors. Forth, since a part of the result of system studies is the design of models and scenarios (and not only assessment of designs, Section 4.1) an open platform for making energy system designs and scenarios could stimulate ideas of future development among broader groups of people.

5 Concluding remarks

Chalmers has a strong position in energy and environmental systems studies and the trend is positive. The divisions of the Department of Energy and Environment make up the core research environment but other research groups also contribute to the field. A wide range of different methodologies are applied targeting different research questions, different socio-technical systems, and different hierarchical levels in socio-technical systems. Society's appetite for answers to complex systems related questions is increasing. Likewise, most large technically oriented research programmes require a component that captures systemic implications. This is welcome and should result in increasing resources for research in the field. However, we also identify risks related to this. First there is a risk that researchers and PhD students get stuck in empirical investigations not having time to deepen their theoretical basis nor broaden their methodological toolbox. Secondly, there is a related risk that research becomes fragmentized, i.e. researchers get stuck with a limited insight into related fields of research, and thereby fail to qualify their results in a well-founded and clear way. This risk is of particular importance for the field of systems studies due to the specific nature of the scientific field (see Section 4). We also see that there is a great unexploited potential in sharing methodological experiences, data and results. Empirically, we find that there are hardly any joint publications between research groups even within the Department of Energy and Environment.

Due to the excellent status and breadth of Chalmers research in the field, we see a great opportunity to steer away from these risks and turn a good environment into a unique research and learning environment. This would require increased supply of high quality PhD courses as well as a range of other forms of cooperation such as procedures for data sharing and joint publication. Furthermore, it requires that means are found to strengthen methodologically oriented research through systematizing existing approaches and exploring new avenues. In particular we would like to see studies that investigate the role of assessments (what is accomplished?), studies that compare assessments in different empirical domains, studies that model dynamics of change in new ways, studies that investigate conflicts between agents and between optimization at different system levels, richer future studies that make better use of historical data, historical studies that make use of structured models and studies that make use of interactive games.

6 Appendix A

Interview Guidelines

A. Systemanalytisk ansats

1. Tekniktyp,
2. Målformulering – typ av resultat
3. Systemavgränsningar: tid, geografi
4. Systemkomponenter: teknik, ekonomi, kunskap, värderingar etc
5. Systemnivå 1: komponent, tekniksystem hårdkopplats, tekniksystem diffust/utspritt, tekno-ekonomiskt system, socio-tekniskt system (ekonomiskt system, socialt system)
6. Systemnivå 2: mikro (en teknik/produkt kedja, en aktör/företag), meso, makro
7. Beaktade mekanismer (grad av komplexitet),
8. Kvalitativa/kvantitativa data
9. Metoder för datainsamling,
10. Hantering av målkonflikter

B. Kontext

Finansiärer
Resultatspridning
Resultatanvändning
Hur sker problemformulering (vem – forskare, uppdragsgivare?)
Syn på systemintervention från forskare
Syn på forskningsintervention från uppdragsgivare

C. Samarbeten

Hur väl är du bekant med annan energisystemforskning på CTH?

Forskning
- Vilka samarbeten finns?
- Typ av samarbeten?
- Syn på sampublicering?

Undervisning

Övrigt

D. Chalmers energisystemarbete som helhet

Vad görs det mycket av?

Vad görs på flera ställen?

Vad görs inte?

Vad borde göras?

Vilka samarbeten bör utvecklas? Inom CTH, Externt?

E. Nyckelreferenser 3-5

Metod-representativa

7 Appendix B

During the course of the interviews, interviewees were asked to provide us with a list of key references published by their respective research groups. The specifications for these references were that they should provide a good description and illustration of the group's system study activities and methodologies. The references provided are listed hereafter for each research group:

Heat and Power Technology

- ”Benefits of Integrating Upgrading of Biofuels in Biorefineries – Systems Analysis”, Eva Andersson, PhD thesis, 2007
- Roger Nordman, New Process Integration Methods for Heat-Saving Retrofit Projects in Industrial Systems”, PhD Thesis, 2005
- “New Opportunities and System Consequences for Biomass Integrated Gasification Technology in CHP Applications”, Åsa Marbe, PhD Thesis, 2005
- “Process Industry Energy Projects in a Climate Change Conscious Economy”, Anders Ådahl, PhD Thesis, 2004
- “Energy export opportunities from Kraft pulp and paper mills and resulting reductions in global CO_2 emissions”, Erik Axelsson, PhD Thesis, 2008

