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meeting the climate change challenge

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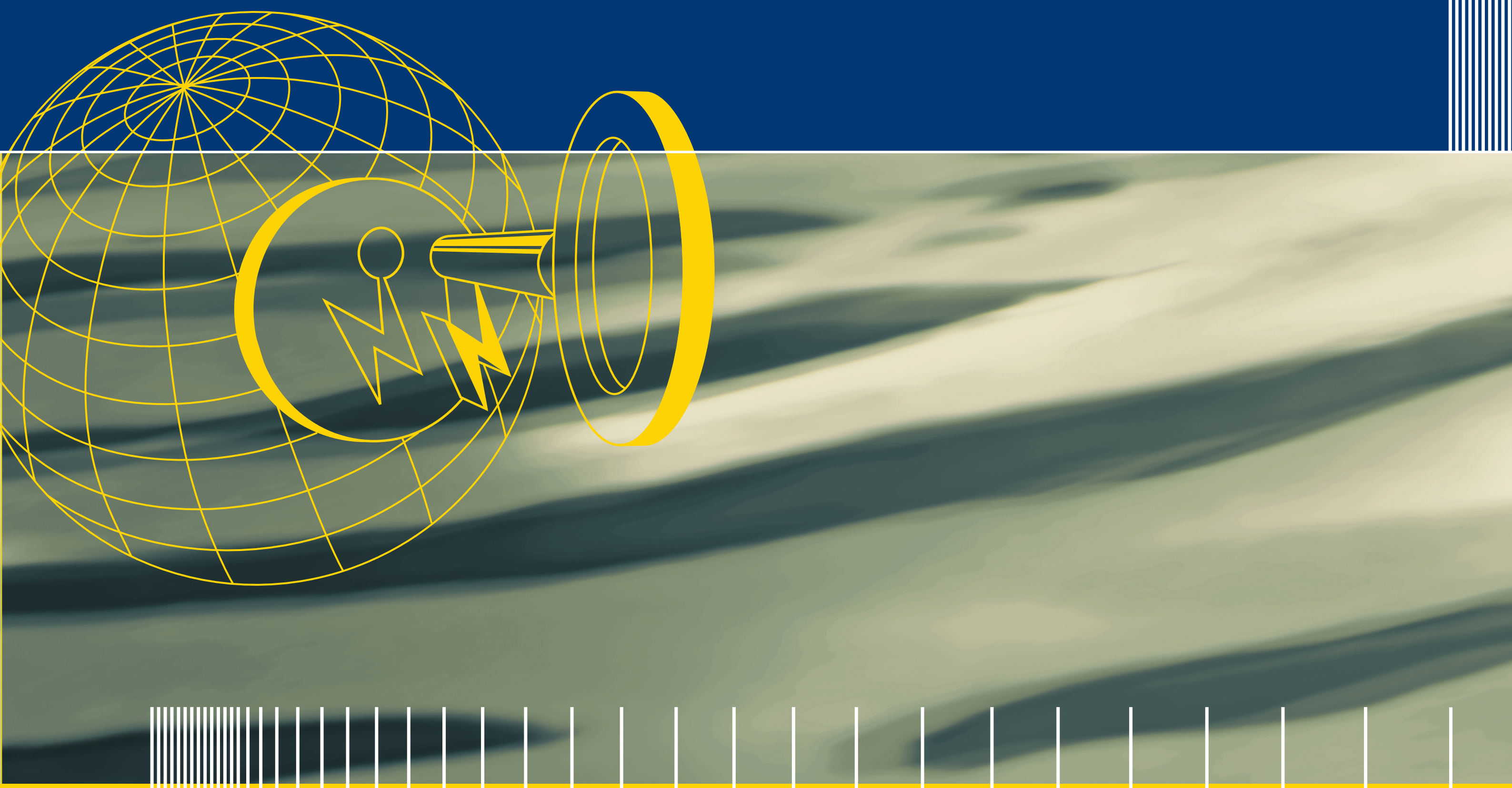

Energy Science Center ETH Zurich (ed.)

Smart Energy Strategies

Meeting the Climate Change Challenge

vdf

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Smart Energy Strategies

Meeting the Climate Change Challenge

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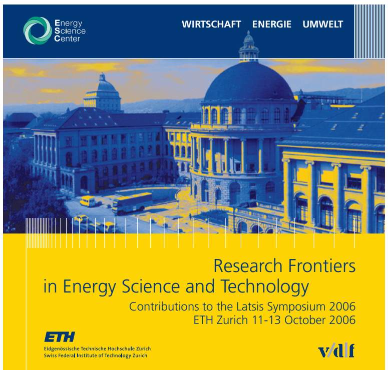
Weitere Bände der Reihe «Wirtschaft – Energie – Umwelt»

Silvia Banfi, Massimo Filippini, Andrea Horehájová, Daniela Pióro
Zahlungsbereitschaft für eine verbesserte Umweltqualität am Wohnort
Schätzungen für die Städte Zürich und Lugano für die Bereiche
Elektrosmog von Mobilfunkantennen, Luftverschmutzung und Lärmbelastung
2007, 192 Seiten, zahlr. graf. Darst., Format 16 x 23 cm, broschiert, ISBN 3 7281 3098 3

Das Buch vermittelt einen umfassenden Überblick der Resultate von drei verschiedenen Methoden zur Quantifizierung der Zahlungsbereitschaft für eine verbesserte Umweltqualität am Wohnort für die Städte Zürich und Lugano. Die Zahlungsbereitschaft wurde für die Vermeidung der Präsenz von Mobilfunkantennen in der Nähe des Wohnortes, für die Verringerung der Luftverschmutzung und der Lärmbelastung ermittelt.

Die vorliegende Studie ist die erste, die sich sowohl mit den ökonomischen Effekten von Mobilfunkantennen beschäftigt als auch zusätzlich verschiedene qualitative Informationen zum Verhalten sowie zur Einstellung der Bevölkerung in den Städten Zürich und Lugano gegenüber diesen Problemen erhebt und auswertet. Die angewandten Methoden und die Ergebnisse stellen einen interessanten und wichtigen Beitrag dar zur Quantifizierung der Zahlungsbereitschaft für eine Verbesserung der Umweltqualität im städtischen Raum.

Energy Science Center ESC (ed.)
Research Frontiers in Energy Science and Technology
Contributions to the Latsis Symposium 2006
ETH Zurich 11-13 October 2006
2006, CD-ROM with texts, illustr. and posters, format 14,2 x 12,5 cm, ISBN 3 7281 3090 7



International experts from the academia and industry discuss their scenarios of future technologies and describe their fields' frontiers. A broad and exciting picture of future energy technologies is revealed. The shown contributions have been presented during the Latsis Symposium 2006 «Research Frontier in Energy Science and Technology».

Main contributions from: Fatih Birol, Konstantinos Boulouchos, Klaus Fröhlich, Lino Guzzella, Eberhard Jochem, Johann Kolar, Wolfgang Kröger, Klaus Lackner, Arun Majumdar, Reinhard Nesper, Christian Ohler, Aldo Steinfeld, Didier Stevens, Thomas Stocker, Felix Wu and Stefan Zimmermann.

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Markus Balmer, Dominik Möst, Daniel Spreng et al.
Schweizer Wasserkraftwerke im Wettbewerb
Eine Analyse im Rahmen des europäischen Elektrizitätsversorgungssystems
2006, 232 Seiten, zahlr. Abb., z.T. farbig, Format 16 x 23 cm, broschiert, ISBN 3 7281 3048 8

Die schweizerische Elektrizitätswirtschaft befindet sich in einer Phase des Umbruchs. Die rechtliche Form der Liberalisierung wird zwar noch diskutiert, in der Praxis ist jedoch vieles schon in Bewegung. In vielen Unternehmen wird überlegt, wie die bestehenden Wasserkraftwerke für den zukünftigen europäischen Markt fit gemacht werden können.

Vor diesem Hintergrund hat das CEPE diese Studie zur Analyse der Wettbewerbsfähigkeit der schweizerischen Wasserkraftwerke im Rahmen des europäischen Elektrizitätsversorgungssystems erarbeitet. In einem Optimierungsmodell werden der zukünftige europäische Strommarkt unter Berücksichtigung verschiedener Szenarien bis zum Jahre 2030 modelliert und Strompreisprognosen abgeleitet. Darauf basierend werden auch neun aktuelle Erneuerungs- und Ausbauprojekte von Wasserkraftwerken in der Schweiz mit drei verschiedenen Methoden bewertet.

Jochen Markard
Strommarkt im Wandel
Veränderung von Innovationsprozessen am Beispiel von Ökostrom und Brennstoffzelle
2004, 348 Seiten, zahlr. Abb. und Tabellen, Format 16 x 23 cm, broschiert, ISBN 3 7281 2955 0

Wie wirkt sich die Marktliberalisierung auf das Innovationsgeschehen im Elektrizitätssektor aus? Anhand der zwei Innovationsfelder Ökostrom und Brennstoffzelle untersucht Jochen Markard die Innovationsstrategien von Elektrizitätsversorgern sowie Lernprozesse in den Unternehmen. Die Ergebnisse zeigen, dass die Unternehmen im liberalisierten Markt zunehmend heterogene Strategien verfolgen, um sich über innovative Dienstleistungen zu differenzieren und neue Kompetenzen aufzubauen. Im Umgang mit neuen Produkten und Technologien entstehen grössere Freiräume und die Innovationsvielfalt nimmt zu. Zugleich wächst das Potenzial, dass sich radikale Innovationen wie etwa die Brennstoffzelle verbreiten und sich letztlich auch in technologischer Hinsicht tief greifende Veränderungen im Strommarkt ergeben.

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Agent-based modelling of the travellers and their infrastructure demand

Kay W. Axhausen
ETH Zurich, Switzerland

This abstract is outlines some of the research presented in "Balmer, M., K. Meister, M. Rieser, K. Nagel and K.W. Axhausen (2008) Agent - based simulation of travel demand: Structure and computational performance of MATSim - T, paper presented at the 2nd TRB Conference on Innovations in Travel Modeling, Portland, June 2008".

The model toolkit MATSim - T provides a variety of tools and resulting approaches to model travel demand and traffic flow and their interactions. The currently preferred configuration is presented in the paper above and in the conference presentation with detailed information about its computational performance. The application is small compared to the abilities of the system, but as computing times scale approximately linearly for the system, it gives an idea of how the system can be used for practical planning studies: a 10% sample of the travellers in the Greater Zurich Area (190'000 agents).

The computing times show that MATSim - T is becoming a reasonable alternative to traditional aggregate four-step - approaches, especially if these implement dynamic traffic assignment. This recent achievement opens new avenues for the application of agent-based models. But it is also clear, that for even larger or more behaviourally complex scenarios the computational performance has to be improved further. Our emphasis will be on the reduction of the number of iterations required, as well as on the further improvement of the shortest path calculations.

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Further literature includes (a complete list of reports can be found on www.ivt.ethz.ch/docs):

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SmartGrids – The European vision becoming reality

Rainer Bacher[1 / 2]
Bacher Energie - Baden, Switzerland

Europe's electricity networks have provided the vital links between electricity producers and consumers with great success for many decades. The fundamental architecture of these networks has been developed to meet the needs of large, predominantly carbon - based generation technologies, located remotely from demand centres. The energy challenges that Europe is now facing are changing the electricity generation landscape.

The drive for lower - carbon generation technologies, combined with greatly improved efficiency on the demand side, will enable customers to become much more inter - active with the networks. More customer - centric networks are the way ahead, but these fundamental changes will impact significantly on network design and control. In this context, the European Technology Platform (ETP) SmartGrids was set up in 2005 to create a joint vision for the European networks of 2020 and beyond. The platform includes representatives from industry, transmission and distribution system operators, research bodies and regulators. Government representatives of Member and Associated states are also part of the ETP. The ETP proposes an ambitious strategy to make a reality of this vision for the benefits of Europe and its electricity customers.

The SmartGrids vision concluded that Europe's electricity networks must be:

- Flexible: fulfilling customers' needs whilst responding to the changes and challenges ahead.
- Accessible: granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions.
- Reliable: assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties.
- Economic: providing best value through innovation, efficient energy management and 'level playing field' competition and regulation.

As a second step following the publication of the SmartGrids vision a Strategic Research Agenda (SRA) has been developed to be a resource for European and National research programmes. It is a strategic document, intended to inform and inspire, facilitating the alignment of Research Programmes within the EU and its Member and Associated States. A key principle in the development of this SRA is that grid users should be at the focus of developments. To achieve this, an integrated approach of technical, commercial and regulatory aspects has been chosen to, seeking delivery of added - value solutions and services to all stakeholders and end customers.

As a third step the SmartGrids Strategic Deployment Document (SDD) will be developed by Oct. 2008 in order to implement the SmartGrids Vision and building upon the SmartGrids SRA. Its aim is to communicate the strategic plan for how we move from today's electric power networks to ones which will enable the realization of the national and EU energy security policies and sustainability targets towards 2020 and 2050.

1 Managing Director, Bacher Energie, Rütistrasse 3a, CH 5400 Baden
2 Dr. Bacher has received a mandate from the Swiss Federal Office of Energy (BFE) for participating in the SmartGrids European Technology Platform. He is a vice - president of the SmartGrids Mirror Group - (http://www.SmartGrids.eu).

Prospects and Challenges for Biofuels

Lionel Clarke
Shell Global Solutions, United Kingdom

Worldwide demand for mobility is steadily increasing at the same time that concerns are mounting over climate change. This is stimulating the widespread introduction of biofuels, due to their capacity to ease supply security, their potential to be grown or sourced locally, and their potential to mitigate growth in world CO^2 production.

In a number of countries governments are encouraging the production of conventional or ‘first generation’ biofuels through mandates and incentives. Industries are responding effectively to these obligations, building experience and starting to deliver the anticipated benefits.

However, it should be recognised that large-scale commercialisation of biofuels raises social and environmental issues that will require safeguards. As a leading biofuel supplier to global markets, Shell is committed to providing sustainable energy, applying its Sustainability Policies to supplier contracts and championing the development of internationally recognised standards in the supply chain. To scale-up biofuels supply to meet future anticipated demand, alternatives to food-based biomass feedstocks will need to be introduced.

To illustrate the increasing range of technologies that must be introduced to deliver new lower-carbon pathways from non-food biomass through to new fuel components, a number of recent technological initiatives will be described. This will include, inter alia, technologies for commercial scale ligno-cellulosic ethanol, ‘biomass-to-liquid (BTL)’ components via gasification and Fischer-Tropsch processes and the development of alternative biomass sources such as micro-algae.

Smart methods for a more rational energy use in industry

Daniel Favrat
EPFL, Lausanne, Switzerland

A more rational use of energy in industry is of growing importance even if the investment criteria with very short paybacks, compared to other sectors, have been a major hindrance to the application of more sophisticated energy conversion equipment or significantly improved processes. One major condition for a proper analysis of an industrial site is not only the availability of reliable energy conversion technologies but also of an efficient information structuring regarding the demand and the detailed energy supply within the different processes. Both are particularly important in a context of growing concerns for the global environment and the security of energy supply.

There exist a number of suppliers of computer - based tools for the energy analysis of industrial sites or processes. They go from monitoring and measurement tools to modelling, simulation and optimisation packages to be complemented by process integration techniques and life cycle analyse databases. Those often only partially meet the practical needs of industries, in particular of those operating in a broad international context with very different economic backgrounds. The synthesis of all the approaches cited above and their integration in a multi - level framework [1] adapted to the different categories of actors is still a challenge. A close partnership between academic research and industry is to be encouraged and can be very fruitful as shown by the recent results of several joined research projects undertaken in our group, particularly when technology transfer is linked with researcher's transfer to industry.

Smart methods in industry imply a combination of approaches [1] including:
(a) top - down analyses starting from the global energy consumption and determining key indicators for a particular plant if possible in comparison with other similar factories. This is facilitated if a common structure exists between factories of a same group and common web based applications exist. Statistical tools are usually heavily used in this type of analysis to correlate energy consumption with production volumes even though it is frequently shown that a surprisingly significant part of energy consumption cannot directly be related to production. Sometime a delicate question in case of multi - service energy conversion units (co - or tri - generation) is the allocation of costs for which we advocate the use of exergy [2,5,6].

(b) bottom - up with the analysis of the processes themselves starting with a synthesis of the requirements and a priority selection based on the 80/20 rule to concentrate on the most significant processes. On the latter, or groups of the latter, detailed energy integration (pinch technology) is applied to exploit both the internal synergies and the adequate placement of power units (cogeneration, heat pumps, Organic Rankine cycles). The best configurations are often modelled in a superstructure and a bi - objective optimisation [4] is then performed to highlight the trade - offs between costs and energy savings or costs and greenhouse gas reduction.

In both approaches the batch or multi - period nature of the processes [1, 3] often requires to extend the analysis to small time periods (monthly or weekly). Quality in data acquisition with data reconciliation techniques is an essential part of the success in identifying promising energy saving measures.

While periodic initiatives to motivate the personal to care about energy savings measures have often resulted in short lasting results, the introduction of systematic energy management programs with adequate indicators and benchmarking procedures will drive to more long lasting effects. A proper information structuring is part of the package and should facilitate the stepwise move towards process and utility upgrades and an increasing use of new technologies. With high fossil fuel prices energy integration and the substitution of fuel boilers, for heating only purposes, by cogeneration, industrial heat pumps and the incorporation of storage is now on the move. Failing to simultaneously adjust to the modern design methodological tools might jeopardize some of the economic benefits linked to the increased investment required.

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Monitoring, Sensing and Control of Future Electric Energy Grids – Key to Enhanced Efficiency and Security

Marija Ilic [1]
Carnegie Mellon University - USA

This talk concerns the basic challenge of transforming today's passive electric power grids into active enablers of efficient and reliable utilization of emerging unconventional energy resources. Our conservative estimate for the electric energy system alone is that a 25% increase in efficiency can be obtained today by such transformation without degrading reliability of services. However, while much of the hardware exists, meeting this goal still poses a fundamental challenge to the current state-of-the-art in systems and network sciences. Any large-scale penetration of intermittent resources is practically impossible without equally large-scale sensing, actuation and online data-assisted decision making by various industry participants, ranging from Independent System Operators (ISOs), Load Service Entities (LSEs), power producers/aggregators, to end users. In short, these resources cannot succeed without significant improvements to the control of the infrastructure.

This talk concerns this broad challenge by viewing the problem as a complex dynamical system in which much needs to be measured and controlled in novel ways relative to today's operating practices. In particular, modeling of the rapidly evolving energy systems as the cyber-based physical systems is put forward as a possible way to make progress. A novel cyber-based dynamic model is introduced whose mathematical structure greatly depends on the cyber - technologies supporting the physical system. It is discussed how the inclusion of these models results in a cyber-based dynamic model which lends itself to the distributed cooperative sensing for making the system as a whole fully observable through interactive cooperation among portions of not necessarily observable parts of the system. It is further shown how is the same model used for developing interactive protocols between the controllers embedded into portions of the system, and the network operator. This, jointly, leads to a synergic framework for a model-based sensing and control of future energy systems. It is further discussed how such model could be used to ensure fully observable system through a cooperative information exchange among portions of the system; this is achieved without requiring all components to be locally observable. Notably, the newly introduced models have network structure-preserving properties that are key to the effective distributed decision making. Particular emphasis is on the aggregate load modeling enabled by novel sensing and data mining in order to facilitate EHV/HV operations. Illustrations of using such cyber-physical systems for integrating unconventional resources in future energy systems are given.

This work is based on joint work with Professor Jose Moura, and graduate students Usman Khan and Le Xie at Carnegie Mellon University.

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Creating a green data center to help reduce energy costs and gain a competitive advantage

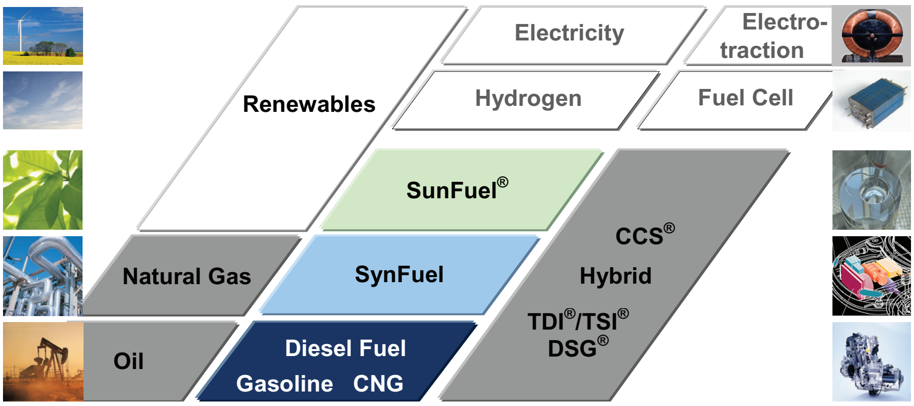
Chris Scott
IBM - United Kingdom

With global carbon emissions from the use of IT reportedly similar to that of the the aviation industry, and soaring energy costs for fuel and power, it is becoming ever more important to scrutinise how continued IT growth can contribute to corporate sustainability. Chris Scott - Site and Facilities Service Product Line Executive for North East Europe will discuss the need to balance the use of IT to manage and to save energy, with the fact that IT itself is a growing consumer of energy. His presentation will also examine what IBM as a company is doing globally to manage the crisis that could develop if things are left unchecked, and how this activity could help other IT users understand and improve their own energy efficiency.

Electrification of powertrain systems – between vision and reality

Wolfgang Steiger
Volkswagen AG, Germany[1]

Future powertrains have to support the development of sustainable mobility. So a strategy for the R&D of those has to contain roadmaps for the main issues: primary energy for transport, energy carrier and the powertrain itself. Those three issues have to be understood as one system and should be optimized in a systems approach.



Such a sustainable mobility system for private passenger transport has to react much on future individual and societal needs, resulting in more diversified cars and powertrains. Especially the needs of long distance transport in rural areas and inner - city transport in the growing number of mega cities require different technical answers.

From high importance is the energy carrier to be used in those different mobility modes. Today worldwide nearly 100% of the energy used in individual mobility is liquid hydrocarbon fuel based on crude oil. A future sustainability based system must rely on a much broader base of different and increasingly renewable primary energies while staying with e few uniform energy carriers in the same time. Beside synthetic liquid hydrocarbon fuel, electric energy and hydrogen are those synthetic uniform energy carriers. Together with the electrification of future powertrains this will open up total new possibilities.

So a two way roadmap may be formed, with one side clearly being focused on combustion engines with some electrical support for further fuel consumption reduction and a second way highly concentrated on electrification using batteries as energy carrier.

On this second pathway, finally leading to an all range battery electric drive train, during the time of increasing electrification, plug in technology with range extenders, combustion engine or fuel cell an hydrogen based, will overcome the lag of energy content in the today's battery systems.

This vision of future powertrains is based on the expected further improvement of the batteries. Cost, safety and durability are the main issues of concern. Lithium - Ion technology is a key factor to overcome those concerns, but still a lot of R&D is needed. Soon we will see the first electric cars, with some restrictions in performance and driving range, on the market. Those cars, not being full competitive, demonstrate that the vision is going to get real.

Finally this leads to sectorial optimized mobility systems with battery electric powertrains for the urban areas, range extender electric cars for the sub urban and combustion engine based for the long distance transport area. Each of those mobility modes will be energized by renewable energy based on biomass and renewable electric power.

1 *Group Research Powertrain*

Should we invest in abatement or R&D into new technologies? Modelling technology choices under uncertainty

Thomas Sterner [1]
University of Gothenburg, Sweden

One aspect of the popular debate on what we should do to face climate challenges concern the relative importance of reducing our emissions (abatement) now versus R&D investments in new technology that will make it possible to reduce emissions more cheaply in the future.

We study the importance for climate policy of uncertainty concerning the gravity of climate change and thus the benefits of abatement. In particular, this uncertainty can have different effects on the benefits of early abatement and R&D to lower future abatement costs. We explore these differences, which depend in large part on the curvature of the marginal abatement cost function-prudence, in other words. With convex marginal costs, increased uncertainty leads to more early abatement, while concave costs allow for less early action, which can be further reduced by R&D. With several competing technologies and the possibility for R&D to change the shape of the abatement cost curves, the impact of uncertainty on the optimal R&D portfolio is more complex. We illustrate our results with the case of two competing technologies, a conventional one with linear costs and a backstop with fixed (but high) costs. The existence of this backstop renders a concave overall abatement curve, but if the backstop capacity is constrained, then portions of the abatement curve may be convex. Finally, we discuss these results in the context of existing climate models and scientific evidence.

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1 *President of the European Association of Environmental and Resource Economists - Professor of Environmental Economics - Dept. of Economics, University of Gothenburg, PO Box 640, 40530 Gothenburg, Sweden - Tel +46 31 7861377 - Fax +46 31 7861326 Conference http://www.eaere2008.org/ - Homepage http://www.hgu.gu.se/item.aspx?id=3519 - Homepage for my research group http://www.handels.gu.se/econ/EEU*

Understanding consumer behavior for energy demand side management. A framework for research

Joana Abreu[1]
Ana Gonçalves[1], Tiago Domingos[1]
MIT Portugal

Introduction

The impact of human activities on the environment is under assessment as there's a growing need for more sustainable pathways. The Intergovernmental Panel on Climate Change (IPCC, 2007) urges for global action due to the increased risk of dramatic changes in the climate, economy and the planet's sustainability, resulting from changes on the mean overall temperature induced by the anthropogenic action on the globe's weather.

Electricity production contributes in 25% to the overall anthropogenic green house gases emissions at a global scale. A scenario of stabilization of the carbon dioxide emission level on the atmosphere traces the goal at 445 ppm emission level by 2030. Demand side management (DSM) actions represent opportunities for carbon dioxide and other GHG abatement, while increasing efficiency and long term competitiveness (Porter 2007). Demand side management control does also to tackle dependence for primary energy and security of supply, especially important for non-producing countries due to market failures (cartel behavior), terrorism, or other foreign policy causes.

DSM actions represent low cost, potentially efficient ways to tackle climate change, accounting for 38%of total abatement potential (Per Alders et al., 2007). However, the potential impact of DSM measures is related to the way governments and the society will be able to transmit and induce behavioral change. DSM at the necessary scale is politically difficult to implement because the target group will partially be inhabitants of countries with very different development standards, therefore , by nature, DSM is highly fragmented and difficult to enforce.

At residential level, DSM actions include house retrofitting, exchanging lighting, and equipments, but also practices which have to do with the way consumers behave and use the appliances. The how, what and when about electricity consumption behavior makes a difference on the electricity bill, but also on the impact on the environment.

Consumer Behavior

The premise of this research is about the necessary behavioral change that may lead to increased sustainability and consciousness of electricity use.

The impact of the action of users on the electricity bill is not sufficient to create awareness around how electricity is used. The user seems to be shielded from the maximization of utility principle, reflected in rational efficiency principles such as unplugging unnecessary appliances, turning unnecessary lights off or exchanging light bulbs.

Behavioral economics research explains these anomalies to the conventional neo-classic economic studies.

Research led by Kahneman et al. (2000), Tversky, A. et al. (2000) have identified several aspects leading to anomalies in rational behavior. The following are examples of anomalies:

- status-quo bias, when the individual decides not to act, even if coming from a worse position and aiming at a better situation due to inertia;
- time inconsistence which reflect different discount rates applied in consecutive moments in time representing the difficulty to do without present benefits in favor of uncertain outcomes;
- the endowment effect, which reflects the difficulty of users to loose perceived pre-acquired rights: the individual is reluctant to trade a benefit, even for a higher price than it's initial cost;
- or reciprocal behavior, which argues that the individual tend to reflect the same kind of behavior transmitted by others.

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MIT Portugal – Sustainable Energy Systems Program - IN+, Centre for Innovation, Technology and Policy Research - Environment and Energy Section, Mechanical Engeneering Department - Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa , Portugal

In line with the current theories of behavioral economics, McKenzie-Mohr et al. (1999) advocate the the need for communication strategies which apart from creating public awareness, foster a greater identification with individuals, overcoming barriers and leading to long-lasting behavior change. The arguments for the need of smaller scale community based strategies are based on experiments that show that behavioral change doesn't occur solely because individuals are better informed. Behavioral change is a complex, intimate process, where personalized and community or neighborhood based actions may have a higher impact in producing the necessary changes.

Experiments have shown the following aspects of human behavior:

- It is easier to commit to a small attainable goal than to a more challenging goal. However, seeking commitment to an initial small step is difficult. This has to do with changing the perception of the individuals about themselves, following an initial request.
- When an individual is actively involved with a campaign, and views himself as part of the path to sustainability it will increase the personal level of commitment.
- Consistent behavior is highly socially valued. Therefore, actions focusing on local communities where public and private actions are more closely related, will foster positive commitment from the individuals which may lead to consistent behaviors.

The experimental framework

We propose to setup an experimental framework which intends to analyze the factors influencing consumer behavior for electricity consumption. The analysis will be supported by the smart metering projects underway with the Smart Metering group at MIT, which have setup a smart metering device called the Energy Box. Such device, distinguishes from existing smart metering mechanisms because of the way it conveys information to the user. Although a complex project, with details outscoping the objective of this abstract, the box is composed of a real time energy meter fitted with a screen that will convey information to the user in a intuitive form.

The way the user will receive information will transform its normal daily functions into impacts on the environment. In case a real time energy market is set into place, the energy box may additionally send information about the cost of energy from period to period, which may lead to rational behaviors, when the user is lead to maximizing its utility. These experiments will be happening both in Boston and Lisbon.

Similarly, and following the existing experiments happening in Portugal in terms of monitoring energy consumption in Portugal using smart metering, we will develop a framework to analyze the results, and modifications of habits.

Applying the knowledge

Going forward, there will be a need to create a unifying consumer behavior theory that will enclose the results that emerge from the experimental work in course. Only understanding the main drivers of consumption and consumers' choice in an objective way and using mathematics as the universal language, will be possible to apply this knowledge on different realities maintaining its applicability. This work will allow to create scenarios of future energy flows including it in the current energy flow models, and to try to understand the impact of government energy policies and incentives.

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Distributed Control Applied to Multi-Energy Generation Portfolios

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1 Introduction

In 2004 the Power Systems and High Voltage Laboratories at ETH initiated the research project "Vision of Future Energy Networks" (VoFEN), which applies a greenfield approach to the design of future energy systems. The main aspect of the project is the consideration of multiple energy carriers, i.e. the analysis is not restricted to electricity but also considers other energy carriers such as natural gas, hydrogen and district heating [1]. By exploiting synergies among various forms of energy, system improvements in terms of overall energy cost reduction, system emission reduction and increase of reliability of supply can be achieved. The couplings between the different energy infrastructures are taken into account with the novel concept of the Energy Hub, which is a generalization and extension of a network node including conversion, conditioning and storage of multiple energy carriers. Energy systems are built up by a certain number of Energy Hubs.

