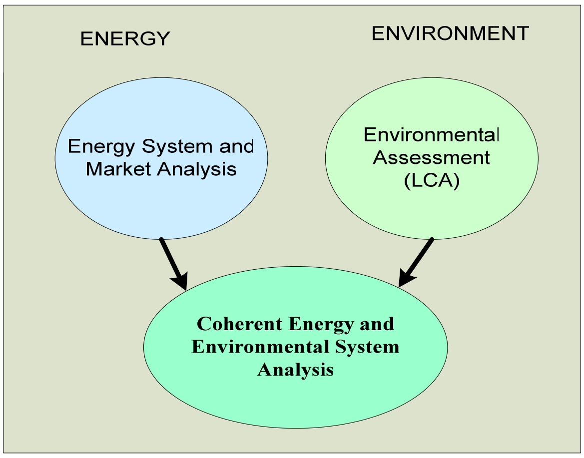
Coherent Energy and Environmental System Analysis

Application for

The Danish Council for Strategic Research
Programme Commission on Energy and Environment



List of applicants:
AAU, Aalborg University
Risø, Risø National Laboratory
DTU, Technical University of Denmark
KVL, The Royal Veterinary and Agricultural University
CBS, Copenhagen Business School
AKF, Institute of Local Government Studies – Denmark
DONG Energy

Appendix a: Project description.

Summary
This project will integrate existing energy and environmental analysis tools in a unique way. Through a combination of life cycle assessment and energy system and market analysis methodologies, the project will be able to meet three of the major challenges of future sustainable energy systems:

1. how to integrate the transport sector,
2. how to develop future power systems suitable for the integration of distributed renewable energy sources, and
3. how to develop public regulation in an international market environment.

Strategic significance
This research is of high strategic relevance due to Denmark's international obligations and national intentions. International obligations such as the Kyoto protocol, Directive 2001/77/EC and Directive 2003/30/EC call for an increased use of biomass or other renewable energy sources. The Danish Energy Strategy 2025 identifies three long-term challenges for the energy sector: Supply security, global climate changes, and growth and trade. All the above challenges are addressed in this proposal. In 2005, *Det Strategiske Forskningsråd* launched recommendations for 10 prioritised research areas (Innovationsaccelererende forskningsplatforme) with the potential of creating more jobs and income for Denmark (Det Strategiske Forskningsråd 2005). This project is implemented in accordance with the prioritised area "Vedvarende energi sat i system" as it addresses renewable energy at a system level.

Research idea and problem formulation
The prioritisation between different renewable energy sources has become of significant importance to the development of sustainable energy systems in countries such as Denmark. Consequently, the design and evaluation of energy systems cannot be done properly without comprehensive environmental assessment tools.

To obtain a truly sustainable energy system, it is important not only to optimise individual sub-systems of the overall energy system (e.g. electricity distribution, transport, production, etc.). Currently, most discussions concerning environmental aspects of energy production focus on greenhouse gas emissions directly related to the production phase. It should, however, be emphasised that all phases, both upstream and downstream of the actual energy production (electricity, fuels, energy carriers), may significantly affect the overall environmental performance of the system. As a consequence, a number of indirectly related processes and impacts must be addressed, too.

Environmental aspects must be assessed at a system level, including all relevant sub-systems (e.g. biomass production, resource handling and upgrading, waste disposal, etc.) and derived interactions (e.g. effects on crop markets, resource scarceness). Environmental impact modelling in a life cycle perspective provides a useful framework for such analyses. However, the modelling must not be performed as an isolated case. It must be combined with a detailed technical knowledge of the systems and technologies involved.

This project provides the necessary multidisciplinary basis for performing a system level modelling of the environmental aspects. The main objective is to initiate concrete co-operation between leading Danish researchers in the energy and environmental field. This unified research will contribute with strategies for an efficient development of the future Danish energy system, in terms of economics, energy and environment. An applied and multidisciplinary research of system modelling, life cycle assessment, electric technology and public regulation constitutes the basis for this development.