Electric Power Engineering

- ”WIND-HYBRID SYSTEMS WITH VARIABLE SPEED AND DC-LINK” Sven Ruin and Ola Carlson (subject area: Wind/Diesel hybrid systems)
- “Interruptible load as an ancillary service in deregulated electricity markets”, Le Anh Tuan, PhD Thesis, 2004 (subject area: Electric power system economics)
- ”Autonomous Power Systems based on Renewables - On generation reliability and system control”, JIMMY EHNBERG, PhD Thesis, 2007 (subject area: Electric power supply issues for small communities)
- ”Voltage Sags: Single event characterisation, system performance and source location”, ROBERTO CHOUHY LEBORGNE, PhD Thesis, 2007 (subject area: disturbances in electric power transmission systems)

Energy Technology

- “Achieving 60% CO_2 reductions within the UK energy system—Implications for the electricity generation sector”, M. Odenberger, F. Johnsson, Energy Policy 35 (2007) 2433–2452
- “Ramp up of CO_2 Capture and Storage within Europe”, M. Odenberger1; J. Kjärstad; F. Johnsson, Submitted for publication
- “The European power plant infrastructure—Presentation of the Chalmers energy infrastructure database with applications”, Jan Kjärstad, Filip Johnsson, Energy Policy 35 (2007) 3643–3664
- “Prospects of the European gas market”, Jan Kjärstad, F. Johnsson, Energy Policy 35 (2007) 869–888

– “Primary energy use for heating in the Swedish building sector—Current trends and proposed target”, P. Johansson, A. Nylander, F. Johnsson, Energy Policy 35 (2007) 1386–1404
– “Common energy and climate strategies for the Nordic countries – A model analysis”, Thomas Unger, PhD Thesis, 2003

Building Services Engineering

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Environmental Systems Analysis

– Baumann, H. (2004). "Environmental assessment of organising: towards a framework for the study of organisational influence on environmental performance." Progress in Industrial Ecology, an International Journal 1(1): 292-306.
– Baumann, H. and A.-M. Tillman (2004). The Hitchhiker's Guide to LCA. Lund, Sweden, Studentlitteratur.
– Bergek, A., S. Jacobsson, et al. (2008). "Analyzing the functional dynamics of technological innovation systems: A scheme of analysis." Research Policy 37(3): 407-429.
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– Steen, B. (1999). A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – General system characteristics. CPM Report 1999:4. Chalmers University of Technology, Technical Environmental Planning, Göteborg, Sweden.

Physical Resource Theory (including Complex Systems)

- Andersson, Claes: Urban Evolution. Göteborg : Chalmers University of Technology. Diss. (Doktorsavhandlingar vid Chalmers tekniska högskola. Ny serie;2301) ISBN/ISSN: 91-7291-619-2 CPL 8453
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Built Environment and Sustainable Development (Dept of Architecture)

Mikael Edén's group

- Edén M (2007) *Energi och byggnadsutformning* (ARKUS. Stockholm)
- Boverket (2006): *Energisk arkitektur. Sköna, driftssäkra och energieffektiva byggnader.* (Boverket. Karlskrona). Skrivne av Edén M, Hagentoft C-E, von Schéle A.
- Thuvander L (2004): *Byggande för en hållbar utveckling i Göteborg. 10 exempel* (Göteborgs Stad, Fastighetskontoret och Stadsbyggnadskontoret. Göteborg.)
- Edén M, Birgersson L & Dyrssen C (2004): "Design for sustainable building. Testing a developed conceptual model for research and practice on existing literature." Paper in conference *ARQUITECTURA 3000 the architecture of in-difference. Barcelona July 1- 2, 2004.*
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Björn Malbert's group

- Formas (2006). Evaluation of Swedish Architectural Research. Stockholm, Formas.
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- Stenberg, J. (2004). Planning in interplace? On time, power and learning in local activities aiming at social inclusion and sustainable development. Göteborg, Majornas Copyprint. (PhD Diss.)

Chalmers EnergiCentrum – CEC
Chalmers tekniska högskola
Chalmers Teknikpark, 412 88 Göteborg

Tel 031-772 1000
E-post info@cec.chalmers.se
www.cec.chalmers.se

Society's demand for answers to complex systems-related issues is increasing. Chalmers has a strong and growing position in energy and environmental systems studies. A wide range of different methodologies are applied targeting different research questions, different socio-technical systems, and different hierarchical levels in socio-technical systems. However, the results of this study indicate that there is an unexploited potential to create a unique research and learning environment by sharing methodological experiences, data and results. This requires that methodology oriented research is strengthened by systematizing existing approaches and exploring new avenues. Examples of how this could be accomplished include investigating the role of assessments, comparing assessments in different empirical domains, modelling dynamics of change in new ways, investigating conflicts between agents and between optimization at different system levels, making better use of historical data, conducting historical studies that make use of structured models, and conducting studies that make use of interactive games.