Based on these concepts, further methods have been developed. One of them is the application of mean-variance portfolio theory to portfolios generating multiple energy carriers. Efficient multi-energy portfolios are determined by considering a set of possible scenarios and technologies. Using this method, investments in multi-carrier energy systems can be planned taking into account relevant risk factors. The resulting technology mixes can be considered as Energy Hubs. A network of interconnected hubs forms a distributed power generation structure where each hub is controlled by its respective control agent. A distributed control scheme is applied in order to guarantee the energy supply of the whole system during operation. In order to arrange coordination between hubs, the distributed control scheme is extended and applied to the geographically distributed portfolios. Here, these two concepts, portfolio theory and distributed control, are applied to a system consisting of three hubs, interconnected by an electricity and natural gas network.

2 Methods Applied to Multi-Energy Systems

2.1 Multi-Energy Generation Portfolios

Considering risks and uncertainties in the energy system planning environment is gaining growing importance. Investment decision makers therefore need techniques for the quantification of these risks. Mean-variance portfolio theory is an appropriate method to take risks of investment projects into account and has successfully been applied to several studies in the electric energy sector [2]-[4].

Inspired by the Energy Hub concept, which enables the integrated modeling of multiple energy carriers, mean-variance portfolio theory is extended and applied to portfolios providing multi-energy outputs, e.g. electricity, heat or chemical energy carriers such as hydrogen. By simultaneously considering various forms of energy during the planning process, this extension of portfolio theory permits a comprehensive long-term investment planning of energy generation mixes.

When considering portfolios with multiple energy outputs, the portfolio energy carrier ratio x_{out}, i.e. the relative share of each output in the total energy output, has to be determined. In this way, a certain value of the vector x_{out} required in the supply area under consideration can be used as constraint in the portfolio optimization in order to calculate efficient frontiers for the desired amounts of energy outputs. For this purpose, the conversion efficiencies of each considered technology with respect to each form of output energy, e.g. the electric efficiency of a combined heat and power plant, are related to the overall efficiency of the converter. The resulting quantity is the share of a certain energy output in the overall energy output of one technology.

The values for conversion efficiencies are chosen as average values over the assumed lifetime of the power plants. For a certain technology i with a conversion efficiency η_{ik} with respect to the kth output energy and a total efficiency of $\eta_{i,tot}$, the share of output k in the total energy output of a converter is

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$$\Gamma_{ik} = \frac{\eta_{i,k}}{\eta_{i,tot}} \tag{1}$$

By means of (1), one can define the *output ratio matrix* $\mathbf{\Gamma}$, which indicates for the whole set of technologies the share with respect to each of the α energy outputs generated by the portfolio:

$$\mathbf{\Gamma} = \begin{bmatrix} \Gamma_{11} & \cdots & \Gamma_{1t} \\ \vdots & \ddots & \vdots \\ \Gamma_{\alpha 1} & \cdots & \Gamma_{\alpha t} \end{bmatrix} \tag{2}$$

Multiplying $\mathbf{\Gamma}$ with the portfolio allocation vector xP, which indicates the share of each technology in the portfolio, yields the portfolio energy carrier ratio $xout$:

$$\mathbf{x_{out}} = \begin{bmatrix} x_{out,1} \\ \vdots \\ x_{out,\alpha} \end{bmatrix} = \mathbf{\Gamma} \cdot \mathbf{x_P} \quad \text{with} \quad \sum_{k=1}^{\alpha} x_{out,k} = 1 \tag{3}$$

With this extension of portfolio theory to multi-energy portfolios, it is possible to determine efficient portfolios that provide an arbitrary number of energy outputs. A detailed description of the multienergy portfolio model can be found in [5].

The resulting generation mixes, i.e. the amounts of installed capacity for each technology, will generally be different for different regions or supply areas as availability of energy sources and consequently generation costs are location-dependent.[1] Furthermore, different attitudes towards risk (averse, neutral or seeking) can result in different choices of points on the efficient frontier. Such issues can result in different generation technology mixes in different supply areas.

The aggregated technology mixes (portfolios) can be considered as Energy Hubs. The energy exchange between these Energy Hubs representing different supply areas has to be coordinated during operation. This is accomplished by applying distributed control, which will be outlined in the following subsection.

2.2 Distributed Control

Portfolios are in general location-specific, i.e. portfolios of different areas are composed of different technologies. As the various generation technologies cannot always be operated at their optimal capacity, e.g. due to limited forecastability of wind conditions, the power generation needs to be adapted during operation and possibly deviates from its optimal value. In order to coordinate this generation adaption as well as the energy exchange between portfolios during operation, distributed control is applied to provide the system wide optimal operation of the whole system. For this, one agent is defined for each area, which is responsible for the energy supply of the respective area. On the one hand the agents have to respect the characteristics of the energy converters and the generation units present in their regional portfolios, on the other hand they have to agree on an overall optimal energy supply with their neighboring areas.

In order to guarantee the energy supply of the whole system, an optimal power flow (OPF) problem is solved taking into account all areas. This optimization problem is formulated by an objective function to be minimized, subject to equality and inequality constraints:

$$\min_{\mathbf{u}} \; J(\mathbf{x}, \mathbf{u}) \tag{4}$$

$$\text{s.t.} \tag{5}$$

$$\begin{aligned} \mathbf{g}(\mathbf{x}, \mathbf{u}) &= \mathbf{0} \\ \mathbf{h}(\mathbf{x}, \mathbf{u}) &\leq \mathbf{0} \end{aligned} \tag{6}$$

where x and u describe the system state variables and control variables, respectively. The objective function penalizes the deviations between the optimal long-term operation point defined by the rated capacities of the converters and generators in the portfolio and the actual operation point, which is determined by the actual short-term load and generation situation during operation:

$$J(\mathbf{x}, \mathbf{u}) = \sum_{i=1}^{n} (\mathbf{u}_{\text{port}} - \mathbf{u})^2 \tag{7}$$

1 *The levelized costs of a photovoltaic plant, e.g., depend on the average radiation intensity at the plant location and costs of wind power plants are strongly influenced by the average on-site wind speed.*

where u_{port} describes the power generations defined by the regional portfolios and u indicates the actual power generations during operation. The system constraints comprise the power flow equations (5) and limits on voltage magnitudes, active power flows, pressures, power generations, etc. (6).

This overall optimal power flow problem is now decomposed into subproblems according to the different regions. Each subproblem is assigned to a responsible control agent. As the individual optimization problems depend on one another, the agents need to coordinate their actions among each other. In order to achieve this coordination, the decomposition method derived in [6] is applied to the considered energy system. The mathematical procedure is illustrated for two interconnected areas A and B.

$$
\begin{array}{ll}
\min\limits_{\mathbf{u}_A} & J_A(\mathbf{x}_A, \mathbf{u}_A, \mathbf{x}_B^k, \mathbf{u}_B^k) \\
 & +(\lambda_B^k)^T \tilde{\mathbf{g}}_B(\mathbf{x}_A, \mathbf{u}_A, \mathbf{x}_B^k, \mathbf{u}_B^k) \\
\text{subject to} & \\
 & \mathbf{g}_A(\mathbf{x}_A, \mathbf{u}_A) = 0 \\
 & \tilde{\mathbf{g}}_A(\mathbf{x}_A, \mathbf{u}_A, \mathbf{x}_B^k, \mathbf{u}_B^k) = 0
\end{array}
\qquad
\begin{array}{ll}
\min\limits_{\mathbf{u}_B} & J_B(\mathbf{x}_A^k, \mathbf{u}_A^k, \mathbf{x}_B, \mathbf{u}_B) \\
 & +(\lambda_A^k)^T \tilde{\mathbf{g}}_A(\mathbf{x}_A^k, \mathbf{u}_A^k, \mathbf{x}_B, \mathbf{u}_B) \\
\text{subject to} & \\
 & \mathbf{g}_A(\mathbf{x}_A, \mathbf{u}_A) = 0 \\
 & \tilde{\mathbf{g}}_B(\mathbf{x}_A^k, \mathbf{u}_A^k, \mathbf{x}_B, \mathbf{u}_B) = 0
\end{array}
$$

The two subproblems are solved in an iterative way, independently but coordinated. The objective and the constraints of the overall optimization problem (4)-(6) are separated and assigned to the areas (only equality constraints are considered here, inequality constraints are handled the same way). The coordination is enabled by so-called coupling constraints (marked by tilde), which contain variables from both areas. These constraints prevent each subsystem from operating independently from the others. The coupling constraints assigned to area A (marked in red) are kept as hard constraints of area A′s optimization problem and at the same time added as soft constraints to the main objective function of area B′s optimization (modified Lagrange relaxation). The same holds for the coupling constraints assigned to area B. For both areas, the variables of the neighboring areas are kept constant and marked by superscript k indicating the iteration step. After each completed iteration step, the updated system variables are exchanged between the areas. Convergence is achieved as soon as the exchanged variables no longer change significantly between two consecutive iterations. Further details can be found in [7].

3 Application Example

Figure 1 shows an example of a hub-based energy system. Firstly, optimal energy generation mixes are determined for the regions (long-term planning). Secondly, short-term operation is implemented applying the distributed control procedure.

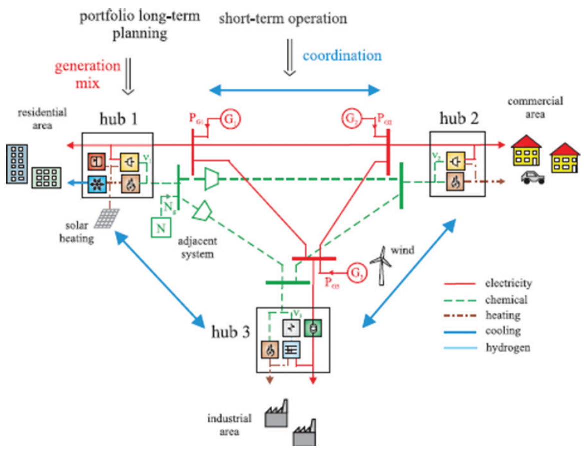

Figure 1: Example of a hub system. Long-term planning determines the generation mix of the hubs, short-term operation enables coordination between the hubs.

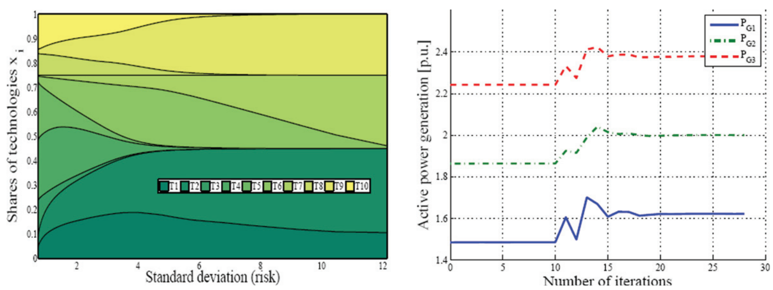

Figure 2: (a) Efficient mixes of generation technologies and (b) active power generation during operation.

The determination of efficient multi-energy portfolios defines the optimal energy generation mixes of the three hubs. To illustrate the process of determining efficient multi-energy generation mixes, a portfolio generating electricity, heat and hydrogen is considered. Heat and hydrogen are generated and consumed locally, i.e. there are no networks between different regions for these two energy carriers. The set of technologies consists of wind (T1), small hydro (T2), photovoltaics (T3), biogas-fired engines (T4), natural gas-fired engines (T5), thermal solar panels (T6), gas boilers (T7) and technologies for the production of hydrogen via electrolysis (T8), via natural gas reforming (T9) and via solar thermal water splitting (T10). In order to calculate the input data for the portfolio optimization (the covariance matrix and the mean returns of the technologies), the scenario-based method described in [5] is used. Applying this method to a portfolio with an output of 45% electricity, 30% heat and 25% hydrogen, one obtains an efficient frontier with the portfolio allocations shown in Fig. 2(a). For each possible risk level, i.e. for each possible standard deviation of return, Fig. 2(a) indicates the corresponding mix of generation technologies.

Depending on his attitude towards risk (averse, neutral or seeking) and the degree of this attitude, the system planner will choose a certain portfolio. In this application example, it is assumed that the system planner in region 1 chooses a low risk level, the system planner in region 2 a medium risk level and the system planner in region 3 a high risk level. The resulting optimal long-term generation mixes in the three regions consequently differ from each other. For the application of the distributed control procedure, certain technologies are aggregated in homogeneous groups, e.g. all technologies exclusively generating electricity are aggregated in one group and their electricity generation is denoted by P_{Gi} with i being the number of the respective region. In the same way, CHP units and technologies generating heat are aggregated in groups. In doing so, one obtains a simplified system which consists of three equal hubs structured like hub 2 in Fig. 1. The results of the portfolio analysis, in particular, the active power generations of all generators P_{G1}, P_{G2} and P_{G3}, the natural gas infeed *Ng* and the operation points of the converter devices, i.e. the CHP units and furnaces, then serve as optimal values u_{port} during operation. The operation point of the converter devices is defined by a factor *vi*, which indicates the share of gas in the total gas consumption of hub i fed into the CHP unit. Consequently (1-*vi*) defines the gas input going into the furnace.

Having obtained the above defined long-term optimal operation values, distributed control is applied in order to ensure the energy supply during operation while respecting the different compositions of generation technologies. In Fig. 2(b), part of the control variables u_{real}, which comprise the above determined optimal operation values, are shown. The active power generation of all generators P_{G1}, P_{G2} and P_{G3} are depicted during the coordination procedure. After 27 iteration steps a coordination among the three hubs is achieved. First, the generators stick to their pre-defined operating points uport as defined by the portfolio. However, no coordination can be achieved on this generation level due to discrepancies within the the electric and gas power flows between the hubs. Thus, each control agent has to adapt the generation of its respective control area in order to fulfill the system-wide energy supply. The same behaviour is obtained for the remaining control variables. The final actual values of the control variables u_{real} differ from those defined by the portfolio u_{port} as the the line losses of the interconnecting networks are not taken into account during portfolio analysis. Both networks, electricity and natural gas, exhibit line losses, especially compressor losses are considerable. A more detailed analysis of the simulation results is presented on the poster.

4 Conclusion

The presented models and methods are extensions of the concepts developed in the first phase of the ”Vision of Future Energy Networks” project. On the one hand, they apply a long-term perspective to the planning of multi-energy generation assets using portfolio theory. On the other hand, the distributed control scheme enables the short-term operation of these generation assets and guarantees coordination between them. Thus, both methods, particularly their combined application, make a useful contribution to the existing methods for multi-energy system planning and operation.

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Biodiesel fuel pathways for the Portuguese road transport sector

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Similarly to most European countries, Portugal is highly energy dependent on oil importations. Portugal imports around 70% of its final energy consumption in the form of oil based fuels [1]. Around 35% of this foreign oil consumption goes to the transportation sector, mainly road transportation. In addition, there is growing public and political concern with the rising greenhouse gas (GHG) emissions, namely CO_2, which are associated with climate change issues [2]. It is estimated that, in Europe in 2005, the transport sector was responsible for 21% of the total CO_2 emissions. Particularly, road transport accounted for 93% of the global emissions [3].

As an answer to this problem, European decision makers have established certain political goals concerning the fuels of transportation sector, namely the European target of 10% of biofuels incorporation by 2020 (which in Portugal has been raised to a 20% target) [4].

In order to comply with these political goals, biofuels production must increase a great deal. The most widely considered biofuel substitute for fossil diesel is biodiesel, which is produced from vegetable oils. The only Portuguese native crop which could be now considered with the purpose of producing biodiesel is sunflower. However, it will not be enough to satisfy the country´s needs so other vegetable oils must be imported. That is the case of soybean, rapeseed and palm oils that are being imported from other parts of the world (Brazil, Canada) in order to produce biodiesel. However, the sustainability and economic/social consequences of using food crops are being questioned [5, 6]. For that reason, new energy sources must be analyzed in order to address these issues. In this sense, microalgae oil appears as a potential solution, since it does not compete with food crops, has much higher production yields and has other potentialities, such as CO_2 capture and water treatment [7, 8].

Accordingly, a life cycle assessment [9, 10] was performed in order to evaluate the described fuel pathways (national sunflower, imported crops and microalgae), having conventional fossil diesel as the reference (see Figure 1). This study included not only a well-to-tank analysis but also a tank-to-wheel, since the vehicle usage simulation was also performed.

For instance, for the calculation of the energy and CO_2 life cycle assessment of sunflower (see Figure 1), the following stages were considered: firstly, the agricultural stage, which includes the seeds production, the tillage, sowing, irrigation, harvesting and drying stages; secondly, the sunflower is transported, the oil is extracted and refined; afterwards, biodiesel is produced from the sunflower oil and processed in order to achieve the quality standards of EN 14214; and, finally, biodiesel is transported, mixed with fossil diesel and then arrives at the filling station.

For these stages the following tools were used: Simapro [11], Gabi [12] and Gemis [13]. For the vehicle simulation stage a micro simulation model for vehicles – Ecogest [14] – was used.

The characterization of Portugal in terms of its biodiesel fuel pathways will allow us to estimate the future potential energy sources in Portugal that will serve the road transport until 2050.

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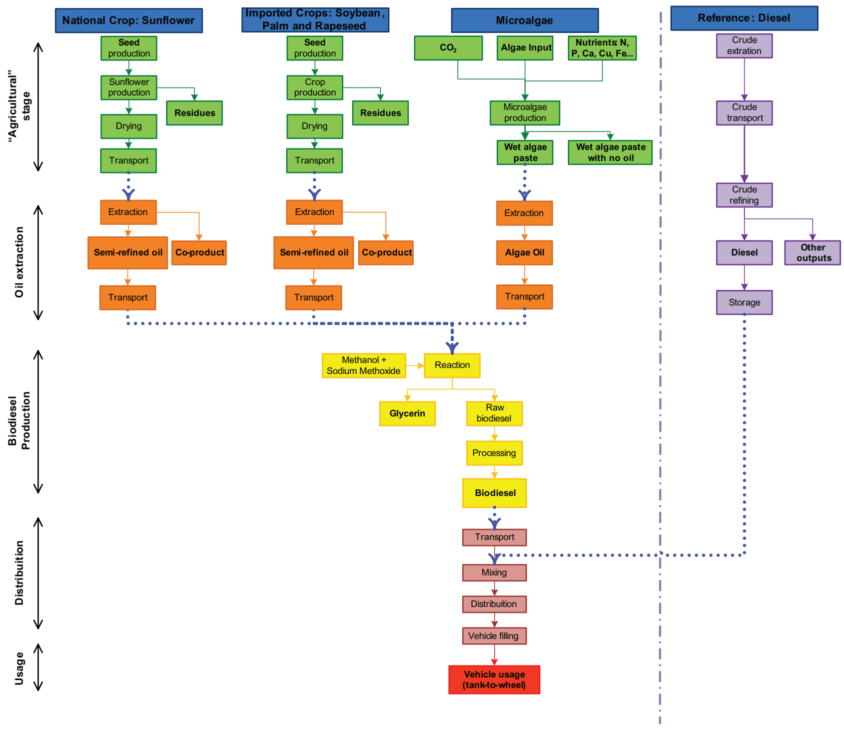

Figure 1: Biodiesel fuel pathways.

This research is being carried out as part of the MIT|Portugal Program and, particularly, in collaboration with the Sloan Automotive Laboratory of MIT.

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Research and development of wind turbines for operation in harsh environments

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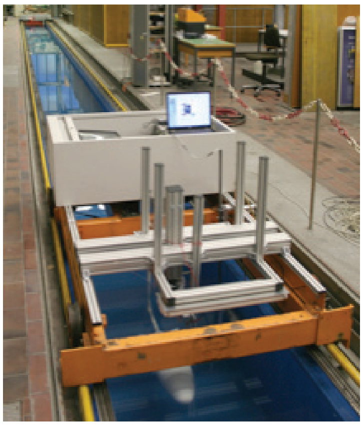
Introduction

Wind energy is currently the source of electrical power with the world's fastest rate of growth, and Europe produces two thirds of the world's wind power. The Swiss government plans an annual production of 50–100 GWh of electricity from wind energy by 2010. The siting of wind turbines is becoming vital in order to sustain this growth and to efficiently capture the natural wind resource.

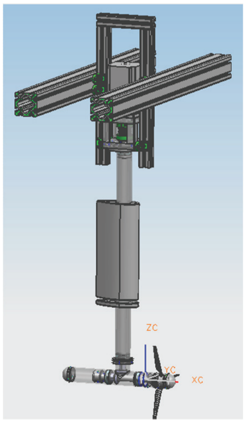
This paper presents some initial experimental and computational work undertaken as part of a longer-term wind energy research project. This project involves the research and development of efficient, cost-effective and reliable wind turbines specifically for operation in harsh environments, such as the Swiss Alps. These environments are desirable because the high wind speeds allow more power to be obtained for a given size of turbine. However, the usage of such sites is presently limited as turbine performance in harsh environments is currently not well understood, and wind turbines are prone to loss of efficiency, overproduction of electricity, damage, significant periods of downtime and even failure.

Water Towing Tank Experiments

The first part of the study involved the flow visualisation of a scale model turbine in a water towing tank, Figure 1.The water towing tank is used rather than a wind tunnel since it allows full-scale non-dimensionals to be matched on a sub-scale model. The tank has dimensions 1 m x 1 m x 40 m and a maximum carriage velocity of 3 m/s. Due to blockage considerations the rotor model is limited to a diameter of 0.3 m and due to cavitation effects its rotational speed is limited to 600 rpm. The tip speed ratio (rotational/translational speed) can be varied from 1 to 8 by adjusting the carriage velocity.



(a)



(b)

Figure 1: (a) Water towing tank (b) CAD illustration of the model turbine.

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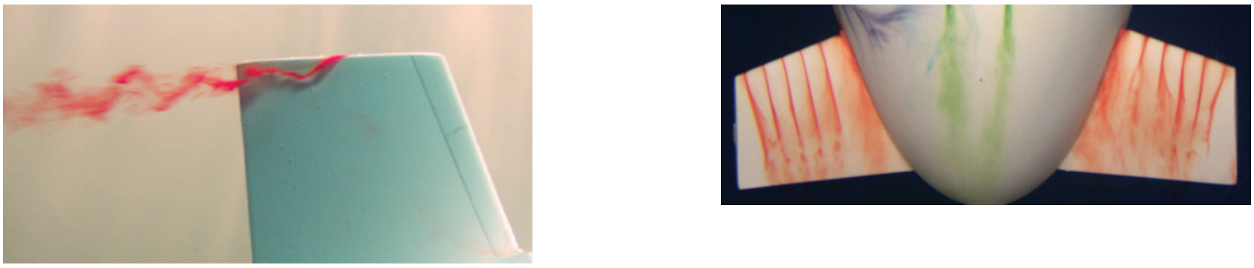
Flow visualisation studies of the turbine's wake structure under different tip speed ratios and yaw angles were conducted using dye injection, Figure 2. The initial results allowed the qualitative assessment of the effect of the wind turbine tower on the wake. It can be seen that the tower has a considerable effect on the wake structure, and could be responsible for power losses up to x% due to vortex shedding from the tower and its interaction with the unsteady wake (results to come in June).



(Here 2 photos from previous studies are shown as an example – actual results will be shown here for the extended abstract and poster – expected in June)

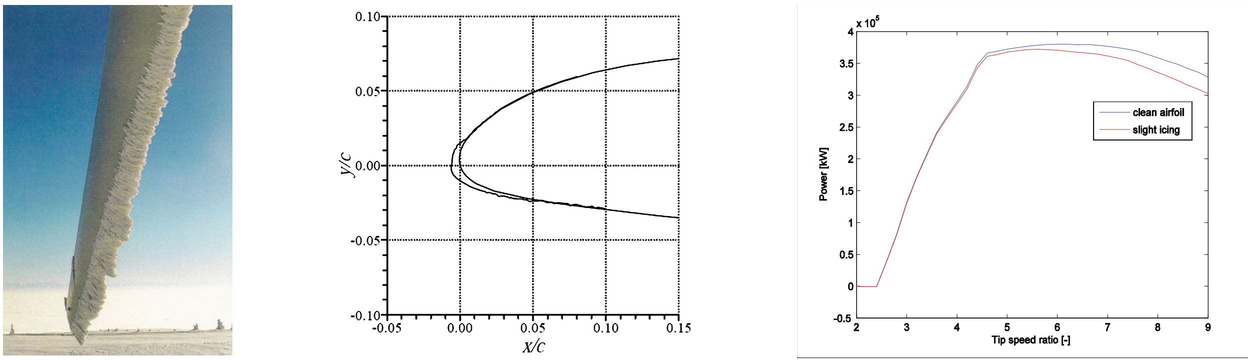
Figure 2: Dye injection flow visualisation examples.

The Effects of Icing on Output Power

The second part of the study involved the numerical estimation of wind turbine power loss caused by ice accretion on the blades in typical Alpine climates. This was done by combining drag and lift coefficients of various iced airfoils using the publicly available 2D computational code XFoil with a BEM momentum method code developed at Imperial College, London, to obtain the power coefficient at a range of tip speed ratios.

Blade ice accretion is recognised as a significant hindrance to efficient wind turbine operation in cold environments, due to aerodynamic losses, load increase and ice throw. However, the effects are not well understood, and further research could lead to developments in wind turbine design, certification and choice of siting.

The results, Figure 3, show that the effect of a even small amount of icing on the power output of a typical wind turbine can be significant (up to 10%).



(a) (b) (c)

Figure 3: (a) Example of heavy icing, (b) Light icing, (c) Loss in power due to light icing.

Future Plans

Future planned work includes Particle Image Velocimetry flow visualisation in the water towing tank under a wide range of turbulent, high yaw, and accelerating flow conditions, as well as measurements of unsteady blade pressure and strain. A blade ice measurement device is under development in order to understand and quantify ice accretion under different conditions. Realistic ice shapes will then be measured and modelled for the towing tank tests in order to better correlate icing with power losses.

Life cycle assessment and external costs of future fossil power technologies including carbon capture and storage

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Introduction

Electricity generation based on fossil fuels remains crucial for covering a substantial part of the steadily increasing power demand in advanced countries as well as the dramatically increasing demand of fast developing countries. An equal installation rate from renewable sources or nuclear does not seem to be realistic in the short to medium term on a worldwide scale. Therefore, electricity production with carbon dioxide capture and storage (CCS) represents a very important option against the increase of atmospheric CO2 concentration and to mitigate the climate change, while at the same time allowing for the continued use of fossil fuels.

Within the NEEDS project (New Energy Externalities Development for Sustainability) of the European Commission (2004–2008) [1], aiming at improving and integrating external cost assessment, Life Cycle Assessment (LCA), and energy-economy modeling as well as applying multi-criteria decision analysis for a technology roadmap up to year 2050, LCA of power generation systems suitable for Europe were performed. This paper presents environmental life cycle inventories and cumulative LCA results as well as external costs of electricity production for selected representative evolutionary hard coal, lignite, and natural gas power technologies with focus on long term (2025-2050) technology development.

Methodology

The environmental assessment covers complete energy chains from fuel extraction through, when applicable, the ultimate sequestration of CO2, using ecoinvent as background LCA database [2]. The power units, namely Ultra-Supercritical Pulverized Combustion (PC) and Integrated Gasification Combined Cycle (IGCC) plants for coal as well as natural gas Combined Cycle (NGCC) technologies are modeled with and without Carbon Capture and Storage (CCS). The three main technology paths for CO2 capture are represented: pre-combustion, post-combustion, and oxyfuel combustion. Transport of CO2 by pipeline over several distances and storage of CO2 in geological formations at different depths like saline aquifers and depleted gas reservoirs, which are the most likely solutions to be implemented in Europe, are modeled based on assumed average European conditions [3-9]. Three different scenarios for technology development, from pessimistic to very optimistic, are included in the modeling, covering the range of possible technical progress till 2050.

Results

The LCA results show that adding CCS to fossil power plants, although resulting in a large net decrease of CO_2 emissions per unit of electricity, is likely to produce substantially more greenhouse gas (GHG) emissions than claimed by near-zero emission power plant promoters when the entire energy chain is accounted for, especially for post-combustion capture technologies and hard coal as a fuel (Figure 1). Besides, the lower net power plant efficiencies due to high energy demand for CO_2 separation and compression at the power plant lead to higher consumption rates of non-renewable fossil fuels. Furthermore, consideration of the full spectrum of environmental burdens besides GHG emissions by application of selected Life Cycle Impact Assessment (LCIA) methods results in a less definite picture of the energy chain with CCS than obtained by just focusing on GHG reduction. Evaluating the environmental performance of power generation with CCS by calculation of external costs per unit of electricity shows a benefit of CCS, relatively sensitive to the monetized damage factor of GHG emissions.

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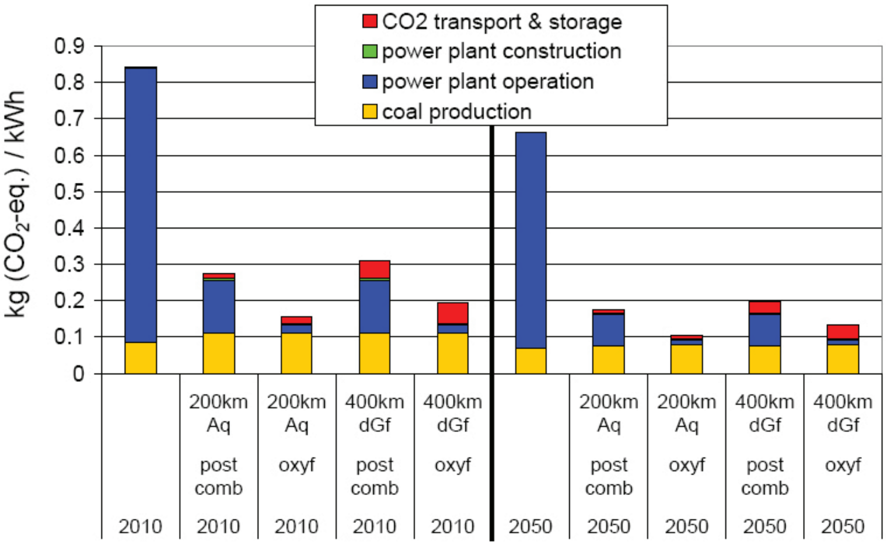

Figure 1: Greenhouse gas emissions per kWh produced at PC power plants (hard coal) for two time frames; CO2 separation by post or oxyfuel combustion; CO2 transport by pipeline over 200 km or 400 km; CO2 storage at depths of 800 m (Aquifer – Aq) or 2500 m (depleted Gasfield – dGf).

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IT virtualization as ecological efficient alternative

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The virtualization of server and storage systems allows the number of physically available components in a data center to be massively reduced, and thereby to significantly lower the energy required by, and the necessary cooling of, today's it installations.

Typical savings in energy and cooling requirements of over 80 percent can be achieved. A rapid implementation of virtualization technology allows not only for a reduced burden on the environment, but also for a better utilization of existing systems as well as significantly more flexible IT infrastructure. This can then be very easily adapted to changing requirements via a central control console. A systematically optimized and standardized implementation results in a more easily maintainable environment, which leads to sustainable lower operational cost in addition to lower energy consumption.

There are already highly optimized virtualization technologies on the market. For example, mainframes that operate hundreds of logical systems with just a few processors, as well as POWER systems that make hundreds of UNIX systems superfluous, or highly scalable x86 machines which replace dozens of conventional x86 systems. These technologies allow a modern data center to be shrinked to just a few single machines.