Research Plan, Empirical and Theoretical basis, Methodology and Innovative Element

The project is organised in five work packages (WPs) representing an overall scenario theme and four sub-themes as illustrated in figure 1. The project will be initiated by defining sustainable energy scenarios which will be relevant in 20-30 years from now and are based on the existing state-of-the-art tools and methodologies of energy market and system analysis and environmental assessment. Such scenarios provide a framework for the four sub-themes to follow. The results of these sub-themes will be gathered in an ongoing process and included in the development of tools and methodologies for a new generation of coherent energy and environmental analyses. These tools will subsequently be applied to the analysis and will eventually be used for a further development of the above-mentioned scenarios, as shown in figure 1.

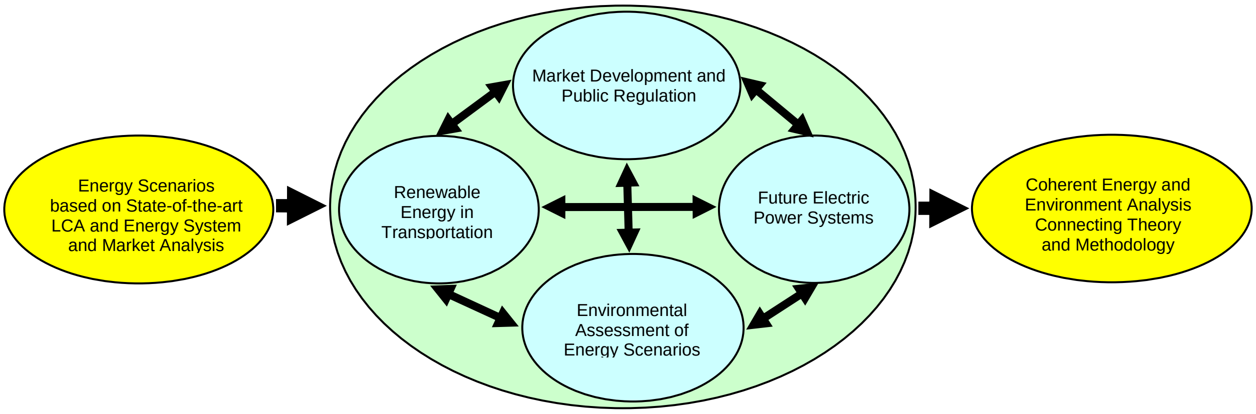


Figure 1: Under an overall range of scenarios, the work will be carried out in four transversal themes and then gathered in an ongoing process and included in the development of tools and methodologies for a new generation of coherent energy and environmental analyses.

The division of the project work into five WPs creates the basis for a highly structured and well organised working process. However, in order to achieve the synergy of combining the energy and environment fields, the WPs are closely related and a significant exchange of knowledge will take place among them.

WP1: From State-of-the-art-scenarios to Coherent Energy and Environmental Analyses

WP1 is divided into three tasks. During the first six-month period, task 1.1 will provide a common framework for the project by defining sustainable energy scenarios which will be relevant in 20-30 years from now. The scenarios will be related to a reference scenario which will be identified by the use of methodologies and models developed by Risø. These tools have, in many cases, been used in the energy planning processes of the Danish Government. The reference scenario will define the energy demand and the relation to economic development. By use of the energy system analysis model EnergyPLAN, developed at Aalborg University, a number of different 100% renewable energy scenarios will be defined, as illustrated in table 1. The final definition of scenarios will be subject to a discussion between all project participants including an international advisory board.

In task 1.2, during the next 3 years of the project, the results of the sub-themes will be gathered and will be included in the development of tools and methodologies for a new generation of coherent energy and environmental analyses. Finally, these new methodologies will be used in task 1.3 for re-calculating the scenarios.

The principal actors of the scenario part and the gathering of the results of the sub-themes will be the project leader and the WP leaders: Henrik Lund, AAU-ddp, Poul Erik Morthorst, Risø, Thomas Astrup, DTU, Poul Østergaard, AAU-ddp, and Niels I. Meyer, DTU.

20-30 years sustainable energy scenarios based on 100 % renewable energy sources (All scenarios include trade on the international energy markets of fuel and electricity)		
	High degree of electricity from fluctuating sources (low degree of bio-fuels)	***Low degree of electricity from fluctuating sources (high degree of bio-fuels)***
Centralised energy system	E.g.: Electricity for transportation. Many large wind farms and few fuel-based centralised power stations.	E.g.: Biofuel for transportation, large bio-refineries and many biofuel-based centralised power stations.
Distributed energy system	E.g.: Electricity for transportation. Many distributed wind turbines and small CHP plants.	E.g.: Biofuel for transportation, bio-refineries, distributed wind turbines and small CHP plants.