The impact in energy efficiency is excellent. Implemented projects achieved energy usage reductions of 80% or even higher, compared to legacy solutions built with conventional IT system architectures.

This poster presentation will focus on implemented projects, the technology behind and what can be achieved with highly virtualized and efficient data center infrastructures.

Drivers for power/cooling focus in a data center

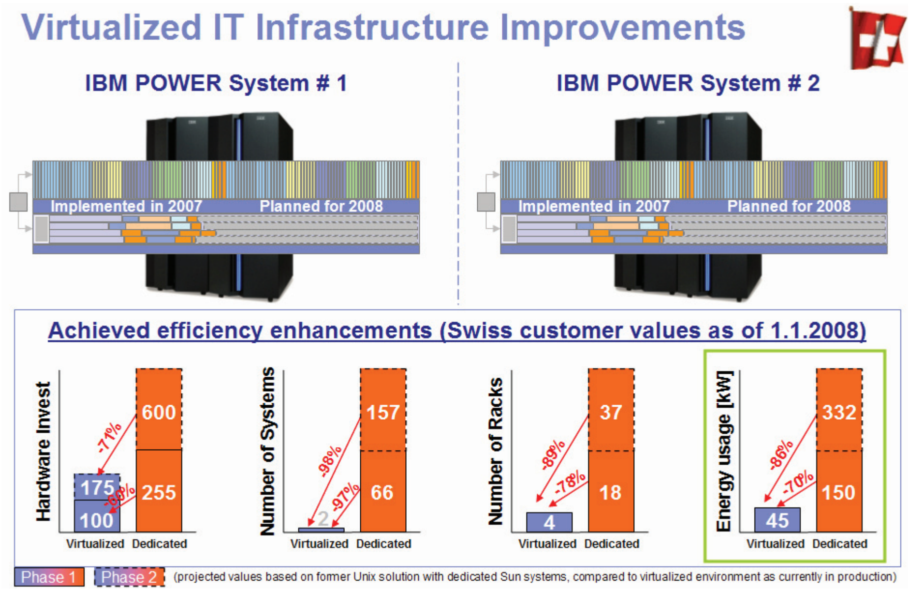
There are several strategic drivers motivating companies to control power and cooling in the data center.

- Additional performance in existing data centers required in today's scale-out server environment.
- Enterprises are realizing significant financial savings by managing power and cooling costs in the data center.
- Cooling capacity thresholds prohibit companies to deploy new servers without costly retro-fitting or new expansion.

Example of projects implemented

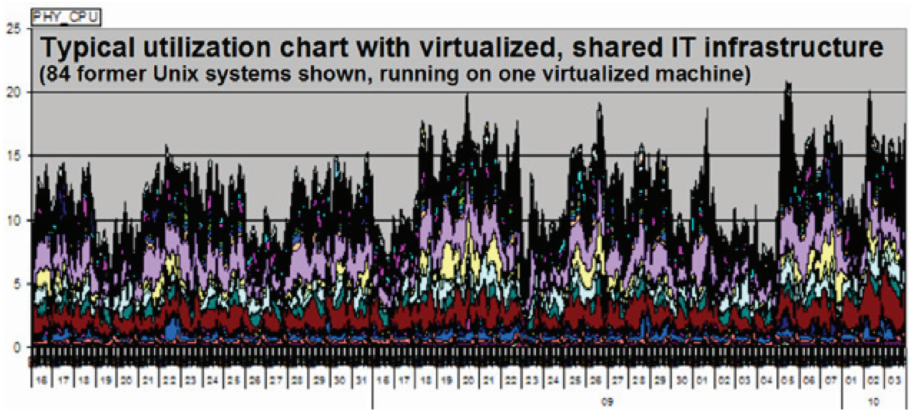
Like other countries, Switzerland with it's approximately 4'000 data centers, home of numerous large corporate headquarters and requirements for large IT infrastructures, will face a slowdown in IT growth due to power and cooling limitations. Several companies have started to deploy highly virtualized IT infrastructures to avoid this slowdown in IT. Accelerated implementation of efficient virtualization technologies has the potential to even reduce the currently required level in energy and its carbon footprint.

As an example, a Swiss midsized company realized a reduction in increased energy demand for power and cooling of more than 86%, or 3.5GWh per year. This has been achieved by the implementation of a complete virtualized IT infrastructure. A reduction of 3.5GWh a year of energy usage is equal to the reduction of the carbon footprint produced by approx. 780 midsized cars (at 150g CO_2/km, each car 15'000km traveled per year, 500g CO_2/kWh for energy generation).



IBM's Approach to solving power/cooling issues

IBM is innovating the IT industry with energy-smart solutions for over forty years, from improving server cooling efficiency to the development of the first petaflop super computer that delivers the most performance per kilowatt of energy consumed, currently at a rate of more than 430Mflops per watt (source: http://www.green500.org).



We don't believe there's a one size fits all solution. IBM's holistic approach in solving customers' data center cooling challenges provides solutions that can beat the heat at the system, rack and data center level and at the same time save in overall energy consumption through the CoolBlue initiative.

Solid-State Transformer Based on SiC JFETs for Future Energy Distribution Systems

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Introduction

In order to reduce the emission of greenhouse gas and replace the limited energy sources like coal, oil or uranium, the number of renewable energy sources is constantly growing. This development results in a rising number of distributed power plants, which are principally subject to substantial energy fluctuations. In order to easily connect the new energy sources to the grid and improve the power quality by harmonic filtering, voltage sag correction and highly dynamic control of the power flow new power electronic systems – so called Intelligent Universal / Solid-State Transformers (SST) – are required. These interconnecting devices would enable full control of magnitude and direction of real and reactive power flow and could replace not controllable, voluminous and heavy line frequency transformers. Based on such devices a smart grid comparable to the internet, where a plug and playconnection of sources and loads, distributed energy uploads and downloads and energy routing for transferring energy from the producer to the consumer, is possible.

In the top of Fig.1 a conventional interconnecting system based on a back-to-back (BTB) converter and slow IGBT devices is shown. This system consists of ac-dc/dc-ac converters and two line-frequency transformers, which provide galvanic isolation as well as voltage level conversion and which have a large volume and weight. In order to decrease the volume/weight of the system and reduce the raw material consumption new topologies [1]–[3], which replace the line frequency transformers by high frequency and high voltage transformers, have been proposed. These proposals are also based on IGBT devices, which significantly limit the feasible switching frequencies and the voltage level of the converter systems. In order to overcome these limits, new converter systems (cf. A, B & C in Fig.1) based on high voltage SiC JFETs cascades, which enable a much higher power density and a significantly higher system dynamic are presented in SectionII of this paper. Furthermore, these systems require a lower number of converter stages, what results in lower system costs and a higher reliability.

In SectionIII a 5kV/50kHz bi-directional, isolated dc-dc converter, which is a key element of the solid-state transformers, is discussed in detail. There the switching behaviour of the SiC switches, the design of the transformer and the achievable performance of the dc-dc converter are presented. Finally, the system parameters of a 1MW solid-state transformer based on the SiC dc-dc converter are calculated and the performance of the different topologies with respect to power density, efficiency and realisation effort is compared in SectionIV.

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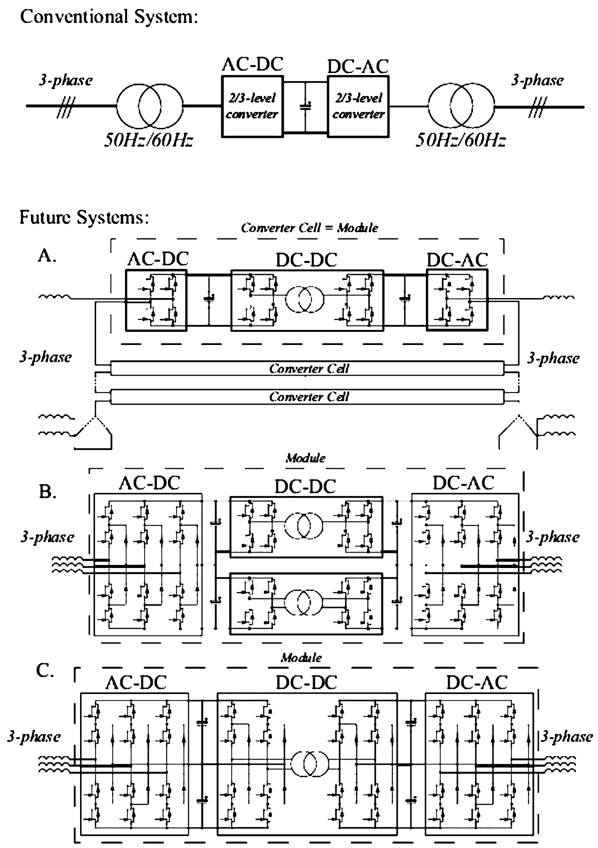

Figure 1: Conventional system with the bulky line frequency transformer; Future solid-state transformers: A. single-phase modular converter cells, B. 3-level converter/inverter and 2-level dc-dc converter, C. 3-level topology system design.

Topologies for Solid-State Transformers

In Fig.1 three different topologies for realising a solid state transformer by applying a high-frequency (HF) and high voltage (HV) single phase transformer are shown. All of the concepts consist of a rectifier/inverter stage and a HF/HV dc-dc converter. Due to the high operating frequency the volume and the weight of the isolating transformer becomes very small in comparison to line frequency based concepts. In order to limit the switching losses at the high frequencies switches based on SiC JFETs, which switch several kilovolts in less than 100ns, are applied. With these devices operating frequencies of several tens of kilohertz are possible. A blocking voltage in the range of several kilovolts is achieved by a series connection of JFETs (Super Cascode). There, the voltage balancing between the single devices is crucial and could be achieved by connecting small resistors/capacitors between the gate and 3-phase 3-phase source of the single JFETs as will be explained in more detail in section III.

Based on the Super Cascode in topology A a 2-level single phase inverter/rectifier stage and a 2-level dc-dc converter are combined in a converter cell. In order to reduce the required blocking voltage of the semiconductors several cells are connected in series. Furthermore, the three converter branches are star connected. With this concept SSTs for medium voltage level (11-35kV) applications can be realised.

Based on the available switches also a direct 3-phase topology as shown in Fig.1 B and C could be used for AC voltages up to 10kV. Due to the reduced number of required switches the system costs reduce and the reliability increase. There, a 3-level boost rectifier/inverter stage is applied, which allows higher operating voltages than a 2-level concept. In topology B the DC link is split up, so that a series connection of two 2-level dc-dc converter as in topology A is possible. There, the balancing of the two dc voltages is possible with the proper control of the AC-DC stage. In topology C 3-level branches are also utilised in the dc-dc converter so that a single dc-dc converter cell is sufficient.

In the final paper a detailed comparison of the topologies and concepts based on 3-phase transformers, which allow a further volume reduction, as well as the achievable system performance with a 30kV SiC switch are presented.

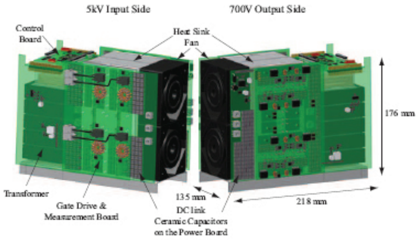

Figure 2: 3D-Model of the proposed dc-dc converter.

5 Kv/50 Khz Bi-Directional Dc-Dc Converter

A key element of all topologies is the HF/HV dc-dc converter, which enables a significant volume reduction of SSTs compared to line frequency concepts. Therefore, the design and the performance of a 25kW converter operating at a DC link voltage of 5kV and an operating frequency of 50kHz is discussed in detail in the following. In Fig. 2 a 3D model of the system is depicted, which has a power density of 4.8kW/ltr. and an efficiency of 97%. There, a SiC SuperCascode with a blocking voltage of 7.5kV and a transformer based on ferrite, which are explained in the following, are applied.

A SiC Super Cascode

The SiC Super Cascode consist of a low-voltage Si MOSFET, a SiC JFET cascade, whereas the number of series connected devices depends on the blocking voltage, and the gate diodes for voltage balancing and turning the upper JFETs on and off. The basic operating principle of the SiC Super Cascode is described in [4] and the concept for voltage balancing is derived in [5]. In Fig.4 the measured switching waveforms for an operating voltage of 5kV and 5 cascaded 1500V JFETs are depicted, which show that the rise and fall times are below 100ns. This fast switching transition in combination with the ZVS switching condition drastically reduces the switching losses. In the final paper simulation results for a 30kV switch based on 6.5kV JFETs will be presented, which significantly extends the useable power and voltage range of this concept.

B 50 kHz-5 kV Transformer

Besides stable and fast operation of the SiC SuperCascode, the design of the integrated HF/HV transformer (cf. Fig.4 is very important for the SST. Due to the high operating frequencies the HF losses in the windings must be limited by a careful design, so that the efficiency of the transformer is high and its volume low. Furthermore, the very step voltage transitions, which are required for the reduction of the switching losses, result in a non uniform voltage distribution within the winding during and shortly after the rising/falling edges.

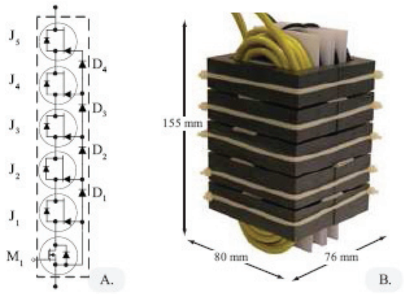

Figure 3: A.: SiC JFET/Si MOSFET Cascade – Super Cascode. B.: 5 kV/50 kHz transformer.

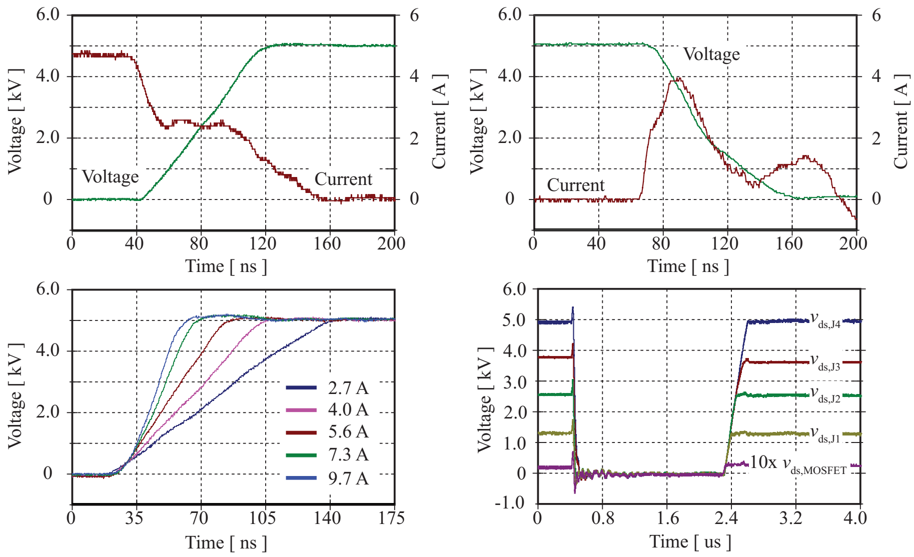

Figure 4: SiC Super Cascode characteristics: Turn on and turn off behaviour (at different current), voltage distribution.

In the final paper the detailed design of the transformer and the calculated transient voltage distribution are presented.

1mw Smart Btb System (Modular Built)

For comparing the different topologies and relating it to the existing line frequency concepts a detailed performance analysis of the proposed BTB conversion systems with SiC SuperCascodes and the performance of a 1MW system will be presented in the final paper (TableI estimated).

Topology	A.	B.	C.
Switching Frequency	50 kHz		
Number of Modules	40	20	20
Volume/Module [dm^3]	6.3	13.5	13.6
Number of SiC Super Cascodes/Module	16	40	40
Total Switch Losses [kW]	27	34	34
Transformer Losses [kW]	2.4	2.4	2.4
Efficiency [%]	97	96	96

Table I: Performance of a 1MW system based on the measurement and design results of the bi-directional dc-dc converter.

Conclusion

In this paper three new topologies for solid-state transformers (SST) based on SiC Super Cascodes are presented and compared. Furthermore, a detailed analysis of the design and the performance of a 5kV/50kHz dc-dc converter with a power density of 4.8kW/ltr., which is a core element of the SSTs, is presented. There, also the operating principle of the Super Cascode and voltage balancing methods as well as the detailed design of the high voltage transformer are explained. Based on these results the parameters of a 1MW SST, which shows an efficiency of approximately 97% and a volume of 0.27m3, are derived and discussed.

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Reducing the Environmental Burdens of an Energy-Intensive Industry: Co-Processing of Alternative Fuels and Raw Materials in Cement Production

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Introduction

Cement production is very energy and raw material intensive. Globally, 5% of anthropogenic CO_2 emissions originate from cement production. About 60% of the CO_2 is released from the calcination of the raw material, while 40% are fuel related. The co-processing of alternative fuels and raw materials (AFR) – the substitution of traditional resources by waste materials – offers a large potential to reduce the environmental impact. Traditional fuels such as coal or heavy oil may be substituted by a variety of wastes, either of biogenic origin (e.g. municipal sewage sludge, waste biomass), or of fossil origin (e.g. used plastics, waste oil, solvents, tires). Traditional raw materials like limestone, marl and clay may be substituted among others by ashes, slags and industrial waste sands.

To evaluate the environmental effects of AFR co-processing, the life cycle assessment (LCA) based decision-support tool *'LCA4AFR'* has been developed. The tool is intended for the cement industry and for authorities. It shall improve the understanding of the environmental impacts of co-processing and may support the permitting process for waste utilization in the cement industry.

Effects of AFR co-processing on the environment

Co-processing of alternative fuels and raw materials provides three main environmental benefits:

Firstly, the substitution of primary fuels and raw materials by wastes conserves non-renewable resources. Secondly, co-processing of waste may reduce emissions. In case of fuel substitution by biogenic wastes, the emission of greenhouse gases is reduced. CO2 emissions from calcination can be reduced if the co-processed wastes contain already calcined minerals (e.g. slags and ashes). Thirdly, co-processing offers a viable option for waste treatment with efficient heat and material recovery without producing residues.

Environmental burdens from waste co-processing may stem from additional requirements to prepare the wastes before feeding them into the kiln. In addition, wastes with a high content of heavy metals may lead to increased air emissions of volatile heavy metals (e.g. mercury) and the accumulation of low volatile heavy metals in the cement.

For a comprehensive evaluation of the environmental impacts all benefits need to be compared against the burdens, including the influence on the grey energy balance and material demand (e.g. for the production and transport of fuels, raw materials and operating materials).

Applied methodology and system modeling

Life cycle assessment (LCA) offers a framework to comprehensively assess the environmental impacts of AFR co-processing. LCA not only considers direct environmental effects of the cement production process but also includes the upstream production chain from the mining of the resources to the material transport to the cement plant. A variety of life cycle impact assessment (LCIA) methods allows either focusing on specific impact categories such as global warming, acidification, and human toxicity, or to produce summarized damage scores by aggregating different damage categories to a single score value.

The core of the cement production tool constitutes a substance flow model, which was set up in close collaboration with a project partner from the cement industry. The upstream data for resource production and transports were taken from an LCA database.

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The LCA4AFR-Tool

Flexibility and user-friendliness as important criteria have guided the tool development. Various cement kiln types, operating modes, and secondary flue gas treatment installations have been modeled. The modular structure of the tool allows carrying out assessments for a large variety of existing cement plants.

The substance flow model that constitutes the basis of the life cycle assessment contains default values for the efficiency of the plant components as well as for the chemical composition, pre-processing, and transport of all resources. If the default values do not correspond to case-specific data, the user may apply own input data.

Emphasis was put on designing the tool for experts in the cement and waste sector, most of whom have only little knowledge of the life cycle assessment methodology. Hence, while the process parameters must be precisely specified and checked, the LCA part has been simplified to selecting the assessment method of choice.

Discussion

The tool is currently being validated by comparing case studies' results to measured emissions. First results show that the environmental benefit of AFR co-processing are the reduction of greenhouse gas emissions, while the effects on harmful emissions for the ecosystem and human health may be either positive or negative, depending on the kiln type and operating modes, and on the level of contamination of the input wastes.

In order to assess whether a specific waste can be utilized more efficiently in other industries than in cement production, the flexible modeling of waste treatment industries/technologies (including landfills, municipal solid waste- and hazardous waste incinerators, co-firing in power plants, and material recycling) will be carried out in the subsequent steps of the project.

Assessment of Indias Efforts on Education, Awareness and Capacity Building on Climate Change

Nitin Chaudhary
India

Climate change is recognized today's greatest environment challenge. It threatens to have major adverse impact on natural world as well as on human society. Recent events have emphatically demonstrated our growing vulnerability towards unpredictable climate. The only way to prevent the adverse impacts is to reduce and stabilize total world green house gas emissions. It means big cuts right away. Education, awareness generation and capacity building are among the proposed strategies to mitigate climate change predicted ill-effects. To achieve this objective, general public needs to be sensitized especially the future generation and government imparts adequate information on the issue so that they adjust their behavior in ways that limit emissions. With this as an objective, the UNFCCC under its Article-6 have identified the importance of communicating this environment concern to the community.

It is evident that communication and awareness programs have a proven record in bringing about behaviour change in health and environmental practices. Successful awareness programs in the field of nutrition, AIDS, ozone-depleting CFCs and conservation is a paradigm. A well-conceived communications programme for addressing climate change issue can similarly be successful if government takes proactive and sensible steps. Realizing this as a significant move, many countries have already started working actively to strengthen their national Article-6 programme taking into consideration their common but differentiated responsibilities and other specific national and regional development priorities. The countries are Kenya, Georgia, Albania, Cambodia, Namibia, Russia, Uzbekistan, and India etc.

The study identified the Indian initiatives undertaken on climate change through education, awareness generation and capacity building and the impact of these activities on general public and students. It also examined how well India is following its commitment. Keeping in view the high prevalence of stakeholders and work done on the subject in the country, the State of Delhi was selected. 120 Students and 95 general public respondents were selected as two broad target groups to examine the effectiveness of awareness generation mechanisms. The study examined the impacts of the education initiative on students and outreach programs by government and other institutions aimed at raising awareness about climate change on general public.

Result and discussion

As of know India has already taken some remarkable steps in the field of climate change awareness. As per its commitment to UNFCCC, India has initiated a project titled as 'Enabling Activities for the Preparation of India's Initial National Communication to the UNFCCC' or the NATCOM project through MoEF in 2001. The project aims at developing the National Communication on climate change involving research institutions, technical institutions, universities, government departments and NGOs. To facilitate the process, under the aegis of the project, several seminars, workshops and outreach programs have been conducted all over India for planning the work, developing linkages and developmental and economic processes pertaining to different components of the National Communication. The process has initiated to identify areas of future research, to strengthen the India's Initial National Communication experience, gaps and future needs have been identified for the development and strengthening of activities for creating public awareness, ensuring meaningful inputs into education, and enabling access to information. A website (www.natcomindia.org) has been developed for dissemination of information and publications arising out of the project.

Many non-governmental organizations (NGOs) namely WWF-India, Winrock International India, TERI etc are also working actively to sensitize public about the climate change issue and have targeted students, teachers, youths and women. It is found that very few NGOs and organizations have targeted farmers and rural folk. The message could spread extensively if NGOs would target a wide cross-section of the population because India's 70% of the population live in rural areas. According to the NGOs most common problems identified are:

- Funds from national and international are inadequate
- Follow-up in developmental programs is feasible but difficult in the case of awareness programs.
- Motivating people to participate in program is difficult task and very few turned up again to attend the workshops after participating once.

Findings of the survey

Before conducting the survey on student awareness level, content of textbooks were assessed to find out what topics on the subject have been covered by C.B.S.E. syllabus committee. After examining 8^{th} to 12^{th} standard books, it was noticed that Science and Social Studies textbooks comprise sufficient subject matter according to student's level of understanding as well as various other environmental issues were also covered.

When gauged the understanding about climate change and whether it's a global problem. Survey indicated that 83% students were well informed and agreed that it's a global problem and many of them were quite clear about the basic facts of climate change. On being asked about the reasons, 67% stated that it is greenhouse gases in general and CO_2 in particular, but very few of them could specify other GHGs. Approximately 8 out of 10 respondents (i.e 80%) felt that its human and his accelerating needs primarily responsible for this problem and some stated that because of escalating use of fossil fuels by developed countries. Some suggestions to tackle the problem of climate change had been given such as by planting tress; lessen use of high voltage equipments, reducing carbon dioxide emission, and use of cleaner fuel like C.N.G etc are some of the measures through which the problem could be solved. Almost 74% indicated that change in behaviour through awareness creation would be an incisive strategy to tackle the problem. Student's opinions were also sought out on modern day lifestyle and the ways to reverse this process. About 79% of students agreed that accepting environment friendly lifestyle would benefit environment as well as help in combating this problem and 72% were practicing environment friendly lifestyle by using bicycle instead of motor vehicles when going to nearby places, switching off the lights and fans when leaving the room and not in use, using public transport and planting trees etc. are among others.

In total 95 respondents were surveyed, to assess the awareness level of general public on climate change through personal interviews. Based on previous studies on this subject, the questionnaire was designed. Only 47% respondents were well informed and this not reflects good sign for future. Those who were aware also agreed this problem would accelerate if present emission rate of greenhouse gases is not checked specifically of carbon dioxide. Only 43% respondents could specify which GHG is much harmful (CO_2) and very few specify other GHGs. 29% revealed that human being and its escalating use of fossil fuels is responsible for this global problem. Approximately 3 out of 10 were in favour of changing lifestyle. As far as the source of information is concerned, 54% respondents indicated by Television, 11.2% mentioned radio while 22.5% said newspaper. However, few numbers of respondent indicated some other sources also such as exhibitions, seminars.

The survey result showed that students are well informed about the issue; however more effort needs to be done to raise the general public awareness. This majority is mainly composed of adults who have little or no formal education, especially in the area of science. Here media has to play significant role and government should also encourage them in creating documentary, publishing articles, stories and organizing events on climate change so that message would spread across the society. The issue of climate change has only recently been a topic within the high school science curriculum, and therefore the younger generation is more aware of the associated issues.

Unfortunately, most people not readily see the effects of climate change in their day to day activities so they do not care much about it. The press and other mass media are playing a vital role to inform the public about climate change problems. Television and radio are by far also seen as being the most influential source for this information. India as a party to UNFCCC has taken some initiatives to achieve the objectives of Article-6 but still there is long way to go. It would be in the nation's best interest to carry forward and strengthen the campaign and educate its population about the effects that climate change would have on the society.

Recommendations

The recommendations given are very specific and relate to the findings observed during the period of the study:

- Information dissemination: Information should be available in a simple and consumable manner to generate action-oriented results.
- Participatory effort: Bring out books and literature documenting best participatory practices, involving local community and government, which would provide linkages to their day to day life, their life style and how traditional knowledge of the common people can be integrated to some simple responses to climate change.
- Easy and Effective Communication: Such books and literature must be written in the language and that is localized with familiar illustrations, making it easy to understand.
- Media's Role: Media is playing a significant role in awareness creation. Through vernacular media message could reach to wider population as around 70% of India's population reside in rural areas. It is also recommended that there is the need of collective action through synchronization of all current and future programs run by civil society or any other department with media.

Experimental determination of the radiative properties of a ZnO packed bed applied in a solar water-splitting thermochemical cycle

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The radiative characteristics of packed beds of ZnO particles, applied in the design of high-temperature solar thermo-chemical reactors, were investigated experimentally. ZnO samples of varying thickness were exposed to a continuous beam of near mono-chromatic thermal radiation in the 0.5–1 μm wavelength range. The overall transmitted fraction measured as a function of sample thickness s obeys an exponential trend exp(–As), with the fit parameter A ranging from (4000 ± 100) m-1 at 555 nm to (2100 ± 100) m-1 at 1 μm. In the forward directions, the measured intensity distri-bution is approximately isotropic, whereas in the backward directions it is well approximated by a Henyey–Greenstein equation with asymmetry factor g ≈ – 0.4 at 555 nm and g ≈ – 0.1 at 1 μm. A Monte Carlo ray-tracing model of the experimental set-up is employed to extract the extinction coefficient and the scattering albedo for the case of non-grey absorbing-scattering medium.

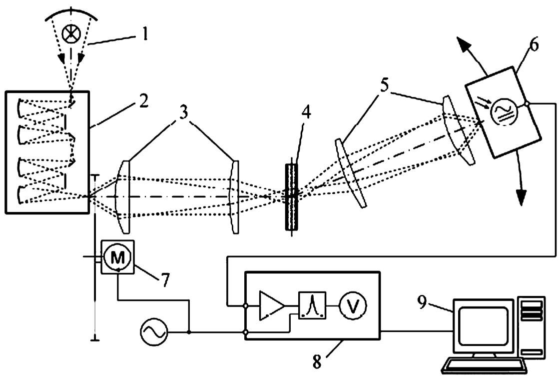

Figure 1: Experimental set-up #1 (with a rotary detector): (#1) dual Xe-Arc/Cesiwid-Glowbar lamp, (#2) double mono-chromator, (#3 and #5) imaging lens pairs, (#4) sample, (#6) rotary detector, (#7) optical chopper, (#8) lock-in amplifier, (#9) data acquisition system.

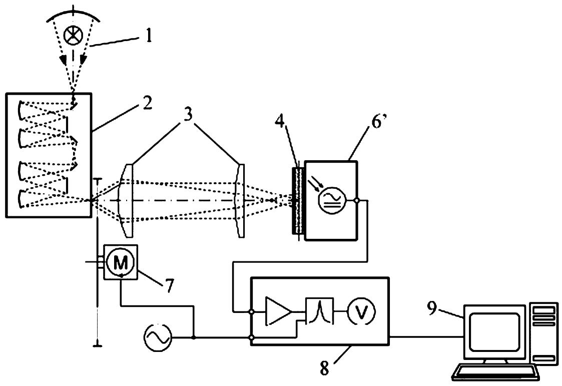

Figure 2: Experimental set-up #2 (with a fixed detector): (#1–4, 7–9) as in Figure 1, (#6') fixed detector.

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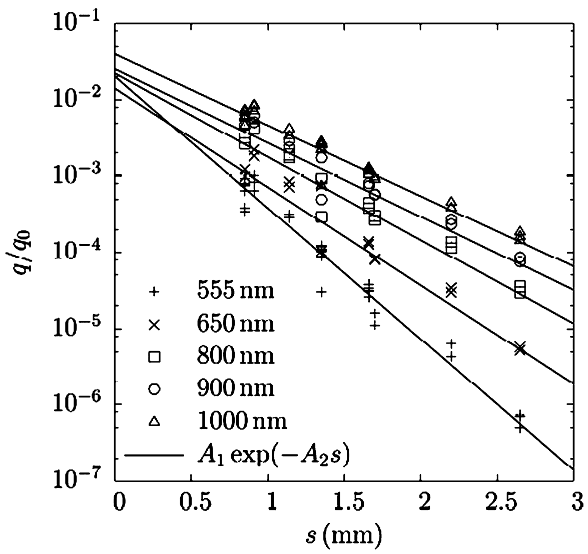

Figure 3: Normalized signal vs. packed bed thickness obtained with set-up #2.

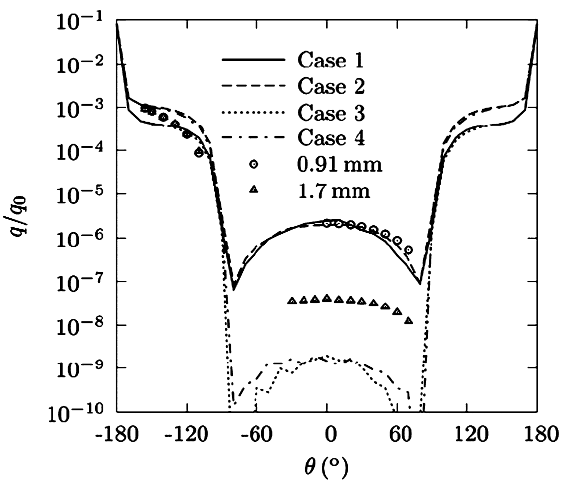

Figure 4: Measurement vs. simulation using a typical Mie based scattering phase function. The graph shows the normalized detector signal plotted against the measurement angle. The measured data is at 555 nm.

Smart individual road transport depends on smart consumers accepting smart cars

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In most European countries, CO_2 emissions from motorized individual transport continue to increase rather than decrease. Therefore policy tools to influence consumer behavior move into the focus of both policy makers and academic research. Reducing average CO_2 emissions of new car registrations is essential to lowering energy consumption for passenger transport in general. Influencing new car purchases is very effective, as each car is sold on the second-hand market several times, and will be on the roads for 11 or more years and perform over 160’000 km.

The EU strategy to lower CO_2 emissions from passenger cars consists of three pillars, the first being voluntary agreements between car manufacturers (ACEA, JAMA, KAMA) and the EU commission with the goal to bring average emissions down to 140 g CO_2/km in 2008/2009. The second pillar is consumer information, consisting of an energy label for each new car on display at the point of sale (on voluntary basis, many European countries have added energy classes “A” to “G” to the label). Since these two elements have shown not to be sufficient in bringing CO_2 emissions down, in the years to come the third pillar will gain momentum: fiscal measures based on the energy label in order to influence car purchase behavior.

As suitable fiscal measure, feebate schemes (a composition of fee and rebate; another term being carrotand-stick) systems are currently being discussed as method-of-choice to influence car purchase behavior. For example, cars having “A” or “B” ratings are eligible for a car tax rebate, whereas those labeled as “E”, “F” or “G” pay higher taxes, such that the scheme as a whole is revenue-neutral. Feebate systems are currently in effect in the Netherlands, Belgium and the United Kingdom. They are under investigation in several other countries. Two different schools can be distinguished: We denote energy-efficiency as “absolute” if relating directly to the amount of energy or CO_2 needed per distance, as “relative” if this amount is divided by any such thing as car length, floor space, number of seats, or curb weight.

Basing tax rebate eligibility on absolute energy-efficiency seems logic at first sight, as energy and/or CO_2 reduction is the final policy target. However, consumers traditionally purchasing larger cars might feel as not being addressed by such a policy. Compared to small car buyers, purchasers of large cars would have to change their behavior more to become eligible for a rebate. Using relative energy-efficiency as policy base (while still pursuing the underlying policy target of CO_2 reductions) would overcome this problem, but could open the door to another: Could such tax rebates motivate people to shift to cars that are larger in size (having higher relative efficiency but lower absolute efficiency)?

We present some highlights from our results from a population-representative Swiss mail-back survey. People where asked about their car choice behavior and likely reaction to hypothetical rebates. Our results confirm that indeed part of the population is likely to change to cars with higher relative but lower absolute efficiency, driven by rebate eligibility. In addition, some people state that a tax rebate would in fact increase their total car purchase budget, which is likely to affect fuel consumption as well. We conclude that such counteracting side-effects cannot be avoided completely. In order to limit and contain its impact on the efficiency of feebate policies, it is important to carefully design the definition of energy-efficiency.

We also present some highlighted results from a multi-agent simulation car market model, where 40 different agent types are distinguished and separate sales statistics for over 3000 different car models are generated. The model includes many elements of so-called bounded rationality: limited (but variable) choice set size, fuel type, gearbox and brand retention rates. Also built-in are elements of psychological effects (mental accounting, marginal utility, reference point effects, etc.) We show which feebate design results in higher efficiency.

While the effect of policy schemes to influence vehicle purchase behavior generally seems to be low (often between 1% and 3% of the average CO_2 emission level of a cohort of new vehicles), such schemes are very cost-efficient all the same: each car will run for 10 to 13 years and run for over 160’000 kilometers, without any continuing efforts by the government being necessary to maintain this level of saving. This often puts such policy schemes, regarding avoidance costs per ton of CO_2, at the same level as insulating residential dwellings, heating system retrofits, etc.

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Thermally driven residential heat pumps based on integrated organic Rankine cycles (ORC)

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The poster presents a study of a residential (about 20kW) ORC-ORC thermally driven heat pump. An ORC-ORC system is composed of an ORC engine cycle and a reversed Rankine heat pump cycle (Figure 1). The condenser (and the subcooler if introduced) is common to both cycles. The power from the ORC turbine is used to drive the compressor of the heat pump cycle. This system works between three main temperature levels and is therefore similar to an absorption heat pump. The proposed concept is a hermetic system using the same working fluid in both ORC's with a radial compressor and turbine on a single high-speed shaft (Figure 2). The use of gas bearings enables the system to be oil-free. This gives the system the advantage of low maintenance costs.

Using the same working fluid in both cycles does not come without difficulty due to the large difference between the high and low temperature levels. Regarding the design of dynamic compressors and turbines a low density fluid is preferred. Moreover the working fluid has to be chemically stable at relatively high temperatures. Refrigerant HFC-134a which can be used at least up to 180°C has been selected at this stage.

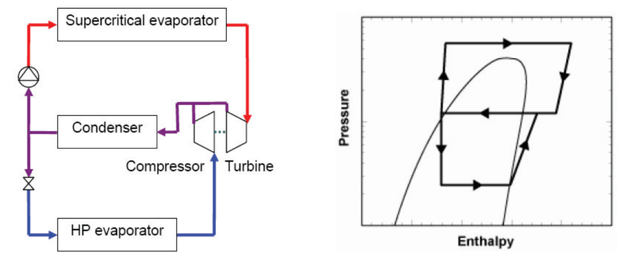

Figure 1: Schematic flowsheet and Log P –h diagram of a simple ORC-ORC heat pump unit.

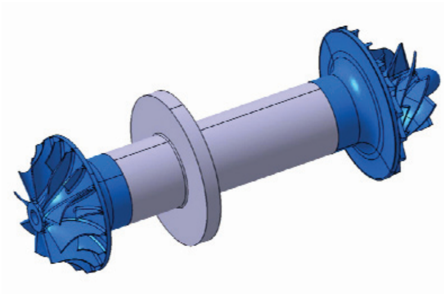

Figure 2: High speed compressor-expander unit.

An ORC-ORC simulation model is developed to study the performances as well as the compressor and turbine design. At first, pressure drops in the heat exchangers and pipes, and heat losses are neglected. The expansion in the valve is considered to be isenthalpic. The pump isentropic efficiency is considered to be constant and equal to 0.5. The losses related to the compressor-turbine shaft are modeled. Turbine and compressor efficiency are estimated using a polynomial function of the specific speed.

Two heat sources are defined. The first one is the combustion gases resulting from a stoichiometric combustion of methane that cools down to a temperature as low as possible (for example to 4°C in winter time of our calculations). Heat delivered by the condensation of the water from the combustion gases is also considered. The second heat source is the glycol water from a geothermal probe (that cools down from 4°C to 0°C in our calculations). The heat demands include domestic hot water and water for heating. Domestic water is assumed to be heated from 10°C to 60°C and the floor heating water is heated from 30°C to 35°C.

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The streams of the heat sources, heat demands and ORC-ORC are thermally integrated using an in-house energy integration computer tool. The streams of the whole system are shown in Figure 3.

An in-house multiobjective optimization tool, MOO, which is based on a genetic algorithm, is used to generate optimal solutions. The pareto curve resulting from a two-objective optimization with the COP maximization as first objective and the compressor-turbine rotational speed minimization as second objective is shown on Figure 4. The flow diagram of an optimally integrated system is given in Figure 5.

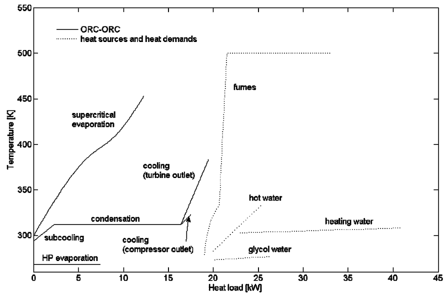

Figure 3: Streams of the system

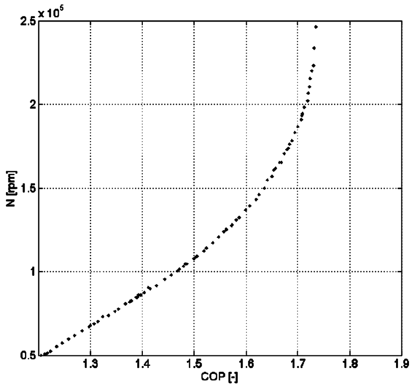

Figure 4: Pareto curve of the optimization with the COP and rotational speed as objectives

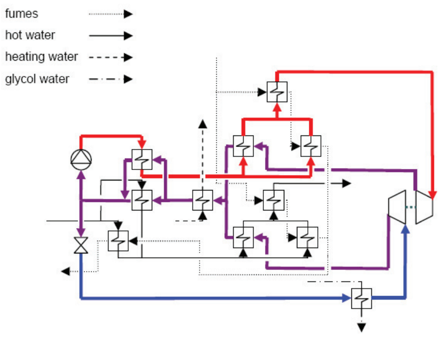

Figure 5: Flow diagram of an optimally integrated system

Depending on the application, the temperature difference in the heat exchanger at the heat source might be substantial which results in large exergy losses. Nevertheless preliminary calculations show that COP's higher than 1.6 could be expected which would be competitive with absorption heat pump alternatives. It appears also that efficient high speed compressor-turbine units for those applications are feasible.

A test facility for an ORC-ORC system of about 20kW with a 1-stage compressor and turbine is being developed at our laboratory.

Utilization of crude natural gases from local small fields as a method of lowering emission of carbon dioxide

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In Central Europe there are small fields of natural gases (only those in Poland estimated at more than 120 billon Nm^3). Located in different geological layers, they are typically of very variable compositions containing from 38% to 85% of hydrocarbons, mostly methane, and with nitrogen as the inert element. The table presents typical molar fractions of gases and their properties. Contrary to Norwegian fields containing CO_2, whose removal is relatively simple through absorption in glycols, our local gases are difficult to purify.

The table presents classical LHV' and LHV" – calculated as energy release of volume unit of gas and stoichiometric volume of air. This parameter is almost constant, which suggests that the calorific value of natural gases in crude molar fraction compositions is not crucial. A far more important parameter, as was demonstrated by many years of experience of the present authors in industrial utilisation of such gases, is the velocity of laminar flame propagation. The calculated methane numbers MN in the table show that an increase in molar fraction of inert gas is accompanied by an increase of the MN. So it is possible to obtain a higher efficiency of reciprocating gas engines by using a higher compression ratio.

Fields	Molar fractions [%]						LHV'	LHV"	MN
	CH_4	C_2H_6	C_3H_8	CxHy	N2	CO_2	MJ/Nm^3	MJ/Nm^3	[-]
Niemierzyce	81.2	0.6	0.0	0.5	17.1	0.4	29.6	3.29	97
Mlodasko	75.8	0.6	0.0	0.5	22.5	0.5	27.5	3.24	99
Paproc	68.5	0.9	0.0	0.2	30.0	0.2	25.2	3.25	105
Zuchlow	56.8	1.4	0.2	0.3	40.9	0.1	21.7	3.18	106
Bogdai	42.0	4.6	2.3	0.5	50.5	0.2	18.6	2.83	93
Wilkow	38.1	0.7	0.1	0.1	61.5	0.1	14.8	3.07	130
Grochowice	34.6	0.7	0.1	0.0	64.5	0.04	13.4	3.01	137

Table 1: Molar fraction of low calorific natural gases in crude composition.

Generally speaking, such gases should be purified from the inert gas and from higher hydrocarbons so as to make them conform to the pipeline standards. They should contain no less than 97% of methane, no more than 1% of higher hydrocarbons and no more than 2–3% of nitrogen. It must be noted, however, that purification of gases with over 50% of inert gas is very costly, particularly for small fields (output flow amount below 20 000 Nm3 per hour) located at long distances from one another.

Nitrogen can be removed through cryogenic technologies or through the use of membranes. The technology of separation of methane and nitrogen on membranes is still being developed and not yet fully applicable on industrial scale.

The discussed gases are typically located in small fields with capacity of production from 10 000 Nm^3/h to maximum 150 000 Nm^3/h. Sending such gases to the pipeline system requires the removal of inert gas either in a small local installation or in a more economical bigger one. Both options increase the cost of exploitation: removing inert gas by cryogenic technology consumes a minimum of 1.5 to 2.5% of primary energy. The transport of gas to a central big cryogenic installation consumes between 0.3 to 0.5% of transported gas for every 150 km.

The cryogenic method of removal of nitrogen requires compressing the gas into inlet pressure of at least 50 bar. Throughout the process liquid methane circulated in the installation must be compressed several times with the total energy consumption not exceeding 2.5% of the total energy of crude gas. Since the outlet pressure does not exceed 16 bar, before transporting the purified gas has to be compressed to at least 55 bar. The engines driving compressors consume at least 1.2% of the gas transported.

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Some local gas fields contain some amounts of oil. Due to the small volume of those fields (typically no more than 1000 tons of crude oil per day) the oil must be carried in railway tanks. In the process of filling the tanks with crude oil big amounts of vapours of hydrocarbons are released into the atmosphere, which is very harmful for the greenhouse effect. The poster presents a special installation for thermal destruction of those vapours designed by the authors.

The above limitations in the use of small gas fields can be dealt with through technologies that are presented in three additional posters listed below:

1) systems of flameless combustion of crude natural gas in highly efficient low-emission technologies used in high-temperature industrial furnaces

2) power generation through:
   a) reciprocating gas engines
   b) gas turbines

The posters show the results of ongoing investigations at our laboratory on the direct use of local natural gases without the removal of nitrogen. Our research has to answer the following questions:

1) Is combustion of naturally composed gases economically justifiable?

2) Can this be environmentally friendly in the sense that the surplus of nitrogen does not result in an increased emission of NO_x or other toxic species, e.g., unburnt hydrocarbons of the formaldehyde type?

The first poster [1] presents the results of investigation of combustion of crude natural gases in modern technology called flameless combustion or alternately highly preheated air combustion- HiTAC. The technology is focused on utilization of gases in glass bath, ceramic industry, steel production and so on. The technology of combustion investigated by the authors consisted in the separate injection of gas and air into the combustion chamber. It was found that combustion of natural gases containing unusual high amounts of N_2 is not harmful concerning the emission of NO_x for technologies where the temperature of air filled into the combustion chamber is not much higher than the ambient temperature. But technologies investigated here with efficiency exceeding 70% require preheating the air to the temperature of only 100K below that of the technological process. This means that for conventional burners the temperature of the flame would considerably exceed the threshold of drastic increase of thermal NO_x. This threshold is due to the dissociation of oxygen starting at local flame temperatures above 1900 K.

Figure 1 presents a comparison of emission of NOx for three cases of combustion:

a) classical gas burner with preheating of air (as in standard recuperators) to 400C,
b) gas burner constructed with twin gas nozzles and centrally assembled gas burner with 100% flow of air and 25% flow of gas, and c/ regenerative burner with extreme preheating of air up to 950oC . As can be seen, in a well designed burner emission of NO_x can be kept even below 50 ppm.

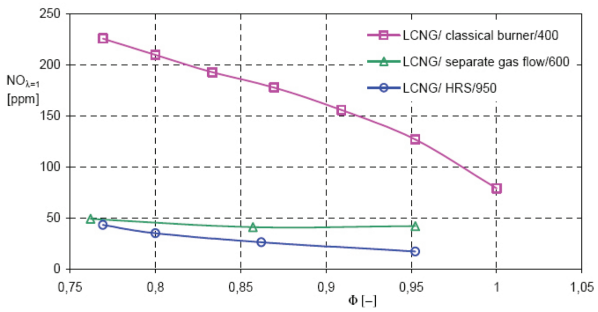

Figure 1: Comparison of emission of NO_x for different methods of combustion and different of inlet temperature of air. LCNG- low caloric natural gas = 75% of CH_4 + nitrogen

The second poster [2] presents the results of investigation of combustion of crude NG in gas engines. This method of gas utilization seems particularly suitable for small cogenerative installations located sufficiently close to the field to allow the sending of gas through the natural pressure of the field.

As was mentioned, crude NG has a very high methane number MN. This makes its burning in reciprocating engines potentially profitable as it is possible through a simple regulation of compression ratio to raise the engine efficiency by over 1.5%. Fig.2 presents the results of investigation of emission of NO_x in a gas engine of 1 MW capacity, revolution: 950 rpm and compression ratio of 1:11. The engine was supplied with gas composed of 38% CH_4 and nitrogen as the rest.

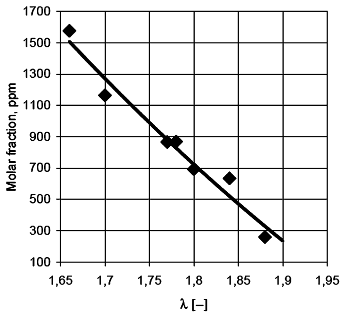

Figure 2: Emission of nitric oxides from gas engine. Capacity of engine: 1 MW, revolution: 950 rpm. Ignition system: prechamber. Fuel gas: 38% of methane +nitrogen.

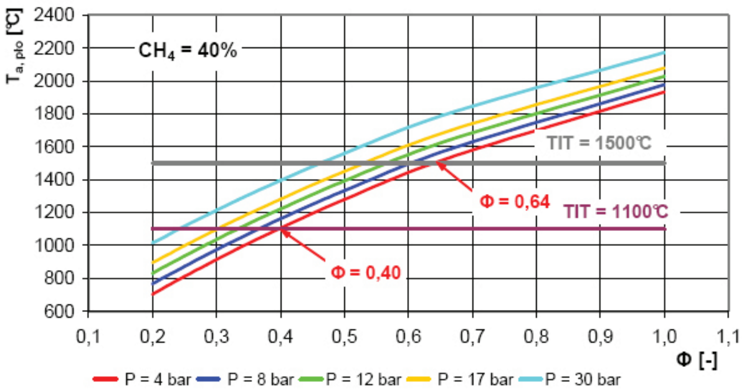

Figure 3: Calculated temperatures TIT for gas turbine for natural gas composed 40% of CH_4 and nitrogen versus inlet pressure operating GT.

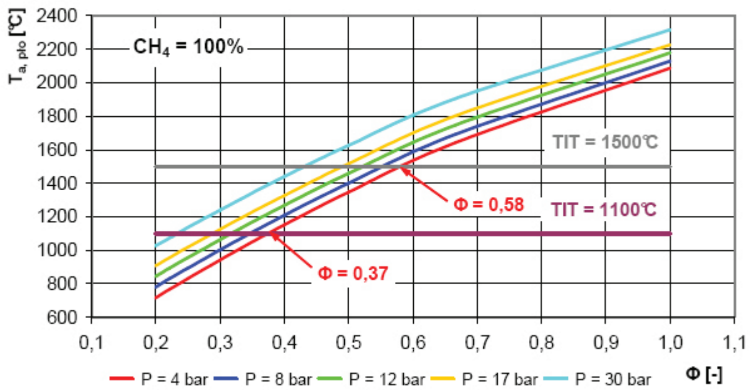

Figure 4: Calculated temperatures TIT for gas turbine for natural gas composed pure of CH_4 and nitrogen versus inlet pressure operating GT.

The third poster [3] presents the advantages of utilization of crude NG in gas turbines. UE Directive 2004/8/EC recommends the development of cogenerative systems CHP. The optimal level assumes the primary saving energy parameter PSE attaining the reference efficiency of at least 52.5%. Such high efficiency is unattainable in reciprocating engines or in simple cycle gas turbines. It can be attained only in systems CCHP of medium and high capacity. The above considerations show that every effort should be made to raise the primary efficiency of gas turbines. The present paper presents some ways of achieving this goal. Fig.3 and 4 show how an increase in the molar content of N2 raises turbine efficiency for typical turbine inlet temperatures TIT of 1100°C and for those currently investigated of TIT ≈1500°C. The calculated coefficients of equivalence ratio Φ for model gases composed either of pure methane or of 40% methane and 60% N_2 are 0.37 instead of 0.40 for TIT=1100°C and 0.58 instead of 0.64 for TIT = 1500°C respectively.

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Energy and CO_2 emission performance of building integrated cogeneration and polygeneration systems

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Building integrated co- and polygeneration systems are related to a potential to deliver energy efficiency and environmental benefits by reduced primary energy demand and associated greenhouse gas emissions reductions. The distributed generation nature of the technology also has the potential to reduce electrical transmission and distribution inefficiencies and alleviate utility peak demand problems. However, the technology competes with other supply options like innovative central electricity generation and heat pump technologies and – for renewable energies – solar thermal and photovoltaic systems and biomass fuelled systems.

The performance in terms of non-renewable primary energy (NRPE) demand and carbon dioxide equivalent emissions has been studied for a number of natural gas driven microcogeneration (MCHP) systems in residential buildings, namely natural gas fuelled solid oxide (SOFC) and polymer electrolyte membrane fuel cells (PEMFC), Stirling and internal combustion (IC) engines, and compared to the reference system with condensing gas boiler and electricity supply from the grid. Ground-coupled heat pump systems were also analysed for comparison. The cogeneration devices were integrated into single-family houses (SFH) and multi-family houses (MFH) of three different energy standard levels: Swiss average residential building stock (Swiss av.), building according Swiss building standard target value for new buildings (SIA target) and building complying with the Passive House standard. Three different grid electricity mixes were considered, using primary energy and emission factors from the Ecoinvent database: European mix according to UCTE, combined cycle power plant (CCPP) and Swiss mix. The simulations were made for one geographic location in Switzerland with the whole-building simulation programme TRNSYS, using the standard domestic hot water and electric demand profiles specified within Annex 42 of the International Energy Agency's Energy Conservation in Buildings and Community Systems Programme (IEA-ECBCS). Combinations of three demand levels were considered. For the MCHP devices, detailed dynamic component models as well as simplified performance map models were used. The models were developed within IEA-ECBCS Annex 42 and partially calibrated with results from laboratory experiments with prototype or commercially available micro-cogeneration devices.

In addition, polygeneration systems, comprising a small natural gas driven cogeneration (CHP) device, a thermally driven cooling (TDC) device and a back-up boiler, were analyzed using models based on average efficiencies. For an office building complying with advanced building standards, different combinations of capacities and efficiencies of CHP and TDC devices were simulated, and the results compared to the reference system with gas boiler, mechanical chiller and electricity supply from the grid. The building loads are determined as 1h-values with the whole-building simulation tool TRNSYS, using standard occupancy and electric demand profiles specified by Swiss standards.

For most residential MCHP systems, reductions concerning NRPE demand resulted with the UCTE electricity mix when compared to the reference system (up to 38%). For the CCPP Smart Energy Strategies 8-10 September 2008, ETH Zürich electricity generation mix, the largest NRPE reductions resulted for the ground-coupled heat pump systems (up to 29%). The maximum reduction with a cogeneration system was 14%. Concerning emissions in terms of carbon dioxide equivalents most cogeneration systems offered reductions for the UCTE electricity mix (up to 23%). However, maximum reductions resulted for the heat pump system (24%). For the CCPP mix, maximum reductions resulted again by far for the heat pump systems (up to 29%). The maximum reduction with a cogeneration system was achieved with the SOFC system in the SFH (12%).

For the polygeneration systems the study showed that the operation time of the cogeneration device (CHP) can be significantly increased when coupled to a thermally driven cooling (TDC) device. A reduction in terms of NRPE equivalents was found in all polygeneration cases with electrical efficiencies of CHP device equal or higher than 17% (lower heating value, LHV) for the UCTE mix, higher than 46% for electricity generated by combined cycle power plants, and higher than 31% for the Swiss mix. NRPE demand reductions were much more influenced by the electric efficiency of the CHP device than by the efficiency of the TDC device. Carbon dioxide emissions were only reduced by polygeneration in the cases of UCTE electricity mix, for CHP electrical efficiencies (LHV) equal or higher than 25%.

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The poster outlines the methodologies applied and the systems analyzed; gives some typical results in graphical form, and makes reference to the related research projects, namely IEA ECBCS Annex 42 (www.ecbcs.org/annexes) and EU PolySMART (www.polysmart.org).

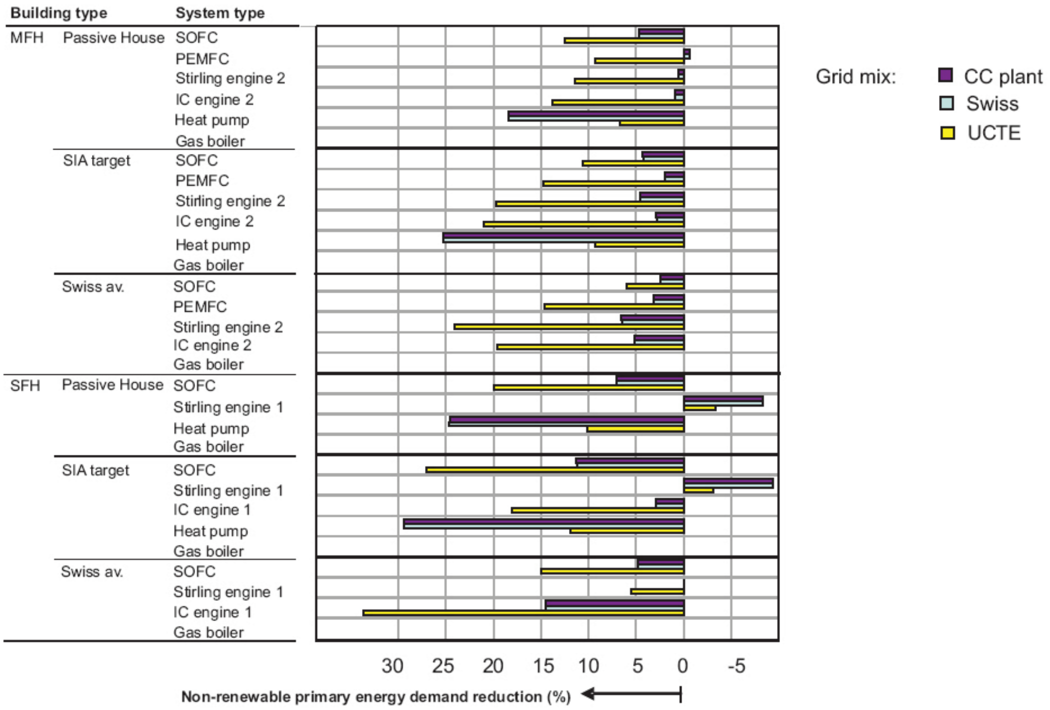

Figure 1: Reductions of annual non-renewable primary energy demand for the residential cogeneration and heat pump systems analyzed, compared to the condensing gas boiler reference system, for the six residential building types and the three grid electricity generation mixes considered.

Spatial potentials for renewable energies

Study results concerning 3 federal states in eastern Austria (Vienna, Lower Austria, Burgenland)

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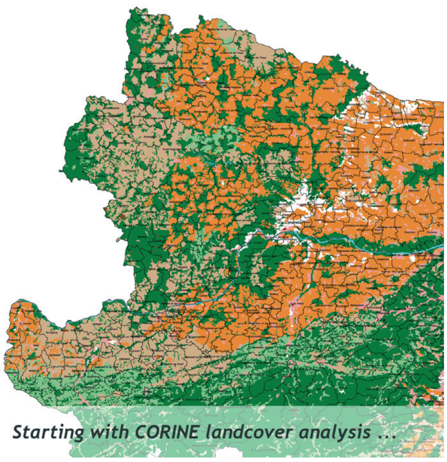
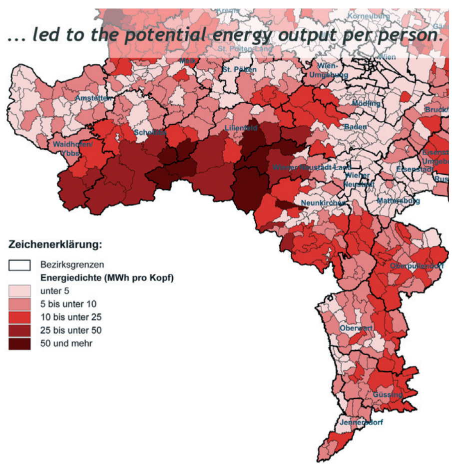
The study “Spatial potentials for renewable energies” analysed the distribution and amounts of renewable energy production in 3 federal states in eastern Austria (approximately 3.5 million inhabitants) with main focus on biomass, geothermal energy and wind power potentials. As many EU guidelines, policy papers, national laws, local mission statements demand an enormous increase in the production of renewable energy and biofuel, accurate data on their spatial distribution and dimension is urgently needed. Therefore all results were visualised in maps down to the level of the communities, which represents an innovative approach since most previous studies included only figure calculations on the federal or national level. **The complete map slideshow (in german) can be viewed here:** http://tinyurl.com/4gr5yb. The main aims were to find “potential focus regions” and to assess the possible additional energy output especially out of local resources in these areas.

Main important results – Biomass

The future of biomass-related energy production lies within a vast pool of rather small-scaled de-centralised facilities, using local resources from the nearby environment. The aggregation of forest, agriculture (including derelict areas), grassland and reed indicated clearly the respective focus areas, representing typical landscape units on the one hand and the per-capita (hectares per person) distribution on the other. Using a simple model showing the probable share of potential energetic use in total (in competition to industrial use or food production) the energy output of 38 Petajoule seems possible in a short-time period. This amount represents a heat capacity for about 1.8 million people. In order to increase efficient biomass energy production without huge transport costs, rural communities with large areas, but low population densities have the best endogenous preconditions, whereas urban regions will always be bound to immense imports of resources.

The aggregation of the different potential biomass areas showed that the most promising regions are the northern and southern parts of Lower Austria. The eastern part of Lower Austria and the northern part of the Burgenland (close to the Neusiedler Lake) can rather benefit from agricultural Biomass. The east shore of the lake also provides a very specific resource – large reed fields – which are ecologically very valuable, but can also provide heat production.