WP2: Renewable Energy in Transportation

The transport sector consumes approximately 32 % of the final energy consumption in Denmark, and this figure has increased during the past 20 years (Energistyrelsen 2005). Transportation relies almost entirely on oil and although some renewable alternatives exist, none are applied on significant scale in Denmark. The substitution of fossil fuels with renewable fuels bears the potential of reducing CO2 emissions and reducing a future dependence on oil from politically unstable regions. Hence, this substitution addresses two out of three major challenges identified in the Governments Energy Strategy 2025 (Energistyrelsen 2005).

Renewable Energy in Denmark is based on multiple sources; wind (20%), waste (31%), and biomass (39%) make up the major part (Energistyrelsen 2005). In the present systems which produce biomass for energy, biomass is in itself considered a secondary product, be it straw from the production of grain or debris from timber production. Therefore, the optimisation of production systems has hitherto focused on the primary products. It is believed that further focus on energy production may lead to changes in agricultural and forestry practices or to the introduction of dedicated energy crops on larger scales. At the same time, these primary production systems must still provide food, forage and materials. Renewable energy is not "green" by default. To gain maximum utility of renewable energy production it is of paramount importance to understand the fundamental mechanisms – actions and interactions – within and surrounding the system.

On the basis of the transport demand projected to 2025-2030, WP2 provides an analysis of comprehensive technology chains for sustainable transport in the entire transport sector. *Methodology* and specific topics to be dealt with in WP2 are:

- Task 2.1: Analysis of present and alternative conveying solutions, such as vehicles driven by liquid bio fuel, hydrogen/fuel cells, electricity or hybrids. The analysis includes both the vehicles themselves as well as the integration of relevant up-stream technologies in the overall energy system, such as electrolysis facilities, charging stations and bio fuel production plants.
- Task 2.2: Identification and analysis of potential renewable energy sources to meet future fuel demands. The analysis encompasses production, storage, supply security and conversion to fuels as well as a quantitative and spatial analysis of resource consumption in the production system from field to plant in a life cycle perspective, including characterisation, quantification and localisation of resource flows in the production system.
- Task 2.3: System analysis and modelling of production systems with a view to optimise production on energy consumption, resource consumption, and externalities as greenhouse gases.

The work to be done in WP2 is linked to WP3 at the technical level as renewable energy systems consists of a range of energy carriers and productions technologies (e.g. biomass, wind, electricity, bioethanol, etc.) WP2 is linked to WP4 and WP5 as regards defining marginal processes and technologies, system boundaries and quantification of externalities.

The theoretical basis of the work in WP2 is optimisation theory, operations research, material flow analysis and thermodynamics. *The empirical basis* of the analyses carried out in WP2 are data from published studies, national and international statistics (e.g. Danmarks Statistik, EU-Stat, FAO-Stat), extension services (e.g. Landbrugets Rådgivningscenter) and LCA databases. *The innovative element* in WP2 lies in its holistic approach to systems analysis including the entire technology chain from agricultural and forestry production to engine technology and fuel distribution.

Head of the Department of Energy Technology, John Pedersen, will conduct the analysis of alternative transportation technologies (task 2.1). Professor Claus Felby and Professor Bo Jellesmark Thorsen, KVL, will head the analyses of agriculture and forestry cultivation of biomass. A major part of the work will be carried out as a PhD project providing a dynamic model of the primary production of biomass. Environmental economist Kim Winther, DONG Energy, will take part in the model layout and data input (tasks 2.2 and 2.3). Professor Henrik Lund, AAU-ddp, will conduct the analysis of energy conversion and link to the overall energy system analysis (task 2.3).

WP3: Future Electric Power Systems

In the electric power system of the future, there will be a need for using the existing resources in a more technically efficient, economic and environmentally better way than in the present system. At the same time, it will be necessary to include more renewable energy supplies, either introduced as small geographically distributed, non-dispatchable units, e.g. micro turbines, connected to the distribution grid, or as large power plant-like units, such as wind farms connected to the transmission grid. If Denmark is to exploit such resources to a higher extent, there will be an ever more present need for power-balancing systems and grid systems accommodating this balancing. The future system must be technically, economically and environmentally optimised; but this optimisation presents many challenges to the future control of the power system both concerning the power flow pattern, the power quality problems and with respect to power, frequency and voltage control at stationary conditions as well as in contingency situations.