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Finding the Right Green IT Strategy is a Great Challenge – The 'Going Green Impact Tool'[1] supports you

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The Data Center Crisis

Lately, environmental issues have been in the news more and more. Concerns about rising energy demands, escalating electricity prices and greenhouse gas emissions are not only entering the agenda of governments but also limit business growth. One of the highly affected business areas is information technology (IT) and IT service providers. So far they were focused on meeting the rapidly increasing computing demand. For this, new high performance and high density IT equipment was deployed, doubling the energy consumption of data centers from 2000 to 2005 (Koomey, 2007). This development is accompanied by new urgent concerns: Rising energy consumption and electricity costs will make operating expenses exceed server capital expenses by 2009 (Brill, 2006). Power and cooling limits will be reached at 50% of the world's data centers by the end of 2008 (Kumar, 2006). Governments, in particular in the EU and the US, are working on new legislation for environmental protection, affecting IT products and operations that cause emissions of CO_2 or other greenhouse gases (Mines, 2007). Furthermore, because of the prominence of global warming concerns, green IT is becoming part of Corporate Social Responsibility (CSR) for any company.

CIOs and other executives are challenged to develop a green IT strategy to minimize those risks to become more energy efficient, and to maintain acceptable operating and investment costs to ensure the company's growth.

The Challenge of Finding the Right Green IT Strategy

Fortunately, green solutions exist already today to improve the energy efficiency of data centers and reduce risks, while enabling CIOs to meet expanding business needs. Nevertheless there is no perfect strategy to create a green data center because of the diversity of design and requirements of data centers. Depending on the issues, there is a long list of possible green solutions varying by impact, cost and sustainability.

To determine the most effective strategy to reduce threats to business continuity, operating costs and upcoming regulatory concerns, CIOs need to develop a holistic view. They have to focus not only at energy-related issues in their data centers but also assess the situation from an economic point of view and with a long-term perspective. This approach will help to realize that some green solutions are only useful as quick fixes, whereas other, more complex solutions with upfront investment will eliminate energy issues and emerging business risks. A holistic assessment to find the right strategy has also the advantage of not being "greenwashed", what is the current side-effect of everyone trying to save the planet.

Where to start with solving problems, where to set priorities on green solutions, and how to meet the right level of accuracy at the assessment are questions CIOs are dealing with. If they look around for help they find overwhelming offers from consulting firms. Many consulting offers based on significant data gathering and analysis without a necessary tool support lead to high costs. Furthermore, it is questionable whether those offers are objective or influenced by solutions from existing partners.

The 'Going Green Impact Tool' Enables the Development of a Successful Green Data Center Strategy

The message is clear: energy-related issues need to be solved, new risks are ahead, and a successful green strategy requires a profound holistic assessment. Existing tools can help – however they are either too technical or too specialized to assist the CIO or other executives in mastering the challenges of "going green".

The 'Going Green Impact Tool' was specifically developed to reveal existing issues, to provide a quick assessment within dynamic scenario calculations, and to allow first recommendations to executives. The tool's aim is particularly on addressing energy-related issues from an economical point of view.

1 *The Going Green Impact Tool was developed by Hannes Engelstaedter during his master thesis at the IBM Zurich Research Lab under supervision of Dr. Erich Ruetsche and in close cooperation with IBM Switzerland.*
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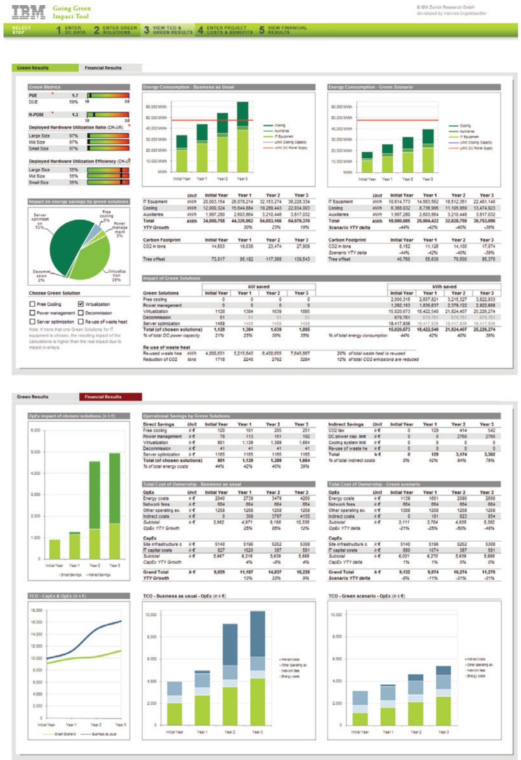

On the one hand, it allows the important holistic assessment in technical and economical terms. On the other hand, it supports the decision-making process of finding the right green solutions and of prioritizing their realization correctly. This includes not only the assessment of energy-related issues of data centers but also the quantification of the impact of green solutions on energy efficiency and the Total Cost of Ownership (TCO). The green solutions currently included in the tool's calculations are server optimization, power management, decommission not productive servers, virtualization, free cooling, and the re-use of waste heat, and the list is growing constantly.

The key differentiator of the 'Going Green Impact Tool' is the possibility to construct different dynamic scenarios for green, energy efficient solutions in comparison to business as usual. To ensure that the most important business risk factors are taken into account, it is possible to simulate the IT equipment growth, the increase of electricity prices, a CO_2 tax, the data center power supply limitations and the cooling system limitations.

Finally, after having decided which green solutions shall be realized and when, the user can run a financial analysis of the green project to determine the costs of realizing the chosen green solutions. This analysis provides information on the return on investment, cash flow, net present value, and payback period.

As the tool was developed to support executives in the decision-making process for a green data center strategy, the underlying principle is the Pareto principle, also known as 80-20 rule. This avoids too high complexity, ensures that the important holistic view is applied and provides results within days rather than weeks or months.

The 'Going Green Impact Tool' is the right support to build different strategic scenarios to master energy-related issues. The tool ensures the necessary holistic view and includes economic aspects through a TCO analysis. Furthermore it provides a solid foundation to maintain business continuity, to prevent being trapped by new environmental regulations, and to ensure acceptable data center operating costs in the long term. There certainly is a challenging time ahead of us to keep up with environmental and energy-related issues. However, from a data center perspective, it is the right time to start dealing with these issues by using the 'Going Green Impact Tool'.

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LaSrFeNi-oxide: a promising cathode material matching proton conductor specifications for intermediate temperature solid oxide fuel cells

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Solid oxide fuel cells (SOFCs), which convert chemical energy directly into electricity by using H_2 or CO gases of a reformed hydrocarbon as fuel are promising power generation devices for more efficient and cleaner energy [1]. They are expected to achieve, for electrical power generation in the 1 kW to 10 MW range, net electrical efficiencies up to 65%. They typically oper-ate at temperatures as high as 800°C, which poses a lot of stress on the infrastructure of fuel cell. Therefore, there is a need for materials that allow SOFC to operate at lower, intermediate temperatures such as 500°C. We identify LaSrFeNi-oxide as a potential cathode material for SOFC, be-cause it has its maximum conductivity in the same temperature range. Together with ceramic proton conductors, the realization of an intermediate temperature SOFC seems to become feasible.

Extensive characterization of the cathode is needed to redouble the efficiency of the SOFCs. Our multinational consortium attempts here an exhaustive experimental characterization of the crys-tallographic and electronic structure of a complete matrix of LaSrFeNi-oxides, including its end members $LaFeO_3$, $SrFeO_3$, $LaNiO_3$, and $SrNiO_3$, including sintered ceramic bars and very thin single crystal films.

The crystallographic structure is determined with conventional x-ray diffraction, supple-mented by high temperature x-ray diffraction and dilatometry to monitor phase transitions (rhom-bohedral-cubic) as a function of temperature and relative Sr content. Core level soft x-ray absorp-tion spectroscopy at the oxygen K shell and Fe/Ni L shell absorption edges allow us to monitor hybridization effects between the 3d metals and oxygen, to determine the potentially transport relevant spin states, and to correlate this information with the electric conductivity.

The Fe 2p spectra of the compounds for low Sr concentration remain essentially unchanged, but for higher Sr content a second component appears in the spectra. Conductivity measurements suggest a transition from semiconducting behavior to metallic as the temperature increases and this transition temperature strongly depends on the Sr content.

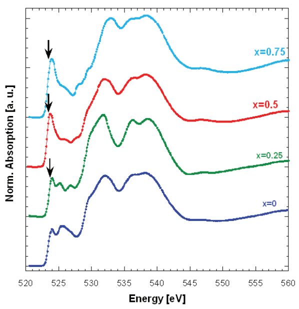

Figure 1: Oxygen K edge x-ray absorption spectra of $La_{1-x}Sr_xFe_{1-y}Ni_yO_3$

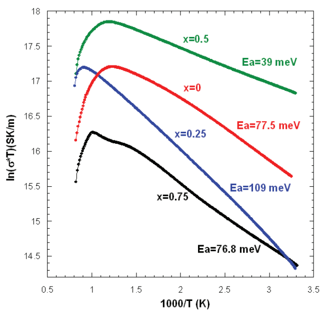

Figure 2: Temperature dependent electric conductivity of $La_{1-x}Sr_xFe_{1-y}Ni_yO_3$

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SmartEnergy: a semantic web for smart services

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Matching production and consumption of resources

Today consumers usually assume that resources are always available in a sufficient quantity and behave accordingly. For example, electricity consumers usually do not limit their electricity consumption when production of electrical energy is struggling to match demand or when the transport or distribution network is close to saturation. Conversely resource providers understand their role as to provide as much resources as required by consumers.

This approach has hit its limits for the following reasons:

- Resource increases are not always possible today and will be even more difficult in the future. For example, increasing the capacity of a traffic road or of a parking lot in urban areas is often practically impossible. Neighbouring population is usually opposed to the construction of a high voltage power line.
- Investment and operation costs are often dependant on the peak capacity of a system. In a demand-driven approach, resources consumption varies widely and peaks a limited number of hours per year. The cost to upgrade the infrastructure for an increase of the peak consumption can be very large. Liberalisation highlights these costs and promotes cheaper solutions.
- Production of many resources can not be controlled by demand. Renewable energy sources like solar cells and wind mills can not be scheduled and the produced energy must be used at the time it is produced.

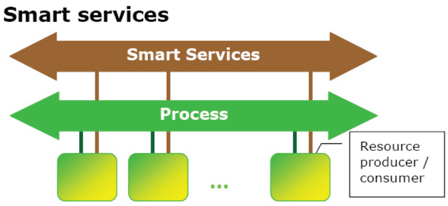

Figure 1: Principle of smart services

Smart services are defined as services allowing or facilitating the mediation between resources producers and resources consumers (see Fig. 1).

The SmartEnergy framework is a distributed information system supporting smart services.

Internet and the web

Smart services require cooperation between elements that are geographically dispersed. Internet is the adapted basis for the SmartEnergy information system:

- Internet access is ubiquitous and the price per transmitted/received bits is going to zero.
- Even if it is intrinsically insecure, internet can be upgraded to meet high security requirements.
- SmartEnergy is used for optimisation and not for critical services. The reliability and the time transparency of internet are sufficient. Safe operation is possible without a SmartEnergy connection.
- Internet connects autonomous entities.
- Internet is independent of any transmission technologies (wireless).

We believe that the critical factor preventing the large-scale deployment of smart services is not the cost of internet access but the lack of standard methods for collaboration between participating devices.

The web has proved to be very successful in building massively distributed networks involving heterogeneous devices and multiple institutions. Moreover, the web has many interesting features for smart services: it is not bound to a limited set of services, provides a uniform access (through a browser) to all services and supports links.

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However, today's web is mostly a web of documents intended for persons whereas SmartEnergy requires also a web of machines.

The Semantic Web

The Semantic Web [1] is a W3C (World Wide Web Consortium) initiative whose goal is to enhance today's web for the machine-to-machine communication.

SmartEnergy is based on the semantic web technology developed in the frame of the S-TEN (Intelligent Self-describing Technical and Environmental Networks) [2] EU research project.

Architecture of SmartEnergy

A SmartEnergy framework is made up of the following elements:

- service users ('web clients'),
- service providers ('web servers'),
- a directory where service users and service providers register themselves ('search engine').

Legacy web servers and browsers can also be SmartEnergy elements. Resource consumers and producers can be either SmartEnergy users or SmartEnergy providers.

SmartEnergy is capable to host an unlimited number of services. Data sharing and links between services can be implemented.

Example of a SmartEnergy Service: Demand Side Management

Demand Side Management (DSM) is the process of managing the consumption of energy, generally to optimize available and planned generation resources.

Distributed energy sources and energy vendors act as service providers. Loads are service users. Service providers publish in a semantic (i.e. in a machine understandable) form the conditions for the sale of their energy (how much energy at what time for how much money). Being aware of the costs, intelligent loads can decide to buy energy from one or several distributed sources or vendors.

In a simpler version, an energy provider publishes on a legacy server its expectations for energy sale and/or purchase (how much energy at what time for how much money). As service users, loads and distributed sources access the energy vendor's expectations and decide to behave accordingly – or not. All actions performed on request of a vendor are logged on the energy vendor's web server.

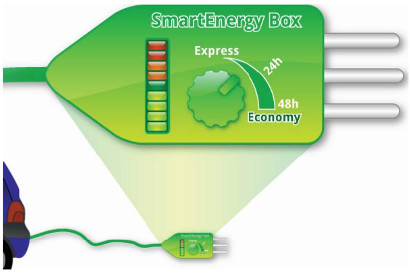

Figure 2: Control of the load process of an electric car.

The SmartEnergy Box (see Fig. 2) shows a possible user interface on the plug of an electrical car.

If the owner selects the position 'Express', the battery is loaded as soon as possible (today's behaviour).

By turning the button clockwise ('Economy'), the car owner specifies at what time he wants the battery to be completely loaded. The LEDs indicate the price of the battery charge operation for the current position of the potentiometer.

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An approach for Plug-In Hybrid Electric Vehicle (PHEV) integration into Power Systems

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1 Introduction

The PHEV initiative, recently accelerated for political, environmental and security reasons, offers a possibility to substantially shift energy demand for transportation from crude oil to electricity. PHEV are meant to recharge their batteries through the grid. Their internal combustion engine (ICE) is only used as an ancillary power source. They are easily understood to introduce a new load as well as a distributed, mobile storage to be used for the power system once connected [1].

Inevitably, both utilization schemes lead to an integration of power and transportation systems. Therefore an integrated model for analysis has to be developed. Agent based modelling (ABM) is intuitive as it is widely used in transportation theory [2] and suitability becomes blatant when considering that PHEV are independent entities with different objectives.

Therefore, the power system model should incorporate agents and be as general as possible to integrate the yet non existent PHEV fleet. Possible repercussions may not ultimately be confined to the electricity network. For this issue the Energy Hub approach [3] is chosen.

2 Agent Based Modelling Approach

In [4] agents are defined to have certain properties like: *Reactivity, Autonomy, Pro-activeness, Intelligence*. The agent based approach refers to the fact that two entities need to communicate in order to act intelligently. PHEVs, inherently autonomic, are presumed to arrive in a certain area at a certain time and need to communicate with their supervising entity for recharging. They reveal their demand, departure time, etc. The supervisor, referred to as PHEV Manager, receives the information, stores and uses it, while distributing available power and imposing load/storage management schemes, incorporating autonomy, reactivity and pro-activeness dependent on the actions and information of the PHEV Hubs.

2.1 The PHEV Energy Hub Model

In [3] the Energy Hub was accentuated to represent an abstract unit of a multi energy carrier system featuring input and output, conversion and storage, being obviously true for PHEV. Now, the Energy Hub equation needs to be adjusted to the demands of typical PHEV utilization schemes, which besides driving are charging, frequency regulation and refuelling. They can be incorporated through a set of situations

$$\Xi = \{\mathrm{D}, \mathrm{RF}, \mathrm{R}\} \tag{1}$$

where D represents driving, RF represents refuelling and R represents charging and discharging (frequency regulation).The output is only kinetic as the demanded electric out- or input in situation R can easily be incorporated through the input vector of the model. An expression including the situations into the model of the PHEV Energy Hub is formulated through a situation decision function. Equation (2) shows the complete model. For simplicity only a series PHEV Hub is modelled.

$$\mathbf{L} = \mathcal{E}(\Xi)\left(\mathbf{C} - \mathbf{S}\right)\begin{pmatrix}\mathbf{P}\\ \dot{\mathbf{E}}\end{pmatrix} \tag{2}$$

with

$$\mathcal{E}(\Xi) = \frac{\partial}{\partial \Xi}\left(\mathrm{D}\ \mathrm{RF}\ \mathrm{R}\right)$$

and

$$\mathbf{C} = \begin{pmatrix} c_{e\,\mathrm{D}}(\mathbf{L}) & c_{gas\,\mathrm{D}} & 1 \\ c_{e\,\mathrm{R}} & c_{gas\,\mathrm{R}} & 0 \\ c_{e\,\mathrm{RF}} & c_{gas\,\mathrm{RF}} & 0 \end{pmatrix} \mathbf{S} = \begin{pmatrix} \frac{c_{e\,\mathrm{D}}}{\eta_e}(\mathbf{L}) & \frac{c_{gas\,\mathrm{D}}}{\eta_{gas}} \\ \frac{c_{e\,\mathrm{R}}}{\eta_e} & \frac{c_{gas\,\mathrm{R}}}{\eta_{gas}} \\ \frac{c_{e\,\mathrm{RF}}}{\eta_e} & \frac{c_{gas\,\mathrm{RF}}}{\eta_{gas}} \end{pmatrix} \mathbf{P} = \begin{pmatrix} P_{e\,\Xi} \\ P_{gas\,\Xi} \\ P_{dis} \end{pmatrix} \dot{\mathbf{E}} = \begin{pmatrix} \dot{E}_e \\ \dot{E}_{gas} \end{pmatrix}$$

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Here, **C** denotes the coupling and **S** the storage coupling matrix, respectively, containing the coupling factors for the different situations which are composed of the converter and storage efficiencies of the power paths. The kinetic load **L** can be calculated according to Newton's second law. $P_e\Xi$ and $P_{gas}\Xi$ denote the power inputs in the particular situation. P_{dis} denotes the dissipated energy. $\dot{E}_e$ and $\dot{E}_{gas}$ denote the power drawn from the battery and the gasoline tank. Regenerative breaking is incorporated through a load dependency of the coupling factors. A more detailed derivation can be found in [5].

Each PHEV Energy Hub Agent simulates driving behavior and chooses departure, track and parking time independently. As soon as connecting, the agent transmits information to the PHEV Manager Agent including *Identity NR, State of Charge (SOC), Arrival Time, Departure Time.*

2.2 The PHEV Manager

The PHEV Manager Agent is an abstract entity relying on intelligent interfaces. He supervises a defined area, registers when PHEV are connecting to the network and receives the information mentioned before. The PHEV Manager updates the connectivity list of PHEV in 15 minute time intervals and adjusts it. Smaller intervals result in more accurate simulation but in longer computation times. Further, cars which are parking shorter than 15 minutes are not considered for recharging and load/storage management. The PHEV Manager Agent aggregates the PHEVs arriving in the supervised area enabling management schemes as well as possible ancillary services as proposed in [6]. In this paper the PHEV Manager will be utilized to study the load shape imposed by the PHEVs connecting in one area and to shed light on possible ancillary potential of the fleet.

3 PHEV Energy Hub Optimization Results

For energy demand estimation stemming from PHEV cycles like UDDS, HWFET [7] etc. a control scheme needs to be implemented. It was proposed to use PHEV mainly in electric mode and switch to a blended mode when the battery cannot supply the demand or to charge sustaining mode once a certain SOC is reached [8].

Keeping the simulations fast, preferring grid charged electricity and using pessimistic assumptions of efficiencies, linear programming was chosen as a control scheme for a worst case scenario. The optimization scheme is denoted in (3). The objective function dependents on the storage outputs multiplied by energy carrier market prices. The focus is laid on grid charged electricity. Deeply depleting battery results in shorter lifetime which is accounted for by *k/SOC* assuring that the battery is more expensive than gasoline once 20% of SOC are reached. The constraints are resulting from the Hub equation and converter specifications [5]. The first and second inequality constraint refer to the total load drawn from the ICE and battery, respectively. The SOC is constrained to lie between 20% and 100%. The output power derivatives for battery and ICE are considered as well. The last two constraints refer to the fact that once the ICE is switched on, it runs with the demanded power for at least 300 seconds, coping with the load or recharging the battery. Figure 1a shows the PHEV Hub cycling through different drive cycles starting with NYCC, UDDS and HWFET. The plot shows the speed profile, the power demand, the power drawn from the battery, the resulting SOC, the power drawn from the ICE and the depletion of the gasoline tank. Obviously, most of the power is drawn from the battery. However, when the battery cannot supply the load due to power or power derivative constraints the ICE starts and keeps its demanded output power for 300s. As the ICE is completely disconnected from the torque constraints of the wheels it is assumed to be operated at constant efficiency for each power output. Once 20% SOC is reached the ICE supplies more of the load while recharging the battery. This control scheme implies a typical utilization scheme for PHEV minimizing consumer costs presuming discharging the battery down to 20% does not affect lifetime. The total driven distance is found to be ca. 130 km.

$$
\begin{array}{ll}
min & \mathscr{F}(\dot{E}_e, \dot{E}_{gas}) \\
with & \frac{d\mathscr{F}(\dot{E}_e,\dot{E}_{gas})}{d\dot{E}_e} = Price_e \frac{\kappa}{SOC} \\
 & \frac{d\mathscr{F}(\dot{E}_e,\dot{E}_{gas})}{dE_{gas}} = Price_{gas} \\
s.t. & \mathbf{L} = \mathcal{E}(\Xi)\left(\mathbf{C} - \mathbf{S}\right)\begin{pmatrix}\mathbf{P}\\ \dot{\mathbf{E}}\end{pmatrix} \\
 & \delta_{gaso}\underline{\dot{E}}_{gas\,\mathrm{D}} \le \dot{E}_{gas\,\mathrm{D}} \le \overline{\dot{E}}_{gas\,\mathrm{D}} \\
 & \underline{\dot{E}}_{e\,\mathrm{D}} \le \dot{E}_{e\,\mathrm{D}} \le \overline{\dot{E}}_{e\,\mathrm{D}} \\
 & \underline{SOC} \le SOC \le \overline{SOC} \\
 & \underline{\dot{P}}_{e\,\mathrm{D}} \le \frac{d\dot{E}_{e\,\mathrm{D}}}{dt} \le \overline{\dot{P}}_{e\,\mathrm{D}} \\
 & \underline{\dot{P}}_{gas\,\mathrm{D}} \le \frac{d\dot{E}_{gas\,\mathrm{D}}}{dt} \le \overline{\dot{P}}_{gas\,\mathrm{D}} \\
 & \delta_{gas} = 1\ if\ \dot{E}_{gas\,\mathrm{D}} \ge 0 \wedge t_{gas} \le 300 \\
 & \underline{\dot{E}}_{gas\,\mathrm{D}} = \dot{E}_{gas\,\mathrm{D}} \\
 & P_{dis} \le 0
\end{array}
\qquad (3)
$$

Each PHEV Hub Agent is assumed to leave its home location between 5 a.m. and 9 a.m. The probability for departure from its home location is given in figure 1b and drawn from [9]. The agents choose the number and shape of their drive cycles individually. The probabilities for both are uniformly distributed.

One to five cycles can be chosen out of: 1. UDDS, NYCC, 2. HWFET,NYCC, 3. FTP 4. NYCC. It is assumed that all PHEV Hub Agents arrive at the same location (work location with connection points). Choosing the drive cycles differently implicates different driving behavior (e. g. aggressive, non-aggressive) and different distance for each Agent.

4 PHEV Manager Simulation at one Network Hub

The PHEV Manager is modelled for only one node in a possible network. Establishing such entities at each node of a Hub network presumes a decentralized control of the PHEV fleet. Especially for large agglomerations it seems realistic considering computation power and time. The PHEV Manager updates his connectivity list while imposing a new load on the Hub. Presuming a known base load pattern (e.g. household or industrial) the overall load pattern changes dependent on the distribution of PHEV Hub arrival and SOC at this Hub node. The manager offers a tool to study the mutation of known load patterns. Obviously, total PHEV load in one time interval is partly dependent on the preceding one, since additionally to the arriving cars in the current period, PHEV already connected can by then be either fully charged or still be charging. No network congestions are assumed. Figure 2a shows the pattern of the adequately aggregated load imposed by 500, 1000

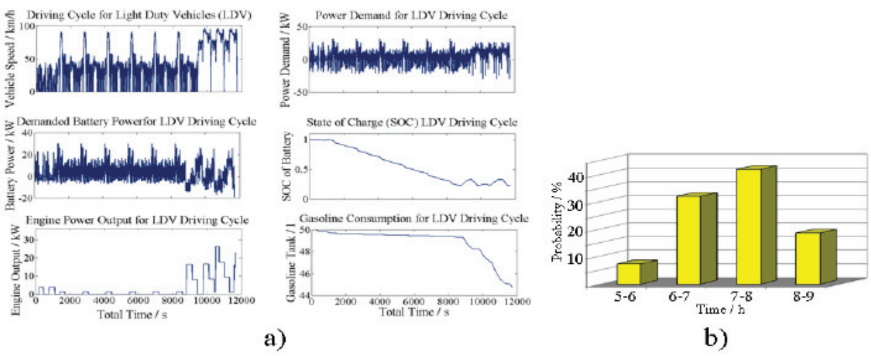

Figure 1: a: PHEV simulation for specific cycle – b: Departure probabilities for PHEV.

and 3000 PHEV Hubs whose energy demand was simulated with the approach described in section III. The PHEV Manager recharges the PHEV Hubs as he communicates and allocates energy in every time interval to each PHEV Hub. The Manager considers the maximum plug capacity- and the SOC constraint, as well as the charging efficiency and departure time of all PHEV Hubs.

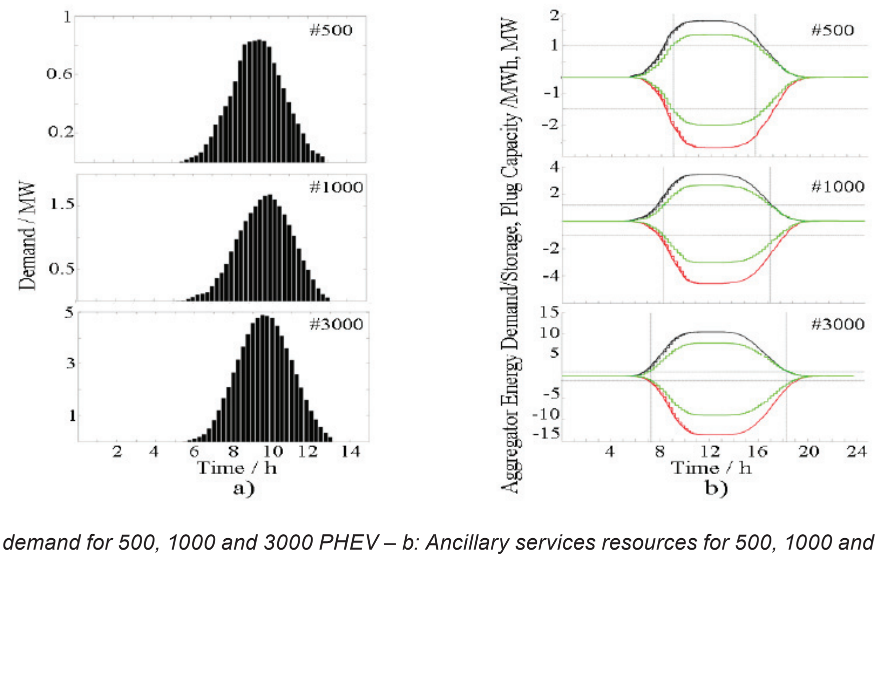

Figure 2: a: Load demand for 500, 1000 and 3000 PHEV – b: Ancillary services resources for 500, 1000 and 3000 PHEV.

Clearly, the peak load is proportional to the amount of PHEVs. The time of peak demand slightly shifts to later times as PHEV amount grows. One main finding is that peak load can be expected two hours after the highest probability of departure. Strikingly, this is independent of the drive cycles as heterogeneous cycles are chosen. The expected value for driving time can be calculated to be 1.2 hours. The value results from an average of 24.2 minutes of driving and three drive cycles, respectively. The shape of the load pattern becomes much more smooth and similar to a gaussian distribution. Cars parking less than 15 minutes are not considered as the minimum parking time is considered to be 7, maximum loading time to be 3 hours, respectively.

Figure 2b shows another aspect of PHEV grid integration mentioned already in [1]. The graphs show the storage and the total load aggregate (no recharging) over time being useful for an analysis of ancillary services potential. The black lines show the total storage at the Hub node, the red lines show the total energy demand, respectively. The stairs depict updating of the manager's connectivity list. The green lines denote the total capacity in MW for regulation down (negative) and regulation up (positive). The Manager is presumed to supply secondary control, so the contracted regulation amount has to be available 100% of the time. The PHEV Manager calculates the regulation capacity in dependence of the individual SOC assuring demanded secondary regulation (up or down) for an hour. A PHEV Hub with 2.5 kWh total storage (SOC = 25%) cannot be evaluated to add regulation up capacity of 3.5 kW, as only 0.5 kW are available for the duration of an hour until the battery is depleted. On the other hand, the PHEV is able to supply 3.5 kW of negative reserve. Evidently, the regulation capacity is smaller than the total demand/storage over a wide window, enabling these services. In figure 2b the contracted capacity is presumed to be 1 MW and minimum time frame 1h, though many TSO have other regularities. Clearly, the contract time frame increases with PHEV amount. The Manager faces an optimization problem, maximizing total profit from ancillary services, either contracting longer but with less power or the other way around.

5 Conclusion

This paper introduces a flexible modelling method for PHEV, able to integrate battery, ICE and even more energy storages and converters. Through its simplicity the Energy Hub approach is able to deliver a worst case electric energy demand scenario for the network minimizing driving costs. Further, the paper introduces a smart grid entity, the PHEV Manager. It is able to aggregate large amounts of PHEV through intelligent communication and is an extension to the known Energy Hub network approach, integrating PHEV into the multi energy carrier network. New load patterns and ancillary service potential can be studied through the entity. Extension to demand management schemes and utilization during black outs are topics for future work.

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Optimal Process Design for Thermochemical Production of Fuels from Biomass

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Introduction

Transport applications are a major global source of greenhouse gas emissions and the production of fuels that are renewable and neutral in CO_2 is an important issue in chemical process research and development. Comparing the CO_2 mitigation potential of different energetic applications of wood in Switzerland, Figure 1 indicates that using this renewable, but scarce resource in the transport sector is among the most CO_2-efficient options. Considering furthermore that energy and CO_2-efficient technologies exist in the heat and power sector, the transport sector is identified as a real challenge for sustainable energy technologies. Contrary to the biological routes that produce bioethanol and -diesel on industrial scale through fermentation or esterification, 2[nd] generation biofuels obtained through thermochemical processing of lignocellulosic and waste biomass by means of gasification and fuel reforming are expected to be truly sustainable since high conversion efficiencies and a decidedly positive environmental balance are achieved.

The poster addresses the optimal design of such thermochemical fuel production processes with respect to its environomic (energetic, economic and environmental) performance.

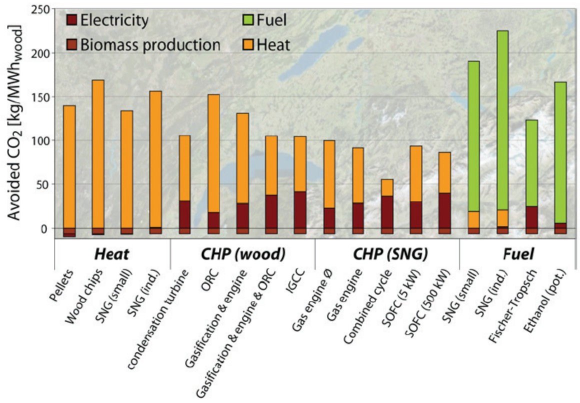

Figure 1: CO_2 mitigation potential of wood for different conversion technologies.

Design methodology

In order to develop optimal processes designs that supply multiple energy services like fuel, heat and power in an energy- and cost-effective way, the challenge is to develop design methodologies that allow the identification of the most promising conversion routes in a specific environmental and economical context. For this purpose, thermo-economic process modelling and integration techniques are coupled with a multi-objective optimisation algorithm to target the best process technology and operating conditions. The basic concept of our method is the decomposition of the problem into several parts, as illustrated in Figure 2. After identifying suitable technology for the conversion steps and arranging them in a block flow superstructure, energy-flow, energy-integration and economic models of the equipment and their interactions are integrated in a multi-objective optimisation framework to compute a set of optimal process configurations with respect to different design objectives. An analysis of the optimisation results with regard to multiple criteria then results in the synthesis of a sound conceptual plant flowsheet.

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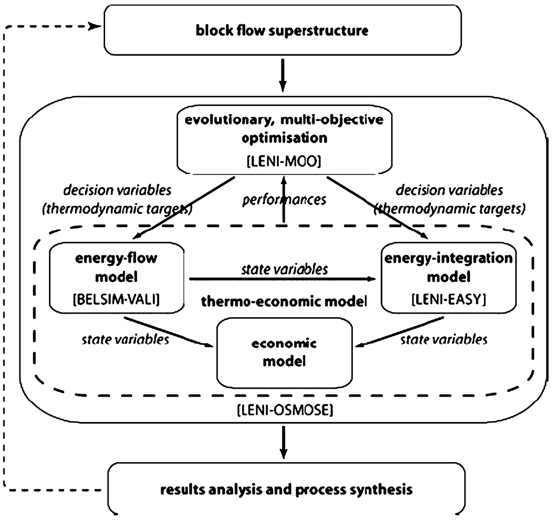

Figure 2: Methodology overview.

Exemplary results

The approach is demonstrated on the production of synthetic natural gas (SNG) from wood, for which an possible plant superstructure is shown in Figure 3.

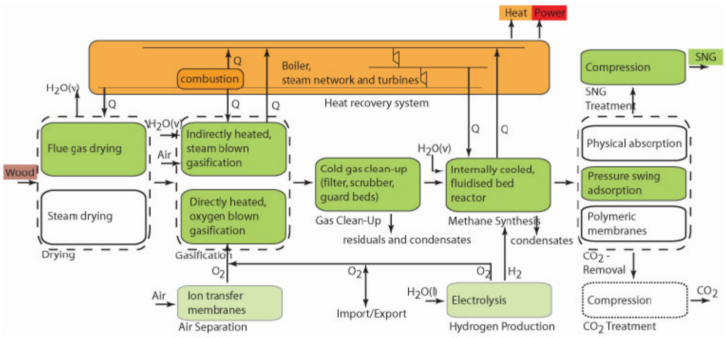

Figure 3: Example of a process superstructure for SNG production from wood.

Using the thermo-economic process model, a candidate process layout for a capacity of 20 MW_{th} of wood with a moisture content of 50% has been optimised with respect to the SNG production, the by-production of electricity by means of a steam-cycle based heat recovery system and the total investment cost of the plant. The decision variables were chosen among the operating conditions of the main conversion technologies and the utility system. Figure 4 shows an example of how some operating conditions of optimal plant configurations are distributed in the search space (bar width) and how they relate to one of the objectives (SNG production, colour). This plot shows for example that low wood humidity after drying should be targeted if the SNG output is privileged over electricity production or that in any case, the gasification temperature should be kept as low as the technology allows.

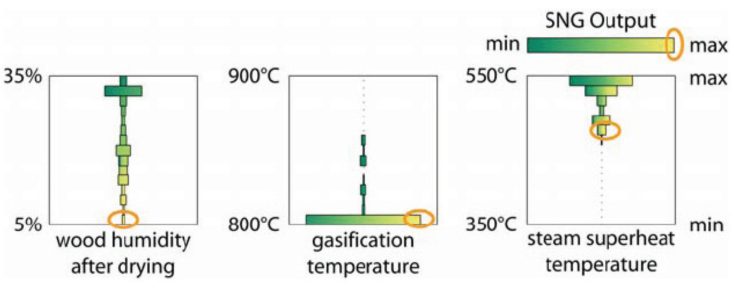

Figure 4: Variable distribution in the search space ranked with respect to SNG output.

After the mathematic optimisation of the process with appropriately chosen objectives, the actual performance indicators like the energy efficiency, total production costs or avoided CO_2 emissions are investigated (Figure 5). From these plots, a reasonable numeric solution can be chosen and serves as a basis for the detailed process design.

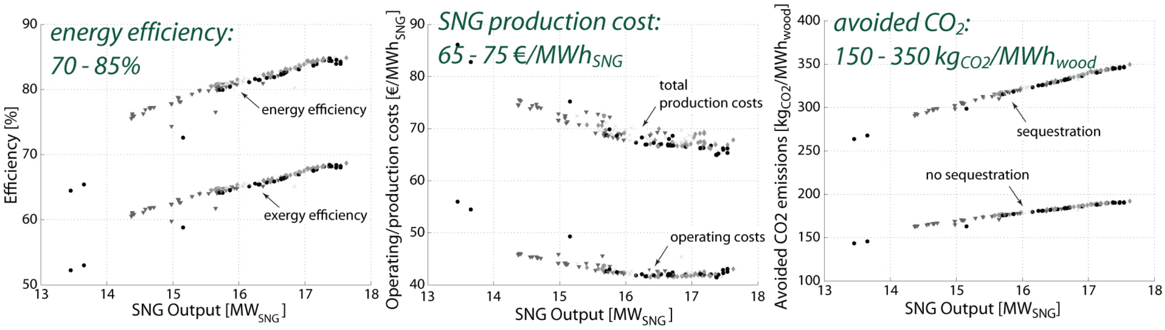

Figure 5: Energetic, economic and environmental performance of the process.

Conclusions

The presented work clearly reveals that process integration and polygeneration of multiple energy services allow to fully exploit the energy potential of biomass. A rationale design methodology including process optimisation with respect to multiple objectives is thereby useful to find the most promising technology and operating conditions and to identify the key issues for the process research and development.

The authors gratefully acknowledge funding provided by Erdgas Ostschweiz AG, Gasverbund Mittelland AG and Gaznat SA, Switzerland.

Introducing Renewable Energy Options in City Redevelopment

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This paper presents first results of a 3-year research project focussing on the introduction of renewable energy in city redevelopment. The project is carried out in cooperation with the Federal Office of Building and Regional Planning (BBR Bonn), the German Federal Ministry of Transport, Building and Urban Affairs (BMVBS Berlin) and the FH Nordhausen, Germany. It is part of the BBR-research initiative 'Experimenteller Wohnungs- und Städtebau ExWoSt'.

The introduction of renewable energy has been an issue for more than two decades. So far, however, the discussion of specific technologies has been in the foreground. This project investigates synergies that are at hand when combining efforts of city redevelopment with suitable options of renewable energy production. Cities change constantly, regardless their size and their location. This process of change can be combined with setting-up a decentralized energy production strategy that citizen can participate in.

Since communities are rarely aware of their complete space potentials, they can hardly assess the opportunities these spaces bear. Due to the variety of green energy production strategies, these spaces can, however, readily be utilized for energy production. In the past, virgin land was consumed to produce energy in conventional ways, often far away from the places where the energy was needed. However, as stated in many European countries, the resource land should be used wisely. This means, that used land, i.e. brownfields, but also so far unused blank urban spaces have to be screened as to their suitability for green energy production.

The project distinguishes between options of producing electrical energy, thermal energy and options that produce both (Fig. 1). It also distinguishes between a concrete potential of energy production and a diffuse potential of energy production. The potential of energy production is screened in four model regions: The City of Stuttgart as a booming region, the City of Gelsenkirchen and Nordhausen as shrinking regions as well as the city of Leipzig as a stable region. In addition, the City of Luzern shall be analysed as a Swiss reference site. Besides the technical boundary conditions for renewable energy production in an urban environment, economic and social aspects are discussed. Good practice examples are introduced and failures are analysed.

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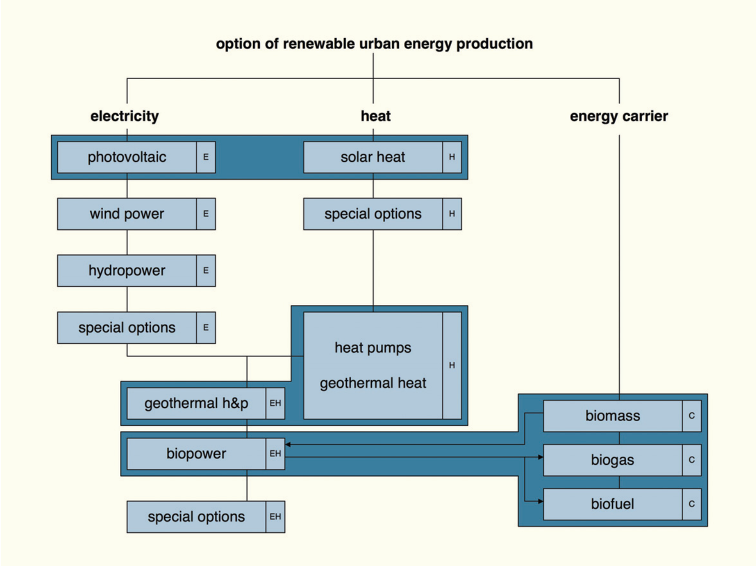

Figure 1: Options of renewable urban energy production as considered in the ExWoSt-reseach project.

The project thus focuses on questions such as: Which options of renewable energy production are appropriate in an urban environment? What are the prerequisites? What are the requirements as to infrastructure, planning procedures and legal aspects? May some options also be utilized temporarily? Can installation of green energy production be easily dismantled? Are there mobile options? Are they economically feasible?

The future city must be compact and climate friendly. This research project tries to add a building stone for archiving this goal.

Derivation of burning velocities of premixed hydrogen/air flames at engine-relevant conditions using a single-cylinder compression machine with optical access

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Experimental work in the field of hydrogen combustion has been carried out in a single-cylinder compression machine. Laminar burning velocities of hydrogen/air mixtures are determined at engine-relevant pressure and temperature conditions. The experimental setup, the processing of the data and the final results are presented.

1 Introduction

Hydrogen internal combustion engines offer the possibility for near-zero emission propulsion systems and are currently researched at BMW Group within the project CleanEnergy. Regarding the analysis of the mixture formation and combustion process of hydrogen internal combustion engines 3D-CFD models are employed using sophisticated combustion models, such as Turbulent Flame Speed Closure (TFC). The models require values of laminar flame speed as input in order to predict the effective turbulent flame speed as a function of the local turbulent quantities. Turbulent quantities are taken from turbulence models implemented in the CFD-solver, while the quality of the prediction is proportional to the effort of the modeling approach (e.g. k-ε, RSM, LES). Values of laminar flame speed have to be provided to the CFD-code in form of tabulated data or algebraic functions and are taken from experiments or from reaction mechanism simulations using kinetic schemes.

Regarding the computation of the hydrogen engine's heat release, it is found that the laminar flame speed is one of the most critical parameters of the turbulent combustion models [1]. Due to the wide range of fuel/air equivalence ratios with internal mixture formation, the value of laminar flame speed has to be known within the entire ignition limits. The present work provides a fundamental contribution to the determination of hydrogen laminar flame speed by means of experimental investigations in a single-cylinder compression machine. With respect to internal combustion engine applications, values of laminar hydrogen flame speed have been determined at high-pressure, high-temperature conditions considering special combustion characteristics of hydrogen. The investigated range of air/fuel equivalence ratio, pressure and temperature conditions at ignition timing are $0.4 \leq \lambda \leq 2.8$, p = 5 bar to 65 bar and T = 350 K to 750 K (Figure 1). This condition range provides a fundamental extension of the existing database found in literature.

2 Experiments

A Single-cylinder compression machine

For the experimental part of this work a single-cylinder compression machine (Figure 2) is employed at the Aerothermochemistry and Combustion Systems Laboratory (LAV) at ETH Zürich. This machine allows the simulation of one combustion cycle of an internal combustion engine by means of a single piston shot. The piston is powered by compressed air. Both the pressure for this compressed air and the initial pressure in the combustion chamber can be chosen in order to obtain the desired thermodynamic conditions at ignition timing. Hydrogen is injected directly into the combustion chamber (DI) and is ignited by a spark plug. The fuel is injected far prior to the beginning of the compression stroke resulting in a homogeneous mixture distribution and a negligible level of turbulent kinetic energy at ignition timing.

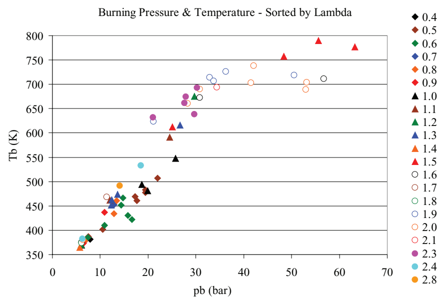

Figure 1: Measured thermochemical conditions.

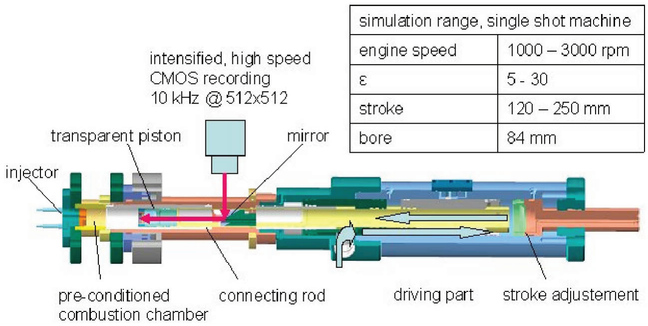

Figure 2: Single-cylinder compression machine [2].

B Measurement Techniques

Two different approaches were used to study the propagation of the flame in order to assure high accuracy. The machine allows visual access into the combustion chamber. OH-Chemiluminescence pictures taken with a high-speed camera provide a first source of the flame front propagation. Piston position and in-cylinder pressure measurements allow a thermodynamic analysis.

3 Post Processing Of Data

A Combustion analysis

A LAV in-house computer code is employed to model the burned and unburned zones of the combustion event by a 2-zone approach. Temperature, density and burning rate profiles are computed out of the known pressure and volume data.

B Flame front velocity

After spark ignition, the flame propagates spherically. Interaction with the cylinder walls and flow field is inevitable, but a half-spherical approximation of the flame with centre at the spark plug is acceptable for calculations. Geometrical dimensions of the combustion chamber are known and allow to write a code that can compute flame radius and surface area for a given piston position and volume of the burned gas (Figure 3).

For the optical analysis a best fit radius can be determined for each picture (Figure 4). With the flame radius known over time, it is possible to calculate the flame front velocity, u_f.

$$u_f = dr_f / dt \tag{1}$$

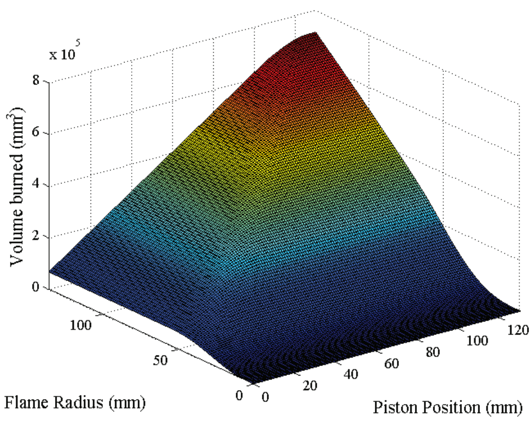

Figure 3: Volume of the burned zone as a function of flame radius and piston position.

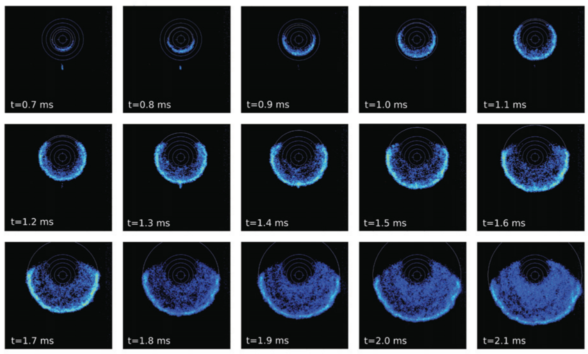

Figure 4: Propagation of laminar flame by OH-Chemiluminescence (λ=1.6, p_{ign}=13 bar, T_{ign}=600 K).

C. Burning velocity

The flame front velocity is the speed at which the flame propagates in reality. Of more interest is the burning velocity which describes the motion of the unburned gas relative to and normal to the flame front and its transformation into products. The difference between the flame front velocity and the burning velocity s_b is the velocity of the unburned gas ahead of the flame front, u_g.

$$s_b = u_f - u_g \tag{2}$$

The density of the burned zone is much lower than that of the unburned mixture due to the temperature rise. Therefore the expansion of the burned gas counts for part of the front velocity. In literature [3] a way is described to take u_g into account using an expansion factor E_f

$$E_f = \frac{u_f}{s_b} = \frac{\rho_u/\rho_b}{[(\rho_u/\rho_b)-1]x_b+1} \tag{3}$$

where x_b is the mass fraction burned and ρ_u and ρ_b are the densities of the unburned and burned fraction, respectively.

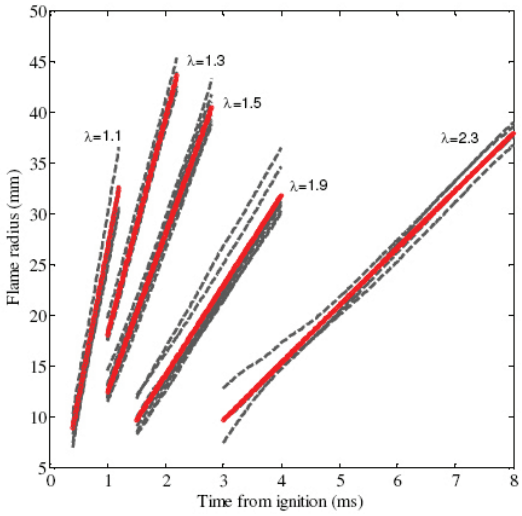

Figure 5: Linear approximation of flame radius.

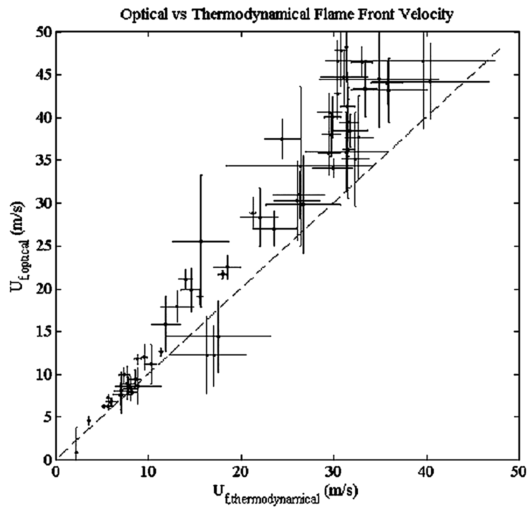

Figure 6: Comparison of optical and thermodynamic data.

4 Results

69 measurement series, each 6–10 measurements with the same conditions are carried out. The flame radius profiles of measurements in the same series are averaged and approximated by a linear function (Figure 5). The derivative of this function is taken as the flame front velocity for this point. The results from the optical and the thermodynamic approach compare very well, especially for the lower velocities (Figure 6).

$$s_b = s_{b,0}\left(\frac{T}{T_0}\right)^{\alpha}\left(\frac{p}{p_0}\right)^{\beta} \tag{4}$$

By means of genetic algorithms a correlation is derived from the thermodynamic results (Thermodynamic Analysis) in the power law form (4), with coefficients for temperature and pressure at reference conditions of 600 K and 20 bar.

$$0.4 \le \lambda \le 2.5 \quad \begin{cases} s_{b,0} = 0.25\phi^6 - 3.4774\phi^5 + 18.498\phi^4 - 46.525\phi^3 \\ \qquad + 52.317\phi^2 - 13.976\phi + 1.2994 \\ \alpha = 0.0163\lambda + 2.2937 \\ \beta = 0.2037\lambda - 0.575 \end{cases} \tag{5}$$

$$\lambda < 0.4 \quad \begin{cases} s_{b,0} = 10.41096 + \dfrac{(7.23 - 10.41096)}{2.5}(\phi - 2.5) \\ \alpha = 0.0163\lambda + 2.2937 \\ \beta = 0.2037\lambda - 0.575 \end{cases} \tag{6}$$

In Figure 7, the flame speed correlation presented in Equations (4, 5, 6) is opposed to two other correlations found in literature [4, 5]. The influence of pressure and temperature is depicted in Figure 8 and Figure 9. The new results are higher, mainly because of stretch and instability effects. In literature [6] calculation methods are described to extract these effects. It was decided for this project to keep the unstable, stretched, quasi-laminar burning velocities, as both effects also occur in combustion engines. Regarding turbulent combustion modeling, the proposed equation provides data of hydrogen flame speed that already include the accelerating effect of flame front instabilities.

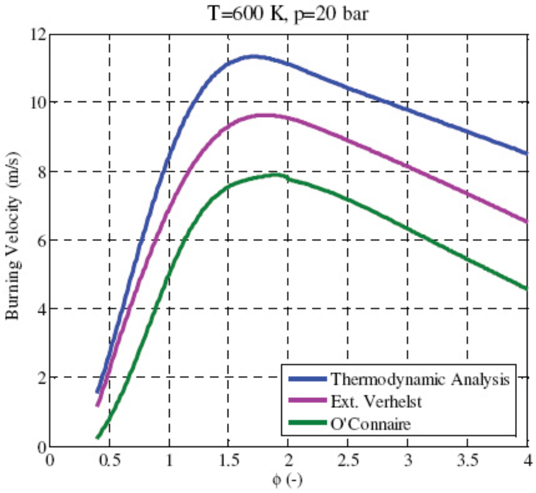

Figure 7: Burning velocity (comparison of different correlations).

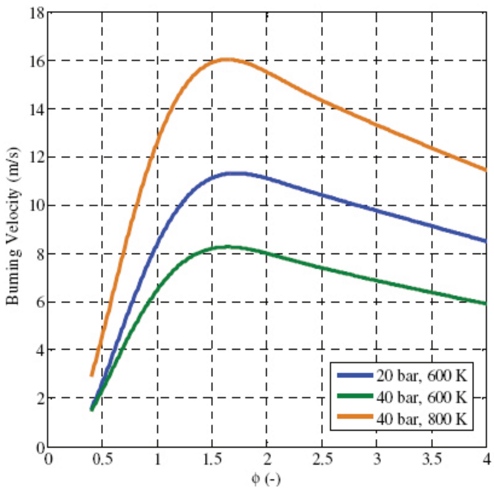

Figure 8: Temperature and pressure influence of flame speed correlation presented in Equations (4, 5, 6).

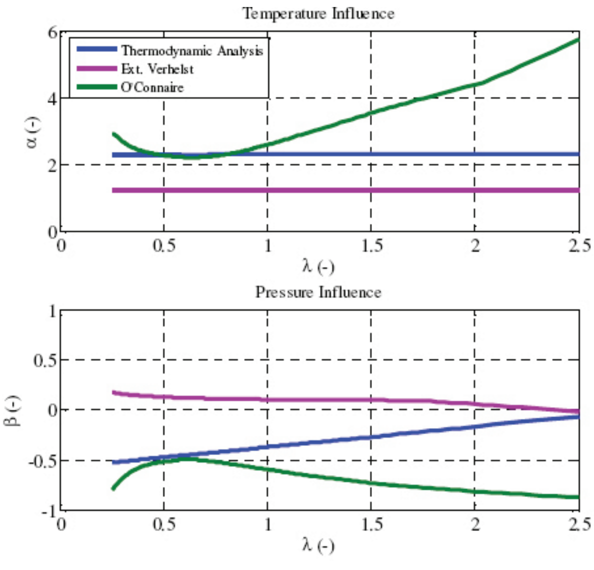

Figure 9: Temperature and pressure influence (comparison of different correlations).

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ENERGIS: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas

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Following the pioneering work of the AGS Tokyo half project, a geographical information system has been developed to model the energy requirement of a urban area. The purpose of this platform is to model with sufficient details the energy services requirement of a given geographical area to allow the evaluation of the integration of advanced integrated energy conversion systems. This tool is used to study the emergence of more efficient cities that realize the integration of energy efficiency measures and of energy efficient conversion technologies and that valorize the use of endogenous renewable energy. The model first uses a geographical system to identify the building characteristics in the area. A typification procedure is used to define the energy characteristics of each building, to model its energy requirement and their perspectives. A data base of typified building models has been constituted. The parameters have been identified using data from monitoring tools installed in the area.

In order to practically compute the annual performances of the energy conversion systems, the building requirement model considers heating and cooling requirements and provides the temperatures of the hydronic system as a function of the ambient temperature. Combining the requirements using the composite curves concepts defines the enthalpy-temperature of the requirement of each geographical sector. This information is then combined with the geographical catalog of the available energy resources like lake water, underground water, geological resources, or waste water treatment plants in order to compute the annual COP for each kind of decentralized heat pump. In addition, heat (cold) distribution system costs are estimated in order to evaluate the integration of combined heat and power options and/or centralized heat pumping systems. Considering the available resources, an aggregation method is then proposed to estimate the best coverage of heat distribution systems. The generated maps have then been used to define the heat and power production strategy in the concerned geographical sectors. An application to the Geneva canton will be presented.

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Integration of Large-Scale Wind Power in a Thermal Power System – The Role of Moderators

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Introduction

The threat of climate change calls for a drastic reconstruction of the power system over the coming decades. A key measure is to find cost efficient ways to deploy renewable electricity generation such as wind power. As wind power reach above a certain grid penetration level the associated variations in wind generation start to influence the power system. In thermal power systems, i.e. systems dominated by condense power plants and combined heat and power plants, these variations result in curtailments of wind power and/or an increased number of startups/shutdowns and part load operation hours of the thermal power plants. Since power plant cycling and part load operation in thermal plants typically imply high costs and emissions, it is important to find ways to reduce the influence of variations on these plants without forsaking large amounts of wind power. This can be done by means of introducing what is here called a moderator in the power generation system. In this context, a moderator refers to a unit in the power system with the ability to reallocate power in time, such as a storage unit or import/export capacity.

Aim and method

By use of a recently developed add on to the BALMOREL model [1] this work investigates the influence of moderating capacity on a power system consisting of 12 large thermal plants with a capacity of 3 741 MW, 1 809 MW smallscale thermal units (unit capacity below 80 MWel) and 2 374 MW wind power. The configuration of the system modelled (i.e. the combination of power generation units) is based on the power system of Western Denmark. The 12 plants in the Western Denmark system with a capacity above 80 MWel are described separately in the model. Start-up and part load costs of these plants are included in the optimization. Plants with lower capacity are aggregated based on fuel (small gas-fired units, small coal-fired units, small biomass-fired units and wind power). Three cases of wind power integration are compared: The system without wind power ('without wind'-case), with current integration as described above ('current wind'-case, 2 374 MW in 2005 with a generation corresponding to 20% of the yearly load if prioritized) and with a doubling in wind power capacity ('40% wind'-case, 4 748MW with a generation corresponding to 40% of the yearly load if prioritized). The simulations apply an ideal moderator, i.e. a moderator where the reallocation of power is not associated with any emissions and losses.

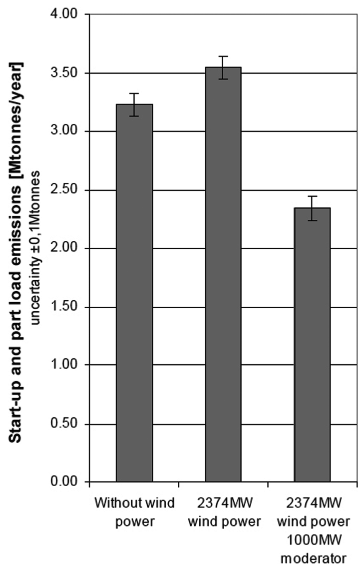

Figure 1: The impact of wind power and moderator on start-up and part load emissions.

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Yet, the net emission reduction achieved with available moderators is assessed by reducing the simulated emission savings with the emissions related to construction and operation of each technology with emissions associated with the moderators (construction and operation) based on LCA data from literature ([2-4]).

Results

What impact does wind power variations have on the power system and how can a moderator reduce this impact?

If wind power is added to a thermal system, there will obviously be a decrease in total emissions since less thermal power generation is needed. However, start-up and part load emissions increase, despite that wind power has no start-up and part load emissions. This increase is illustrated in Figure 1 comparing the three cases of wind integration studied. The increase is due to the variations in wind power generation to which the thermal units have to adjust. As a moderator is added to the system, start-up and part load emissions decrease below the original levels, since the moderator can manage not only wind power variations but also demand variations. In the system without moderator about 25GWh wind power is curtailed yearly whereas with a moderator curtailment is completely avoided.

How much moderating capacity is needed?

The optimal size of the moderator depends on the size of the variations in the system and the ability of the moderator to store energy. Assuming additional wind power capacity is distributed in the same manner as existing capacity, the size of the variations depends on the wind power capacity. We have added moderating capacity in 500 MW steps to the current wind case with 2 374 MW wind power and to the 40% wind case with 4 748 MW wind power. The results are illustrated in Figure 2. The model simulations shows that if the moderator has to be balanced daily, i.e. the storage capacity is small and input to the moderator has to equal output from the moderator on a 24h basis, a 1000 MW moderator is just as good at reducing the negative impact of variations on the system as a 2000 MW moderator. Most of the reduction is realised by the first 500 MW moderating capacity. This holds for both the system with 2 374 MW wind power and with 4 748 MW wind power, since the daily balanced moderator mainly manages variations in demand (and thus indirect decrease occasions of wind power curtailment) which are of the same magnitude in the two systems. The daily balanced 1000 MW moderator reduces emissions with 7.5% in both systems. A moderator with higher storage capacity, where input to the moderator has to equal output from the moderator on a weekly basis, provide the 2 374 MW system with no additional benefits. However, in the case of the system with 4 748 MW wind power such a moderator has the potential to reduce emissions further. The reduction increases as the capacity of the moderator increases, as shown in Figure 2. A weekly balanced 2000 MW moderator reduce emissions with 15.5% in the system with 4 748 MW wind power.