This WP analyses the over-all scenarios with the view to identifying the optimal future design of the power system and the associated control strategy. In this respect, it enters into an iterative process with the main scenario development as it influences the technical possibilities, while it is also influenced by the requirements from the general scenario analyses. *Methodology* and specific topics to be dealt with in this WP are:

- Task 3.1: Static and dynamic simulations of new power system structure cases, i.e. for instance micro grids, cell-based self-organised networks or a power system based on large renewable power plants with fluctuating power production. The main focus will be on small grids where the power flow in most cases will be bi-directional which can cause voltage quality problems. It will be determined if the control should be made locally or centralised. Another issue is the fluctuating power generated by renewable energy units, and it will be investigated if energy storages can be helpful both with regard to stability problems and considering feeding electrical vehicles or other kinds of transportation from the distribution network.
- Task 3.2: Evaluation, analysis and the selection of future control strategies for different power system structures. The purpose of this part of the project is to develop systematic methods for system level assessment and recommendation of alternative control strategies for the electric power systems. Such methods will be used for assessing different types of control strategies for the power systems supporting the scenarios defined in the project.

- Task 3.3: Incorporation of electro-technical design parameters into the EnergyPLAN model. The results of the analyses in Tasks 3.1 and 3.2 will be incorporated into the development of overall scenarios of the project and will also provide an electro-technical basis of Task 3.3. In this task, the energy systems analysis model EnergyPLAN, which is being used for the general energy systems scenario analyses, will be improved.

Common for the three tasks is a high degree of methodology development as the field is new and the target ambitious. Close links are foreseen to the environmental analysis, addressed in WP5.

The theoretical basis of the work of this WP is function modelling, transient analyses, control theory and load-flow modelling. *The empirical basis* of the WP are grid data from energinet.dk and relevant distribution companies, data concerning geographical distribution of production and consumption from the same sources as well as from other WPs of the project, and data from DEFU and existing models. *The innovative element* in this WP lies in its combination of general energy systems scenarios and analysis and electro-technical analyses of the power system. The iterative process formed by this combination is an innovative element of the project.

A major part of the work will be carried out as a PhD project at AAU and a PhD project at DTU. The principal actors of the WP are: Professor Jacob Østergaard, Ørsted-DTU, Assoc. Professor Birgitte Bak-Jensen, AAU-iet, Assoc. Professor Johannes Petersen, Ørsted-DTU, and Assoc. Professor Poul Østergaard, AAU-ddp.

The establishment of technical possibilities and limitation of the future power system has a large influence on determining viable overall energy systems scenarios and hence on the environmental impact of future energy use. This is addressed in the following WP.

WP4: Market Development and Public Regulation

Long-term sustainability scenarios for the Danish energy market may be described in terms of technological development, economic feasibility and environmental performance. Nevertheless, if appropriate policy instruments are not used actively, these scenarios may never be realised as markets will not develop. New research shows that markets do not pre-exist, but become institutionally constructed through a historical process in order to adjust to particular technological systems. This WP analyses the importance of designing the energy markets so that long-term sustainability scenarios might be reached through efficient regulatory instruments. These instruments do also take into account the presence of energy market failures and particularly adapted technological systems. There will be a close collaboration especially between WPs analysing biomass and electric systems. *Methodology* and specific topics to be dealt with in this WP are:

- Task 4.1: In order to identify the most efficient public regulation configurations, a number of criteria for market functioning will be analysed, including cost-effectiveness, optimal renewable development and environmental consequences.
- Task 4.2: Market failures such as monopolies and externalities call for regulatory intervention like price regulation. Compared to other industries, externalities in energy production are high in proportion to the costs paid by the producer. Furthermore, international market integration requires the establishment of international regulatory bodies. This WP will analyse all relevant market failures to be handled by markets and instruments.
- Task 4.3: Within the specified energy system scenarios, the implications of different market designs will be analysed and evaluated according to the criteria identified above. Institutionalised market structures develop gradually over time in order to adjust to particular technological systems. Therefore, new designs of energy markets call for experiments. Consequences for the energy system will be analysed using system simulation models.