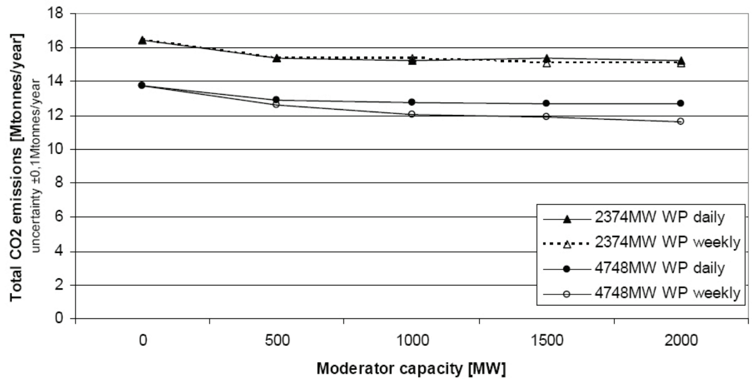

Figure 2: The relationship between moderator capacity and total system emissions.

Given the moderators available, what net emission savings can be achieved?

In difference to the ideal moderator (i.e. with no emissions associated to the reallocation of power) used in the optimizations, real moderators are associated with emissions due to construction and operation. Here we have compared the emissions associated with four storage technologies suitable to act as moderators to the emission savings due to moderation in the optimizations. The moderators are pumped hydro, compressed air energy storage (CAES), flow battery and sodium sulphur battery (NaS battery).

In addition, we have included the alternative to manage variations through import and export. Naturally, this option is only available if the neighbouring systems differ in demand and/or wind power production patterns or have excess moderating capacity. The net emission savings if applying a 1000 MW moderator or a 2000 MW moderator to the wind thermal system with 2 374 MW wind power can be found in Figure 3 (left and right respectively). The net emissions reduction with a daily balanced 1000 MW moderator is 0.40-0.75 tonnes/MWh for the moderators investigated (Figure 3, left) and the corresponding reduction with a weekly balanced

2000 MW moderator is 0.36-0.76 tonnes/MWh (Figure 3, right). Using CAES as moderator gives the lowest emission reduction in both cases, and the emissions related to the moderator are 21–43% and 24–46% of the total reduction respectively with this moderator type. The reason is of course that moderation in this case is associated with the combustion of natural gas. A transmission moderator gives the highest net reduction in emissions, and the emissions related to the moderator are 0.4–5% of the total emission reduction for this type. However, due to geography and composition of neighbouring power systems the possibility to apply transmission as well as pumped hydro and CAES might be limited.

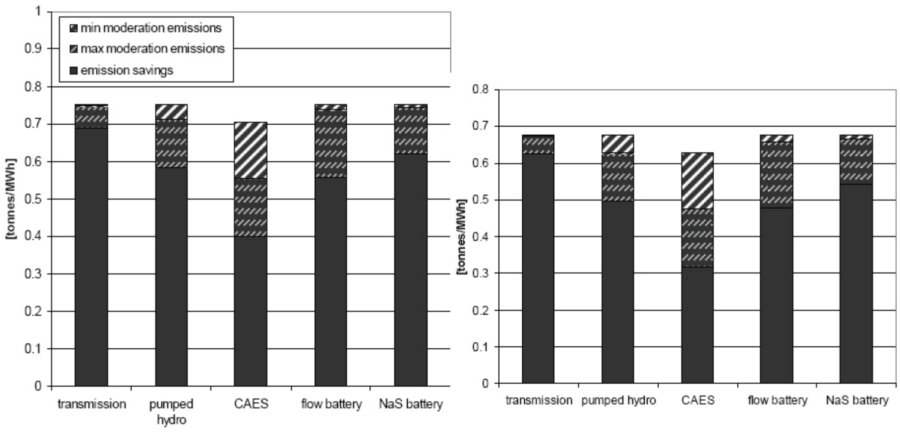

Figure 3: Net emission reduction potential of five existing moderator technologies.
To the left: a 1000 MW daily balanced moderator. To the right: a 2000 MW weekly balanced moderator.

Conclusions

The results of this work show that an ideal moderator (i.e. no emissions associated to moderation) is able to decrease the CO_2-emissions from the wind-thermal system with 7.5% if it can provide daily reallocation and 15.5% if it can provide weekly reallocation of the power produced (i.e. balance input and output over one weeks time). For a moderator which is limited to daily reallocation, the emission reductions are almost independent of wind power penetration level, i.e. the reductions in emissions are from an improved management of demand variations. The moderator providing weekly reallocation is particularly efficient at reducing emissions in systems with large-scale wind power (the 4 748 MW wind power case for the system studied, corresponding to a 40% grid penetration). The reduction in emissions is in both cases mainly due to the avoidance of start-ups of thermal units, but there is also a decrease in emissions due to a reduction in part load operation hours and in wind power curtailment.

Finally, it can be concluded that a large share of this emission reduction can be realised with existing moderator technologies. From an emission reduction perspective, transmission is the most efficient, and CAES the least efficient moderation technology for the system simulated.

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The Evolution of Wind Power

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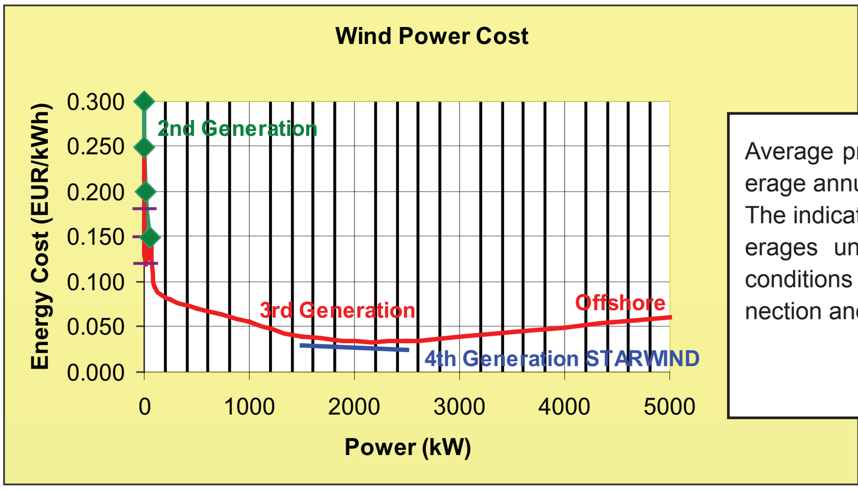
Wind is the oldest technically exploited energy resource, reaching back to ancient times thousands of years ago, originally used to move Chinese, Viking and Greek sail ships, grind cereals and pump water. The use for electricity generation is known since the invention of DC and AC generators. Gearless turbines and advanced tower construction technologies help to reduce the cost of manufacturing, transport, erection and maintenance, and are extending the life considerably up to 30 years and more.

The 4th wind power generation is virtually maintenance free, if there are no abrasive climatic conditions like sand storms and salty water breezes. The electricity production cost in the optimal 1–3 MW power range can be much below grid electricity rates in favourable wind situations.

The matrix shows the characteristics of the four successive wind power generations with approximate cost in favourable locations without excessive road access and grid connection cost. Gear problems limited the life of conventional 2nd and 3rd generation wind turbines and steel towers caused high transportation cost due to road profile problems from the few possible manufacturing locations. The 4th STARWIND generation saves about 40% copper and 90% steel, which both became very expensive.

The Evolution of Wind Power to the 4th Generation

	1st Generation	2nd Generation	3rd Generation	4th Generation	Remarks
Time Period	4000 BC-1800	19th Century	20th Century	21st Century	about STARWIND
Uses	Water Pumping	Power Generation	Power Generation	Power Generation	STARWIND supports
	Grain Mills	Mills			the grid in blackouts
Types	Mechanical	Electric	Electric	Electric	The STARWIND
			Geared & Gearless	High-pole gearless generators	gearless generator has higher efficiency,
			Generators (mainly 4 or 6 poles)	with permanent magnets	about 5 % better and 50 % copper saving
			Auxiliary Exitation	(no slip rings)	less maintenance cost
Wind Blades	Wood & Cloth	Wood / Metal	Plastics (PE)	Plastics (Epoxy)	STARWIND using
	hand-adjusted	stalled	pitch control	or Bio-Plastics	advanced wind blade
	or fixed (stalled)			fail safe pitch control	design with lighter, stronger epoxy resin
Towers	Wood	Wood	Steel or	Concrete	patented STARWIND
	(carpentry)	(handycraft)	concrete made with slip moulds	pre-stressed and (self-mounting)	extruded long-life concrete tower
Erection	Manual	Manual	High-rise Crane	No high-rise Crane	Lower logistics, crane
Power Range	**1 - 20 hp**	**0,1 - 50 kWp**	**0,1 - 6 MWp**	**1,6 - 2,6 MWp**	& production cost



Average production cost at an average annual wind speed of 7 m/s. The indicated cost are industry averages under normal installation conditions with close-by grid connection and easy road access

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Exploiting the Energy and Managing the Climate Change Potentials of Natural Gas Hydrates

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Energy supplies and climate change are two of the greatest global challenges of our time. Thus, natural gas hydrates – which have been discovered to contain large quantities of natural gas and also hold the potential for CO_2 sequestration, generate a lot of interest. Natural gas hydrates are ice-like materials which occur naturally on earth in ocean floors and permafrost regions. They are made up of a network of water molecules which have natural gases trapped in them. The amount of natural gas, mainly methane, in such systems is enormous. Conservative estimates put the amount of energy in natural gas hydrates as more than twice the energy in all other fossil fuels put together. These hydrates thus have the potential to support the energy needs of the earth for centuries and the fact that they are widely spread on earth – including along the coastal waters of many countries such as United States, Japan, China and India – ake them extremely interesting.

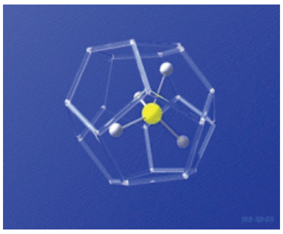

Figure 1: Structure of natural gas hydrate.

Apart from the huge energy resources, however, natural gas hydrates have strong links with climate change. They have the potential to magnify or remedy climate change depending on how they are handled. These materials are only stable at low temperatures and methane is twenty times worse than carbon dioxide as a green house gas. The implication of this is that if methane is released into the atmosphere in the course of the exploitation of these materials, there will be a resultant increase in global warming. Non-exploitation is equally not an option because with the present increase in atmospheric temperature, due to climate change, these materials will soon start melting and methane could be released uncontrollably into the atmosphere. The resultant global warming will enable the release of yet more methane. This cyclic run-away scenario is better only imagined.

The main objective of our research is to conduct an in-depth study into the physical chemistry and chemomechanics of gas hydrates with a view to developing safe and practicable methods of producing natural gas hydrate sediments, possibly combined with CO_2 sequestration. Another closely linked objective is to study the use of quaternary ammonium salts for the stabilisation of gas hydrate sediments and hence preventing them from contributing to sea floor instabilities, climate change and blowouts during drilling operations.

As a precursor to the high pressure synthesis of natural gas hydrates, tetrahydrofuran (THF) hydrates were synthesised and characterised as low pressure analogues. Tetra butyl-n-ammonium bromide (TBAB) hydrates have also been synthesised and characterised towards developing stabilisation techniques for gas hydrates. A high pressure apparatus for the synthesis and study of natural gas hydrates and sediment-hosted hydrates has been designed, developed and used in our laboratory.

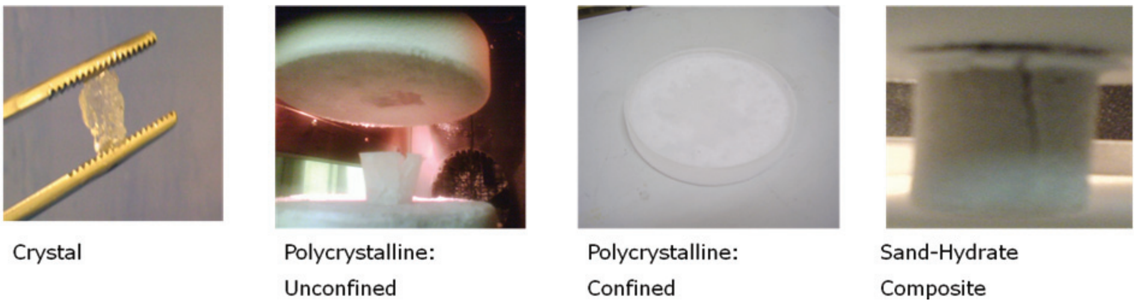

Figure 2: Different forms of THF hydrates synthesized as low pressure analogues.

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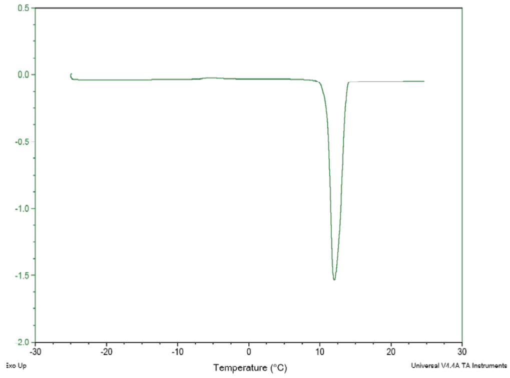

Figure 3: DSC of TBAB hydrate

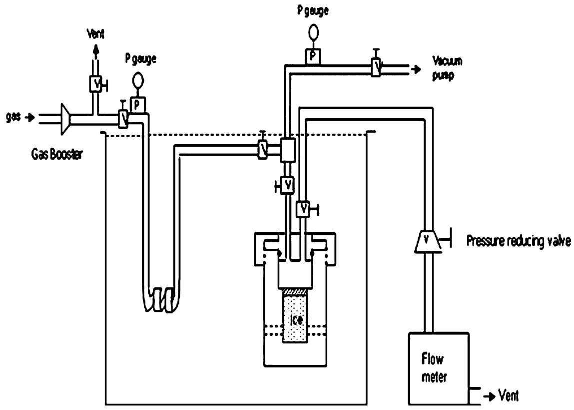

Figure 4: Schematic of high pressure apparatus

The poster will share our research on natural gas hydrates which is aimed at combined energy production and climate change mitigation.

Ultralight Electric Vehicle for Urban Mass Transportation

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The limits imposed by road space, energy consumption, air pollution, global warming and material resources are a great challenge for future mass transportation in densely populated Asian cities. A revolutionary and unique structure makes it possible to build a compact two-seat vehicle with a closed cabin, 1.7 m long and 1.2 m wide, having an empty weight of only 65 kg (with batteries). The innovation consists of a light but strong sandwich plate with a foam core, to which the 4 wheels and the two seats are attached. The cabin is made of elastic foam with exterior fabric reinforcing. It has the shape and the function of a large safety helmet. Instead of doors the entire cabin is lifted up from the platform and swings back. The foam cabin can be mass produced at low cost and offers higher safety than an electric bicycle, also for pedestrians.

Steering is with a mechanical joystick, equipped with a sliding sleeve for controlling the power and a lever for braking. Using the hand for braking increases the safety also. The brushless DC motor with permanent magnets provides 1250 W of mechanical power at 4000 rpm. At a speed of 25 km/h on a flat road with one person only, 350 W of electricity are needed. The range with one battery charge is about 30 km. The energy consumption is 1.6 kWh per 100 km, which is equivalent to 0.6 liters of gasoline per 100 km including the efficiency of the electric power plant and the energy used for the fabrication of the battery.

Because batteries are expensive and heavy, electric vehicles must be as light as possible. The smaller battery of a light vehicle can compensate the higher cost of a lightweight structure. Small vehicles moving with regular and reduced speed allow a higher traffic flow when road space is limited. At 25 km/h the vehicle remains compatible with electric bicycles. A faster vehicle needs more energy per kilometer and must also have a greater range. Both factors lead to a much larger battery, with higher weight and cost.

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Local Load Management: Coordination of a Diverse Set of Thermostat-Controlled Household Appliances

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1 Introduction

The idea of Demand Side Management (DSM) in power systems, although in principle known for decades, has been getting an increasing amount of attention during the last few years. In its traditional form, DSM basically consists of the deactivation of large loads during peak hours, e.g. through financial incentives for users [1,2] or remote-controlled by the electricity provider (e.g. by ripple control equipment). The goal of these approaches is usually the reduction of the overall peak electricity demand. More sophisticated control tasks as e.g. the provision of ancillary services, however, cannot be tackled with these concepts.

Conversely, recent DSM approaches, also referred to as load management, seek to go beyond peak-shaving applications: they include operation on shorter time scales (minutes instead of hours) and the control of smaller units (such as flexible household loads) and shall make an active contribution to grid control by enabling the appliances to both reduce and enforce consumption in a controlled way. This requires a coordination of a multitude of units using two-way communication and novel control algorithms. An example for a mixed-integer optimization approach to achieve a coordinated appliance operation can be found in [3]. If successfully applied, load management can offer various advantages for the participating parties as outlined in the following. Increase in grid security and enhanced control possibilities, peak load reduction and ancillary service opportunities for electricity service providers (such as the provision of tertiary control reserves), grid integration of intermittent renewable energy sources and reduced final consumer prices are examples for possible positive impacts. Apart from that, device-dependent load shedding in the case of a contingency can be an attractive option to complement or replace the less graceful automatic load shedding schemes which cause blackouts in entire regions.

2 The project Local Load Management (LLM)

The project Local Load Management is targeted at unifying the mentioned advantages of an active management of a high number of loads in a single system. It is conducted by ETH Zurich, University of Applied Sciences North-Western Switzerland (FHNW), Atel Netz AG, and Landis+Gyr, and financially supported by SwissElectric Research. The two major parts of the project aim at developing the necessary communication infrastructure for appliances and households, and suitable control strategies coordinating a multitude of devices. In the second part, an economic framework for introducing LLM in a liberalized electricity market will also be developed. Figure 1 depicts the communication infrastructure within the household, realized e.g. via Power Line Communication (PLC).

The first focus of research of ETH is a strategy for coordinating the power consumption of a diverse set of household appliances. To minimize comfort losses for the user, only appliances with a storage capacity for thermal energy, such as refrigerators, freezers, heat pumps, and electric water boilers, are considered for fulfilling normal-operation, non-emergency control tasks. Note that distributed generation units such as photovoltaic panels and electricity storages like batteries of electric vehicles are optional and shall be included in a second step. The impacts of device-dependent load-shedding schemes will also be evaluated in a later stage of the project.

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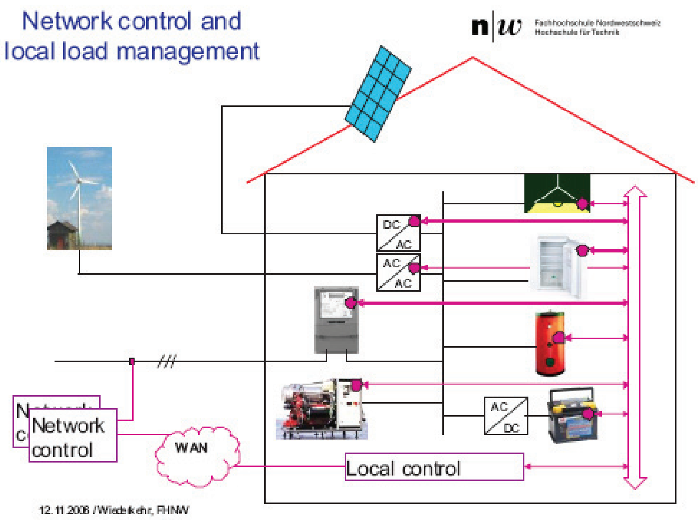

Figure 1: Communication infrastructure for Local Load Management in a household (Source: FHNW).

3 The coordination problem for thermostat-controlled appliances

In the sequel, a first approach to a coordinated control of a cluster of several hundred thermostatcontrolled appliances will be presented. In this paper, only refrigeration devices will be treated; for heating devices, an analogous reasoning applies. First, a simplified dynamic model and assumption set for an individual appliance will be introduced, which will be combined thereafter to a larger group of devices ("cluster"). The stochastic properties of this cluster will be discussed, followed by a first proposal of a control strategy and some corresponding numerical results.

3.1 Simplifying assumptions and appliance modeling

The following assumptions are used for modeling the refrigeration device:

- The mass m to be cooled in the refrigerator is constant. The contained goods have a constant average heat capacity $\overline{c}$.
- The air and the device components contained inside the cooling zone of the refrigerator are attributed to the mass m and the average heat capacity $\overline{c}$ is changed accordingly.
- The temperatures are such that no phase changes take place in the refrigerator. The temperature T is uniform in all parts of the device.

The thermal energy content of a device can be described in relation to the ambient temperature T_{amb}. Its internal state, constituted by the inside temperature T, can then be expressed by the relative energy content $E_{\mathrm{th}}^{\mathrm{rel}}$. This creates a relation to the temperature boundaries T_{min} and T_{max} of the thermostat (hysteresis controller). For a cooling device, this yields:

$$E_{\mathrm{th}} = m \cdot \overline{c} \cdot (T_{\mathrm{amb}} - T) \quad , \tag{1}$$

$$E_{\mathrm{th}}^{\mathrm{rel}} = \frac{T_{\mathrm{max}} - T}{T_{\mathrm{max}} - T_{\mathrm{min}}} \quad . \tag{2}$$

Further attributes of the devices are the net thermal storage capacity $E_{\mathrm{th}}^{\mathrm{net}}$ (energy range between the minimum and maximum temperature constraints) and their rated electric power consumption $P_{\mathrm{el}}^{\mathrm{rated}}$ when switched on.

By basic thermodynamical reasoning, a differential equation for the inside temperature can be derived, which is influenced by heat transfer through the refrigerator walls and the opposing effect caused by the cooling aggregate. Expressed in terms of $E_{\mathrm{th}}^{\mathrm{rel}}$, this yields:

$$\frac{dE_{\mathrm{th}}^{\mathrm{rel}}}{dt} = -\frac{1}{\tau}\left(E_{\mathrm{th}}^{\mathrm{rel}} - E_{\mathrm{th,\ amb}}^{\mathrm{rel}}\right) + \frac{k}{\tau} u \quad . \tag{3}$$

Here, $E_{\mathrm{th,amb}}^{\mathrm{rel}}$ describes the relative thermal energy content of the ambiance

$$E_{\mathrm{th,\ amb}}^{\mathrm{rel}} = \frac{T_{\mathrm{max}} - T_{\mathrm{amb}}}{T_{\mathrm{max}} - T_{\mathrm{min}}} \quad < 0 \quad . \tag{4}$$

The time constant τ and the amplification factor k represent the terms

$$\tau = \frac{m\,\overline{c}}{A\,\overline{\alpha}} \quad , \tag{5}$$

$$k = \frac{\varepsilon_{\mathrm{ca}}\,\eta_{\mathrm{comp}}P_{\mathrm{el}}^{\mathrm{rated}}}{A\,\overline{\alpha}\,(T_{\max} - T_{\min})} \quad , \tag{6}$$

where ε_{ca} is the coefficient of performance of the cooling aggregate, η_{comp} is the efficiency of the compressor, A is the refrigerator hull surface and $\overline{\alpha}$ the average heat transfer coefficient. The input *u* is a binary variable constituting the hysteresis switching controller (thermostat) which acts according to the switching rule

$$u = \begin{cases} 1 & \text{if} \quad E_{\mathrm{th}}^{\mathrm{rel}} \leq 0 \\ 0 & \text{if} \quad E_{\mathrm{th}}^{\mathrm{rel}} \geq 1 \end{cases} \quad . \tag{7}$$

A “reasonably realistic” parameter set of the appliances described by the above model can be found by using available data from refrigerator manufacturers (e.g. daily energy consumption values for approximating the term $A\,\overline{\alpha}$) and assumptions (e.g. the contained mass and heat capacity). For constructing a dynamic model of an entire appliance cluster of several hundred devices, certain stochastic distributions of these parameters are assumed in order to reflect differences between the devices in the cluster.

Note that the parameters of the appliance cluster are assumed to be constant and perfectly known for the control strategy presented in the sequel. Model uncertainties and stochastic user interactions, such as opening the door and loading the refrigerator with additional goods, will be incorporated later.

3.2 Stochastic properties of clusters of several hundred appliances

Although the operation of an appliance cluster with a given parameter set is completely deterministic according to the presented modeling, stochastic properties can be derived for the instantaneous overall power consumption of n thermostat-controlled appliances, which is described by

$$P_{\mathrm{el}}^{\mathrm{total}} = \sum_{i=1}^{n} P_{\mathrm{el},i}^{\mathrm{rated}}\, u_i \quad . \tag{8}$$

For larger clusters, the switching variable u can be regarded as a Bernoulli-distributed stochastic variable. The probability of the device being switched on $P[u = 1]$ is equal to a value p_{on} which is equal to the percentage that the device is switched on during its normal duty cycle. It can be derived by taking into account the daily electric energy consumption $W_{\mathrm{el}}^{\mathrm{daily}}$ [kWh/d] of the device ($P_{\mathrm{el}}^{\mathrm{rated}}$ expressed in W):

$$p_{\mathrm{on}} = \frac{\frac{1000}{24\,\mathrm{h}}\,W_{\mathrm{el}}^{\mathrm{daily}}}{P_{\mathrm{el}}^{\mathrm{rated}}} \quad . \tag{9}$$

Based on straight-forward stochastic considerations, the expected value E and the standard eviation σ of the overall power consumption of the cluster are

$$\mathrm{E}\left[P_{\mathrm{el}}^{\mathrm{total}}\right] = \mathrm{E}\left[\sum_{i=1}^{n} P_{\mathrm{el},i}^{\mathrm{rated}}\, u_i\right] = \sum_{i=1}^{n} P_{\mathrm{el},i}^{\mathrm{rated}}\, p_{\mathrm{on},i} \quad , \tag{10}$$

$$\sigma\left[P_{\mathrm{el}}^{\mathrm{total}}\right] = \sqrt{\mathrm{Var}\left[\sum_{i=1}^{n} P_{\mathrm{el},i}^{\mathrm{rated}}\, u_i\right]} = \sqrt{\sum_{i=1}^{n} (P_{\mathrm{el},i}^{\mathrm{rated}})^2\, p_{\mathrm{on},i}\,(1 - p_{\mathrm{on},i})} \quad . \tag{11}$$

3.3 Outline of the control strategy

The control task to be solved consists of a coordination of the operation of the individual appliances such that the overall power consumption $P_{\mathrm{el}}^{\mathrm{total}}$ can be maintained approximately at a given setpoint and track a trajectory of setpoint changes. As suggested by the previous section, the stochastic nature of the instantaneous power consumption of an uncontrolled appliance cluster has to be addressed. It does not seem practical to try to eradicate the fluctuations around the expected value completely, as this would lead to an excessive switching behavior of the devices. As an alternative, a corridor $P_{\mathrm{el}}^{\mathrm{corridor}}$ of acceptable deviations in upwards and downwards direction from the setpoint is proposed.

The control strategy proposed here ensures a confinement of the power consumption to the desired corridor whilst avoiding excessive switching actions for sufficiently large device clusters. It is based on a one-time-step prediction of the overall power consumption of the cluster, including switching actions between the current and the next time step caused by the switching controllers. According to that prediction, the need for an *additional* increase or reduction in power consumption can be established in order to stay within the outlined corridor. Based on the value $E_{\mathrm{th}}^{\mathrm{rel}}$ and the current "on/off" state of the appliance cluster, a number of appliances which will be subject to enforced switching can be selected. The deviation from the usual device duty cycle can be kept in acceptable limits by a suitable choice of these devices. For the enforced (de-)activation, a switching impulse of one time step is sent to the device, which then toggles its on/off state and resumes normal operation within its temperature boundaries.

3.4 Numerical results

Now a test of the proposed coordination algorithm is conducted using a cluster of 500 refrigeration devices with a rated electrical power of 100, 150 or 200 W (approximately equal shares). The stochastic considerations outlined before suggest that the cluster has an expected power consumption value of 19.251 kW with a standard deviation of 1.441 kW. The aggregated net thermal energy storage capacity is calculated to $E_{\mathrm{th,max}}^{\mathrm{total}} = \sum_{i=1}^{n} E_{\mathrm{th},i}^{\mathrm{net}} = 10.644\ \mathrm{kWh}.$

For the simulation experiment, four scenarios are defined: Scenario 1 represents the uncoordinated operation of the appliance cluster. In Scenario 2, the power consumption setpoint is chosen equal to the expected value, and the flexibility corridor $P_{\mathrm{el}}^{\mathrm{corridor}}$ in which the overall power consumption is to be confined is chosen as one standard deviation in both directions. In Scenario 3 this setpoint is changed by upward and downward steps, whereas in Scenario 4 a more complex setpoint trajectory consisting of steps, ramps and sinusoids is imposed. The simulated time is six hours for all scenarios.

Figure 2 depicts a comparison of the four scenarios in terms of overall power consumption (left), the relative thermal energy content (middle, 50 representative appliances are selected) and the overall instantaneous thermal energy content (right), which represents the "charging level" of the virtual energy storage constituted by the thermal inertia of the appliances.

It can be seen that the proposed algorithm is able to force the power consumption into the corridor around a defined setpoint. As long as the setpoint is equal to the expected consumption value of the LLM cluster, the overall thermal energy content of the cluster does not change significantly. Deviations of the setpoint from the expected value cause the "storage" to fill or empty itself as shown in the right column of Figure 2. Note that $E_{\mathrm{th}}^{\mathrm{total}}$ should be prevented from reaching its upper or lower boundaries $[0, E_{\mathrm{th,max}}^{\mathrm{total}}]$ (depicted as horizontal lines), as this leads to chattering switching actions and failure to attain the corridor of desired power consumption.

Now the question arises whether comfort losses for the users of the appliances are caused. To this end, the total number of switching actions and the total energy consumption are compared for the four scenarios as shown in Table 1. The comparison is made for the whole cluster, as well as the two "best-off" and "worst-off" appliances. The total increase in switching actions is substantial if the cluster is operated close to the boundaries of $E_{\mathrm{th}}^{\mathrm{total}}$ for longer periods, whereas the effect on the total energy consumption seems negligible. Note that the distribution of these impacts on the appliances is not equal, which will require e.g. an equalization strategy over onger time spans or a suitable monetary compensation scheme.

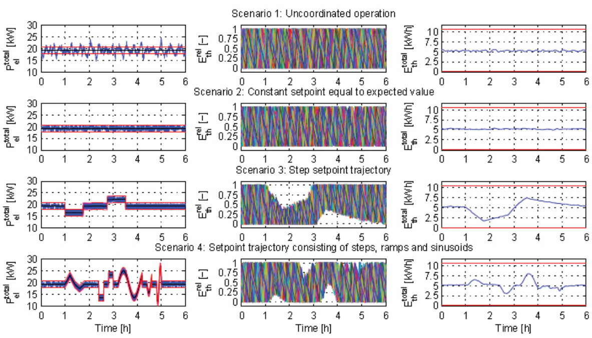

Figure 2: Comparison of overall power consumption, individual th. energy and overall th. energy.