- Task 4.4: Founded on welfare economics, the possibilities of using new and existing regulation instruments in achieving long-term environmental targets will be analysed in a national and international context. In particular, the interactions between markets and instruments will be treated. The portfolio of regulatory means investigated will include: Tradable emission permits, feed-in tariffs, green certificates, green taxes, subsidies and monopoly price regulation, as well as conventions that favour certain types of energy.
- Task 4.5: The international aspects of regulation get increasingly important, e.g. EU market integration calls for coordinated regulatory initiatives to cope with monopolies. System simulation models will be used for describing the consequences of the coexistence of national vs. international markets and regulation instruments.

The theory basis and methods applied in this WP imply the analyses of market failures and regulatory instruments based on economic welfare theory and analytically explored by partial equilibrium modelling. Consequences of alternative market designs and the utilisation of different regulatory instruments will be quantified in the systems simulation tools EnergyPLAN, Balmorel and Wilmar. *The empirical basis* of this WP includes energy market data, production costs of alternative energy technologies, the development of the Danish Renewable Energy market, demand elasticities, energy and CO_2 taxes and CO_2 quotas. *The innovative element* of this WP is the way in which market and instruments are chosen in an iterative process alongside technological and system development, thereby aiming at achieving an overall optimised energy system. Normally markets and instruments are used for implementing given strategies.

The principal actors of this WP are: Research Specialist P.E.Morthorst and Head of Energy Systems Programme F.M.Andersen, Risø, Professor F.Hvelplund, AAU-ddp, Professor P.Karnøe, CBS, and Associate Professor J. Munksgaard, AKF.

WP5: Environmental assessment of energy scenarios

The environmental assessment of the energy scenarios generated in the other WPs will be based on state-of-the-art Life Cycle Assessment (LCA) methodology and further developments within system boundary setting and assessment methodology targeted towards energy systems. Special focus will be on comparative assessments and the concept of consequential LCA within which the identification and modelling of demand-supply relations and the marginal fuels and energy supplies are key elements. *The methodology* and specific topics to be dealt with in this WP are:

- Task 5.1 will cover methods and procedures for definition and identification of primary as well as secondary services provided by the studied energy systems in order to assure full system equivalence and comparability. The will be done in interaction with WP1.
- Task 5.2 will cover evaluation and development of procedures for identification of marginal processes and activities with importance to energy systems. Further, WP5.2 will include a discussion of marginal processes and activities with respect to system boundaries influenced by market design and regulation instruments (relates to WP4).
- Task 5.3 will focus on collection of LCA data for relevant sub-processes as well as identification of marginal processes and activities with respect to technology chains (relates to WP2 and WP3).
- Task 5.4 will include system level impact assessment modelling of the scenarios defined in WP1 as well as evaluation of key sub-processes and activities related to the specific technology chains and market design aspects in WP2-WP4 with respect to the environmental profile of the overall energy scenarios. Task 5.4 will build in the outcomes of Tasks 5.1 – 5.3.

The theoretical basis for the work in this WP includes life cycle and environmental impact assessment, material and resource flow analysis, and sensitivity analysis. *The empirical basis* of the analyses is technical data describing energy, resource, and material consumptions, and emission data related to investigated energy production technologies as well as other relevant activities and processes. *The innovative elements* in this WP include development of procedures for determining marginal activities related to impact assessment on energy systems as well as integrated evaluation of specific technology chains combined with evaluation of the overall energy scenarios. The combination of energy system modelling with environmental impact modelling in this project is a new approach to the evaluation of energy systems.

LCA modelling performed in this WP will be based on existing technology data as well as input from the other WPs in the project. The importance of data quality, system boundaries, and assessment methodologies will be thoroughly evaluated and discussed. A strong emphasis will be placed on further development of existing assessment methodologies and adoption of these towards use on energy systems. The principal actors of this WP are: Dr Thomas Astrup (DTU-M&R), Dr Henrik Wenzel (DTU-MEM), Dr Per Christensen (AAU).

No issues concerning IPR, data security, use of animals for experimentation or questions of health, environment and ethics are relevant for this project.