Cluster Property	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Switching actions (total):	15290 (100.0 %)	15681 (102.6 %)	21999 (143.9 %)	17771 (116.2 %)
Switching actions (lowest):	100.0 %	90.9 %	132.0 %	106.3 %
Switching actions (highest):	100.0 %	112.0 %	155.6 %	127.3 %
Energy demand [kWh] (total):	115.35 (100.00 %)	115.49 (100.12 %)	115.32 (99.97 %)	115.46 (100.10 %)
Energy demand [kWh] (lowest):	100.00 %	89.34 %	90.97 %	89.34 %
Energy demand [kWh] (highest):	100.00 %	107.24 %	109.86 %	110.00 %

Table 1: Comparison of increases in switching actions and energy losses for the simulated six hours.

4 Conclusion and outlook

In this paper, a coordination algorithm for a number of thermostat-controlled household appliances with thermal inertia has been presented. It consists of a one-step prediction of the autonomous switching actions within the appliance cluster and coordinated switching impulses that toggle the on/off state of other selected appliances. This enables the appliance cluster to track a setpoint trajectory, which does not have to be known in advance, within certain limits.

It can be seen that the number of switching actions over a certain time span increases depending on the severity of the control action. Generally, the increase in switching actions is small when the cluster is operated near 50% of its maximum thermal energy content $E_{\mathrm{th,max}}^{\mathrm{total}}$ (which is also attained approximately in uncoordinated operation), and increases when the upper and lower boundaries of $E_{\mathrm{th}}^{\mathrm{total}}$ are approached. In terms of overall energy consumption, control actions have an influence through the temperature dependence of heat losses.

Further work will include a more detailed appliance modeling, the inclusion of other appliance types, consideration of stochastic user interactions and model uncertainties, and the exploration of more elaborate predictive control and optimization algorithms.

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Ethics for Energy Technologies

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Recently the topic of worldwide energy supply has become an increasingly urgent issue. It is assumed nowadays that renewable energies will be the energy sources of the future because of the depletion of fossil fuels and the increasing global warming which is caused by the production of CO2 from burning fossil fuels. Especially energy production from biomass and photovoltaics are potential future energy sources because they ensure a sustainable supply. For the energy supply based on the corresponding processes land area is needed, where the required area for energy production from biomass is higher than for the energy generation with photovoltaics.

At the same time the world population as well as the consumption of food is increasing. Furthermore the energy consumption per capita is rising worldwide because in populous countries like China and India the standard of living is increasing. For both, the rising demand of food and energy being supplied from renewable sources, and area will be needed. Via global balance sheets it can be shown that by the year 2050 – assuming that nutritional habits are the same as today – most of the usable land area will be needed to guarantee food and energy for every inhabitant. If the world population will be increasing only slightly faster, there will not be enough land area to ensure both (Pfennig, 2007).

To manage this situation answers to several questions need to be given which partly constrain human rights of every man, for example the actions that need to be taken to reduce the population growth. A suggested solution could be the acceleration of the development of the developing countries by financial aid of the developed countries, because an increase of the standard of living normally leads to a decrease of the number of births in a country without impacting human rights.

Another important human right is the right of every human being not to be undernourished. As shown before, the population growth leads to a higher demand of nutrition and energy. Even today not in all regions of the world enough food for every inhabitant is available, so that it is expected that the population growth will intensify this problem. A partial solution could be a worldwide plant-based nutrition. The land area per person which is needed for conventional food is more than twice as much than that needed for purely plant-based nutrition.

According to these arguments there is a need to discuss how the right to bear children and the right of sufficient nutrition can be balanced. To find an answer to these questions an interdisciplinary work appears to be necessary. Therefore, at the RWTH Aachen University a project has been implemented, in which scientists of natural, engineering and social sciences as well as philosophers will work together to find and evaluate feasible scenarios of human development.

Within the scope of this HumTec-Project at AVT • Thermal Process Engineering a model will be developed, based on which ethical and normative statements are deduced that form the basis for political decisions. The basic of the model will be global balances in a first step which will be validated and refined in the future. The needs and desires of the population, which are the driving forces of human action, will be modelled by fluxes of material. Figure 1 shows a first idea of the fluxes to be accounted for in balances.

1 *AVT - Thermal Process Engineering - www.avt.rwth-aachen.de*

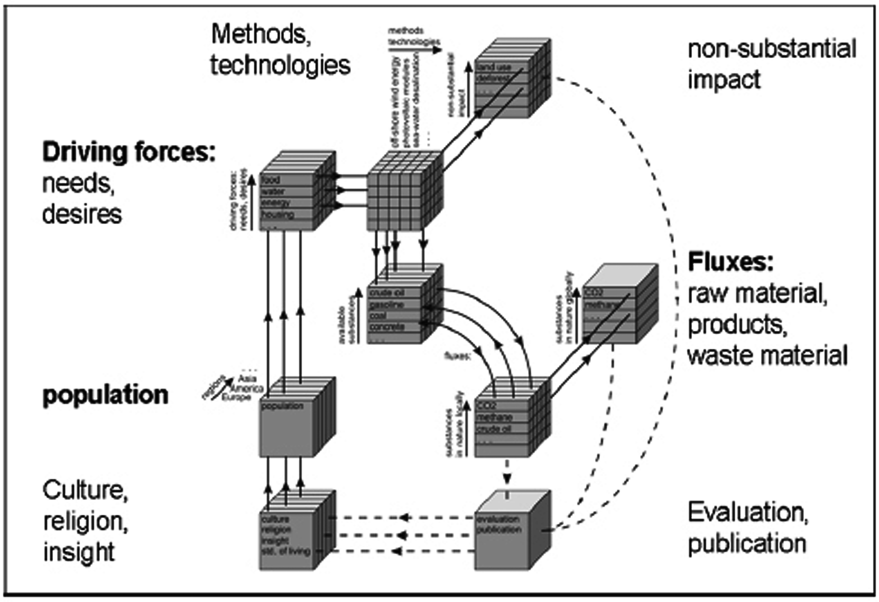

Figure 1: Schematic representation of the balances and fluxes represented in the modelling tool.

The needs and desires of every human being for food, water and energy lead to fluxes of different materials like raw material, products and waste material. To satisfy these needs different methods and technologies can be used. The fluxes also generate a non-material impact, e. g. by deforestation. Those fluxes will be modelled by global and local balances. The evaluation of the fluxes, which is depicted by the dashed lines in the figure, will also be included in the model and be the basis for the ethical implications.

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PV-H2-research-boat SOLGENIA: Emission free energy supply and data management for optimized use of energy

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Introduction

In view of the increasing problem of energy supply, the University of Applied Sciences Konstanz developed a research boat powered by photovoltaic and fuel cells. The core question of the research project is, if such a combination represents a viable option for recreational and commercial boating. To answer this question, long-time performance-studies of each component by itself and in combination with others in marine environment are necessary. An Information-Management-System (IMS) interfacing to about ninety parameters was developed, providing the basis for analysis (Figure 1).

Energy supply system

The energy supply system consists of two energy conversion units (PV-generator and fuel cell) and two energy storage units (battery and hydrogen tank). A DC/AC-inverter together with an asynchronous motor converts the electrical energy into mechanical energy for the propeller. The voltages between the three fuel cell modules as well as the PV-generator and the battery are adjusted by DC/DC-converters (see figure 1).

The hydrogen will be provided by an electrolysis unit within the laboratory driven by a PV-generator and stored on land. One of the research aims is to adapt the hydrogen production depending on solar radiation to the hydrogen demand by the stationary fuel cells (in the laboratory) and the mobile fuel cells (in the boat).

Information management system (IMS)

The requirements which the IMS has to fulfil are quite complex: 1. a real-time control-system has to operate the boat and process the parameters, 2. a graphical user interface has to provide meaningful and clear information for skipper as well as service and scientist, 3.measured data has to be periodically transmitted to a data bank at the institute for further processing. Use of the Internet gives independence of location.

Energy management

Energy management is one of the main tasks of the IMS. One of the research aims is to develop and optimize the management rules. The energy system itself consists of one controllable (fuel cell) and one not controllable energy converter (PV-generator) as well as of two energy storage devices (battery and H2-tank). Parameters affecting the energy management are among others: speed of boat, distance to travel, battery capacity and solar radiation. These parameters are either measured directly or calculated by the IMS.

The Solgenia additionally will be used as laboratory unit in teaching: The students shall become familiar with the fundamental problems of managing renewable energies.

Graphical user interface

An industrial touch panel PC serves as man-machine-interface. The graphical user interface was divided into two basic groups: skipper and service/scientist. The menu for the latter group was protected by password to prevent an inexperienced skipper from creating any mischief. In one of the skipper menus, the energy management system informs about the best way to reach the destination with the least amount of energy consumption (Figure 2).

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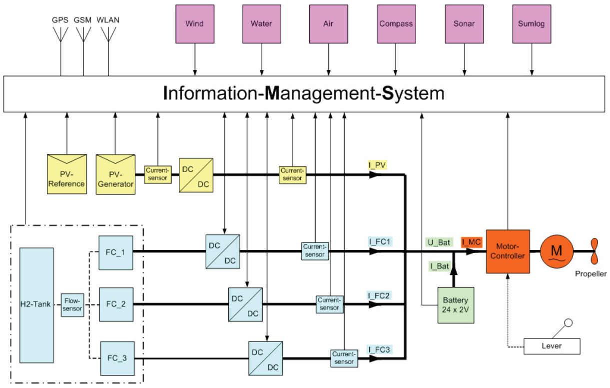

Figure 1: Schematic system diagram of the PV-H2-Boat.

Figure 2: Skipper menu for energy check.

Figure 3: Solgenia on Lake Constance.

Appendix

Technical Data of the Solgenia

length:	8,5 m	PV-generator:	720 W_p
width:	2,5 m	battery capacity (80%):	210 Ah
beam:	0,5 m	system voltage:	48 V
displacement:	2,5 m³	fuel cells:	3 x 1,2 kW
		hydrogen tank:	70 l, 350 bar
propeller:	3 blades, 1125 min^{-1}		
diameter:	406 mm (16“)		
pitch:	292 mm (11,5“)	asynchronous motor:	4/8 kW, 2300 min^{-1}

Direct Simulations of Radiative Heat Transfer in Porous Media

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Solar chemical reactors for effecting high-temperature gas-solid transformations usually feature cavities containing directly-irradiated two-phase solid-gas reacting media [Steinfeld and Palumbo, 2001]. Effective thermal transport properties such as the extinction coefficient, scattering phase function, scattering albedo, thermal conductivity, and viscosity are needed to model heat transferchemistry interactions for anticipating the consequences of a given design decision on the reactor's performance, and for optimizing the reactor design for maximum energy conversion efficiency. In general, materials encountered in solar chemical reactors are of complex composition and structure, and the properties, especially at high temperatures, can be determined by combined experimentalnumerical studies. Of particular interest are pore-level tomography-based Monte Carlo ray-tracing [Petrasch et al. 2007] and direct pore-level CFD simulations [Petrasch et al. 2008] assisted by spectroscopic measurements [Osinga et al. 2006, Coray et al. 2007, Lipiński et al. 2008].

A computational technique is developed to study heat transfer phenomena in porous media such as opaque reticulate porous ceramics (RPCs) [Petrasch et al. 2007, Petrasch et al. 2008] and packed beds of large semitransparent particles. Exact geometrical representations of the media are obtained using computer tomography. A unique mesh generator has been developed to produce unstructured tetrahedral meshes from grey levels of the tomograms. Radiative heat transfer phenomena are computed by executing the collision-based Monte Carlo method directly on the grey levels. The general methodology accounts for absorption and scattering in both phases, and for interface phenomena such as reflection and refraction. Convection and conduction heat transfer phenomena are computed on the unstructured tetrahedral mesh. Moreover, the Monte Carlo solver can be coupled to the convection-conduction solver, both run on the unstructured mesh to directly compute combined heat transfer in porous media. Stochastic oscillations in surface radiative sources can be reduced by decreasing mesh resolution used in the Monte Carlo computations as compared to mesh resolution used for convection and conduction.

The current and future developments include application of the technique to predict radiative properties of packed beds containing (1) large $CaCO_3$ particles and (2) carbonaceous materials, and (3) to study radiation-conduction-convection-chemistry interactions in porous materials encountered in high-temperature solar reactors.

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Solar Thermal Energy in Nyon Site

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During the years 2006 and 2007, Novartis Consumer Health S.A. and BMG Engineering AG evaluated the process energy saving potential of a building at the Novartis site in Nyon VD. In this building an Active Pharmaceutical Ingredient (API) is being produced in a batch process. Besides a range of measures to reduce process energy consumption, waste heat recovery measures were identified. As the temperature level of the available waste heat streams is rather low, their efficient use to meet process energy demands is hindered. This issue is a commonly known problem of waste heat recovery in industrial processes.

However, through the use of solar thermal collectors at the production site in Nyon VD, the temperature level of the waste heat streams can be upgraded and therefore meets process heat demands. The scope of the study is a technical and economical analysis of the solar thermal system, also regarding the applicability of such a solar thermal system at other production sites.

By means of process simulation, the amount of waste heat originating from a batch process was modeled as a function of time as well as the process energy demand of another batch process and the facility heating. The heat output of different solar thermal collector configurations (different collector orientation and field size) was modeled as a function of daytime and season for the production site in Nyon VD. The results were used as input parameters for the aforementioned process simulation.

The efficiencies of the two subsystems solar thermal collectors and waste heat recovery measures were analyzed, as well as the overall system efficiency for the combination of the two subsystems for three different system configurations. Finally the economics (net present value) of the system were analyzed which take part in the investment decision-making of Novartis Consumer Health S.A.

This study was co-financed by the Swiss Federal Office for Energy. The Institute for Solar Technology SPF from HSR Rapperswil covered the solar modelling, technical and IT expertise.

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Advanced integration of energy conversion, production processes, and waste management in chemical batch plants

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In the chemical batch plants industry, the production of chemicals on industrial scale heavily relies on the availability of utilities such as energy in different forms (e.g. steam, electricity, brine), cooling water, ice and others. These utilities represent a significant share of the production cost of chemicals and define to a large extend the environmental impact resulting from chemical production. The efficiency of utility usage in chemical industry is primarily defined by two major factors, the efficiency of the utility generation (e.g. steam production) and the efficiency in using the generated utilities for achieving as high productivity of chemicals as possible. The quality of the process integration considering together the chemicals production, the heat and power integration and the waste management is critical for the process design. An approach considering the site scale integration of the chemical batch plants has to be developed in order identify the energy savings potentials during the design of either utility generation systems or chemical production processes. One of the major aspects in this context is the waste treatment in general and solvent management in particular. The increased process integration, e.g. recycling of material flows, reduces the amount of waste to be treated and many waste treatment technologies require additional utility input (e.g. stripping, sewage treatment) has to be compared with energy valorisation for utility generation, e.g. by generating steam through waste incineration. This is particularly an issue for the huge amount of waste solvents that are generated in pharmaceutical and fine chemical production as it is typical in batch plants. Recycling of solvents requires additional utility input (typically in form of steam used in distillation columns) while incineration of solvents can heavily be used for utility generation. Life-cycle assessment and economic considerations can deliver an answer on the environmental or economic more favorable option.

The project under development is a join project between ETHZ and EPFL and aim at studying and developing methods to consider batch chemical plants design with more energy-efficient chemical production. The new approach will be able to identify optimal integration beween energy conversion, production processes, and waste management options while considering all boundary conditions such as a variable product portfolio in chemical batch plants.

The first results of this study will be presented. These include a method for defining the energy requirement of the batch chemical processes and a method to realise the large scale combined heat and power integration of chemical batch plants.

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Sufficiency – Does Energy Consumption Become a Moral Issue?

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1 Introduction

One may state that the smartest, cheapest and most sustainable energy is the energy not used. Basically, there are three ways to reduce energy use: First, there are strategies to increase technical efficiency, that is to provide a certain level of energy services with lower energy input; second, there are strategies to increase economic efficiency, that is to "get the prices right", internalising externalities and thus leading to efficient levels of energy services given individual agents' preferences. Third, there are sufficiency strategies (Princen 2005), which make the levels of energy services itself a topic for discussion and aim at lowering those. In addition to these reduction strategies, there is "clean" energy with relatively low external effects. A combination of those strategies may be most promising for a sustainable energy system. However, the current debate on sustainable energy systems is largely dominated by technical and economic efficiency and clean energy strategies, while sufficiency plays a minor role only (an example is the debate in Switzerland, see e.g. Jochem 2004, Berg et al. 2007, ESC 2008).

This focus on efficiency faces several problems. First, there are the problems of technical efficiency: the rebound effect (simplified for energy efficiency: lower energy bills increase disposable income, which in turn is used for (more energy-intensive) consumption elsewhere – the size of this effect is subject to controversies, see e.g. Dimitropoulos and Sorrell 2006) or a target shift of targeted measures (simplified: more energy efficient automobile motors are not used to drive the same mileage with less gasoline, but rather to increase mileage or to use heavier cars with the same gasoline input, i.e. at the same costs), or an increasing total (if the aggregate total units demanded for a certain energy service grow faster than the energy use per unit decreases). Second, there are the problems of economic efficiency: identifying prices for all goods involved with the corresponding information and weighting problems related to cost-benefit and other valuation analysis. Third, clean energy may face problems of scale, when relatively low external effects add up on aggregate (cf. the various problems related to global bioenergy strategies, e.g. the potential competition for land and water between biomass for energy use and food; see e.g. Muller 2008 for some overview and references). Finally, there are the missed opportunities for increased sustainability from not employing sufficiency strategies.

Thus, if not for other reasons, the precautionary principle suggests that the current debate on sustainable energy systems be complemented with an unbiased and critical discussion of sufficiency. In the context of social sciences, focusing on peoples' attitudes, motivations and behavioural patterns regarding sustainability and related concrete actions, sufficiency is currently addressed to some extent (e.g. Kaufmann-Hayoz and Gutscher 2001, Gutscher in Jochem 2004, Jamieson 1992, 2006). Actually, a discussion of sufficiency would neither be new. It has been led in the context of the environmental movement in the 1960ies and 70ies. It inspired the debate on sustainable energy consumption, but did not effect in fundamental behavioural changes and general implementation of sufficiency strategies. It was characterised by an often overly naïve attitude towards behavioural changes and social engineering. This is a danger of any sufficiency strategy: being ideological, anti-liberal and fundamentalist.

A modern conception of sufficiency should account for this legacy. Naïveté and ideology need to be avoided. In my research, I explore such a modern concept of sufficiency, which is adequate for a liberal society. In particular, I frame sufficiency in a philosophical context, thus complementing socio-psychological approaches. This requires the question "How should we act?" to be posed as a clearly moral and normative question, accounting for the important role efficiency plays, but not relying on it as the sole legitimate guiding principle. Other principles are the precautionary principle, justice or "do no harm". These principles and related basic ethical concepts such as "responsibility" are however partly shaped in a historical context of non-global problems and personal interaction. A translation into today's situation and its specific complex problems such as an equitable, sustainable and reliable energy system is thus necessary. This becomes evident when addressing basic questions such as "Who is responsible for climate change?".

Besides these fundamental problems regarding the adequacy of traditional ethical key concepts for today's problems, there are also fundamental problems regarding concrete action, such as the fact that millions of per se harmless individual decisions can have detrimental effects on aggregate and the separation of actions and their consequences in a globalized world (Höffe 1993, Bandura, in press).

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Such considerations motivate framing life-style questions such as energy consumptions as moral questions. Moralization of some issues in the ongoing debate on sustainable energy systems is one way to incorporate sufficiency. Clearly, the consequences of this course of action for liberal societies have to be discussed in detail, as a key a characteristic of liberal societies is the fact that fundamental questions of lifestyle such as religion, sexual orientation or political attitude are decidedly no moral questions any more and clearly should not become such again. A discussion of which lifestyle questions may become moral again and why is thus of paramount importance.

In this paper, I avoid this question by focusing on the concrete question whether energy consumption today becomes a moral issue and how this relates to sufficiency. Using an example to discuss sufficiency along the lines laid out above avoids the necessity to differentiate in detail which lifestyle questions are moral, which are not and it avoids weighting different lifestyle aspects. This helps to in detail investigate the process of moralization of such hitherto non-moral aspects. A more general discussion of this has to be provided at a later stage of the research. Focusing on such a concrete example also emphasizes the importance of the single individual as a consumer and of his/her responsibility. It can thus help to make general problems such as responsibility for climate change etc. more tangible.

The structure of the paper is as follows. First, the relation of sufficiency to efficiency is clarified in detail (section 2). Many strategies for sufficiency can be understood as encompassing long-term strategies for (economic) efficiency. This helps to at least partly reconciling economic or efficiency based approaches with the idea of sufficiency. Second, using the example of a sustainable energy system in Switzerland, current policies, largely based on technological and economic efficiency and clean energy and their effects are reviewed. Referring to the goals of sustainably energy systems, hypotheses on what is missing to reach those with the above mentioned policies are developed and substantiated (section 3). Section 4 presents sufficiency as an alternative approach. It also discusses the potential of a moralization of the problem and a shift in goals. Section 5 discusses the consequences of such a new approach. What would a consequent sufficiency strategy and moralization mean for society at large, which problems may arise, what does it mean concretely and how could it be implemented? Section 6 concludes.

The following contains a very short description of the chapters, indicating the main topics and lines of thought for my research.

2 Sufficiency as Efficiency and Beyond

Increased technical efficiency refers to increased output for a given input, reduced input for a given output or increased output with increased – but less increased – input. Increased economic efficiency refers to “pareto-improvements”, in the energy debate often reflected by interalisation of externalities (“getting the prices right”). Sufficiency, on the other hand, addresses the level of output per se – and not in relation to the inputs, resp. it asks whether an economic activity needs to be performed and not whether it is performed “efficiently”. Examples are:

- technical efficiency: reduced gasoline consumption for the same travel distance and car weight.
- economic efficiency: putting a price on pollutants; or setting harvest quotas for a fishery to assure its annual renewal. This can be seen as a sufficiency strategy: setting a limit level to the harvest by not harvesting more than the quota. I emphasize that this is not yet sufficiency, although it is formulated via maximal levels of use. The quota is not derived from a notion of “satisfaction” or “enoughness”, it is thus long-term, wisely implemented efficiency.
- Sufficiency: finding “sufficient” levels to mobility: how much (auto-)mobility is “enough”? or of (heated) living-space needs: how much is “enough”? This goes beyond efficiency and it brings out the fundamental problem of sufficiency: how much is “enough”? How is it determined and who determines it?

3 Common Visions for Sustainable Energy

3.1 What is done and what this effects

Examples of goals and measures for sustainable energy systems are reduced domestic electricity consumption although use of appliances and living-space increase, reduced transport fuel use (better logistics, more efficient motors, brake-energy recycling) or increased efficiency in industrial energy use (heating, cooling, etc.).

“Soft” issues play a minor role only – and then, mainly on the level of socio-psychological aspects of acceptance of new technologies etc. in society. Only view strategies involve true changes in habits, e.g. increased public transport and car-sharing.

3.2 Goals for Sustainable Energy

The goals of current policy for sustainable energy systems are to develop strategies assuring constant or increasing energy services use levels with decreasing energy input ("efficiency" strategies). Such strategies, ideal in an ideal world, may fail to wholly achieve their goals in real world. Therefore, the current discussion on sustainable energy systems should be complemented with a discussion of the energy services use levels themselves ("sufficiency" strategies).

4 One Step Further

This deficit cannot be remedied with additional measures to reach the given goals, changes in these goals are necessary (and adequate measures to reach those have to be developed). Thus, the energy services use levels themselves need to become topic of the discussion, not only their efficient realisation.

However, concrete values for "sufficient" use levels can hardly ever be determined with rational arguments. Rational arguments lead to efficient use levels, that can take any value, given they are supplied "efficiently". But implementation of this faces the problems of efficiency strategies mentioned in the introduction.

Here, I thus justify Implementation of sufficiency strategies primarily as an alternative approach to complement the ideal approaches for an ideal world (efficiency) that do not fully achieve their goals in a real world. But if not by rational arguments, how then such levels may be determined and implemented?

5 Sufficiency, Moralization of Lifestyle and Society

There are basically two paths of implementation, namely mandatory or voluntary. Mandatory – by prescription – is clearly no viable path in a liberal society. It only has potential for some extreme cases (and such that are unimportant regarding reduction of personal freedom with respect to avoidance of external effects), such as prohibition of water-scooters on Swiss lakes. It thus remains voluntariness – embedded in a wider societal discussion. This can be captured by several aspects of a "moralization" of the underlying "problem" – here: energy consumption –, i.e. of lifestyle decisions. Key aspects of this are

- temperance and conceptions of a "good life" ("How much energy services do I need?")
- "do no harm" principles ("Do I harm others by my energy consumption?")
- principles of justice ("What was my consumption in a just and sustainable global energy system?")
- and also the precautionary principle, although this can also be an efficient strategy under risk aversion.

Although all this should be discussed under absence of governmental prescriptions regarding life-styles, an encompassing discussion on this is needed, including the policy level.

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Integrated Assessment of Technical Oriented Paths for the Future Cars Powertrains on a Swiss Case Study

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1 Background and Introduction

In the coming decades, the use of energy confronts society with new challenges for which new solution strategies have to be developed. The first consequences of climate change, the mid-depletion point of oil and the re-concentration of crude oil production in the Middle East demand for more efficient use of energy and a shift to less carbon intensive resources. Increasing population and the global economic development influence the energy drivers and boost in the end the demand for enegy services. R&D and innovations that help to realize energy efficiency potentials are a key factor for decoupling energy demand from the increasing needs. Moreover new technologies allow the substitution of conventional fuels with biogenic and renewable energy carriers. Reducing the dependence on fossil fuels involves in a structural change of the whole energy system by a stronger interconnection between the conversion and the end energy sectors besides a qualitative as well as quantitative extension of the classic conversion sector. The path towards decarbonization will increase the share of electricity in the final energy demand on the one hand and on the other hand new secondary energy carriers like hydrogen and biofuels will contribute to the substitution of conventional fossil fuels. Therefore, a long term perspective and an integrated energy system analysis, that allow the simulation of the whole energy chain, including the interactions between traditionally separated sectors as well as the production of alternative and renewable fuel, is needed to develop strategies to meet future, energy-related challenges.

2 Simulation Tool and Methodology

The *Energy Navigator* is an energy model system focused on Switzerland with a considered time frame until 2035. It integrates a module which converts demographic and economic inputs into energy drivers, the final energy demand models, the energy conversion models and a macroeconomic model. The Navigator uses a scenario approach allowing the transparent simulation of changing boundary conditions, the evaluation of uncertainties through sensitivities and the assessment of different technical oriented development path for pecific sub-systems. Hard links between the different modules assure the consistency and enhance the significance of the results.

This modelling structure can address new problems which have increasing relevance and allow the deep understanding of the whole system that is in the end the precondition to recognize and exploit potential synergetic effects of coupled mechanisms.

3 Options for the Transportation and Implications on the Conversion Sector

The described simulation system has a dedicated transportation module which includes most of the means of transportation for the passenger as well as for the freight mode. The dynamics of the cars fleet is computed with a very detailed differentiation which includes the powertrain type, the power, the weight and the construction year as cohort. The development of the transport performance in terms of person’s kilometer is a function of the demographic and economic deveopment and is as well differentiated into the cars categories basing on census data. The values for the specific consumption derive from importers specifications for the present and are calibrated with statistic for 2006. Future values rely on technical assumptions on the reduction based on plausible efficiency improvements. The market share for new cars with alternative powertrain is displaced in the weight categories so that the additional weight or extra components (e.g. batteries) is automatically taken into account for the consumption data.

Fixing the development of the transport performance and varying the diffusion of new technologies individually in different simulation runs enables to assess the effects of changes in the fleet structure. 5 scenario variations for the forced penetration of different powertrains were performed, i.e. for H_2 driven internal combustion engines, conventional full hybrids, plug-in hybrids, H_2 driven fuel cells and full electric battery driven cars. On the conversion side water and steam electrolysis were applied for the production in the cases which involve in the demand of H_2. The corresponding results were compared with the reference case in terms of energy demand and CO_2 emissions.

The findings point out that new powertrain technologies will play a key role in the design of the future mobility allowing sensible efficiency gain and emission reductions. The (partial) electrification of the propulsion chain is more suitable than the switch on H_2 driven concepts, for which an implementation would mean an improvement compared with the reference case only under very strict constraints on te efficiency and on the CO_2 emissions of the related electricity production methods. Moreover, the progressive substitution of fossil fuel towards the electrification of the system for an energy efficient, low carbon intensive individual mobility will have complex influences on the conversion sector and induce new interactions between the demand and the supply side which have to be considered for a consequent planning, also in order to recognize and exploit synergetic effects (e.g. the use of plug-in hybrids for energy storage and power generation on demand).

Implications of Large-scale Introduction of CCS in the North European Electricity Supply System

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This study examines possible pathways for the electricity supply systems in Northern Europe (Germany, UK, Denmark, Finland, Sweden and Norway) until the year 2050. The focus is on the response to an assumed common stringent CO_2-reduction target and on the role of Carbon Capture and Storage technologies (CCS). Special emphasis is put on investment strategies in terms of turn-over in capital stock, timing of investments and the infrastructural implications of large scale introduction of CCS. The analysis is carried out with the aid of a technoeconomic model, in which a scenario including CCS is compared to a scenario excluding this option. The Chalmers Energy Infrastructure databases provide information on present and planned power plants down to block level for plants exceeding 10 MW net electric power (see fuel mix of current national systems respectively in Figure 2). The phase out of the present capital stock (power plants) is based on assuming technical lifetimes for these plants, which yield residual capacities in each year, here referred to as the *phase-out pattern*. CCS technologies are assumed to become commercially available in 2020.

The age structure of the power plants indicate that full turn-over in capital stock will take several decades with the present generation capacities accounting for around 50 percent of generated electricity in 2020 (see Figure 1). The development of the electricity generation, as seen in Figure 1, stems from assuming a CO_2 cap commonly introduced among the regions of 20 percent emission reduction by 2020 and 60 percent by 2050 relative to 1990 emission levels. The results show that the year 2020 and 2050 targets can be met at a marginal cost of abatement in the range of 25 to 50 €/ton CO_2 over the period studied. The CO_2 target by the year 2020 is met by implementation of renewable electricity and fuel shifting from coal to gas. After 2020 CCS technologies constitute an attractive way for cost efficient and almost CO_2-free base load, given the assumptions made in this study. However, wide spread application of CCS is an infrastructural challenge with respect to building up CO_2transportation and storage systems and expansion in coal supply systems. Given the price assumptions applied, gas may not be competitive once CCS enters the system causing early retirements of such units or possibly stranded assets.

Figure 2 shows that under a common emissions trading scheme CCS is introduced in Germany and the UK (see Figure 2), which currently have the largest shares of conventional fossil fired capacity. The results also indicate that CCS may become an insignificant option in the Nordic countries due to lower electricity prices and better conditions for renewables than Germany and the UK.

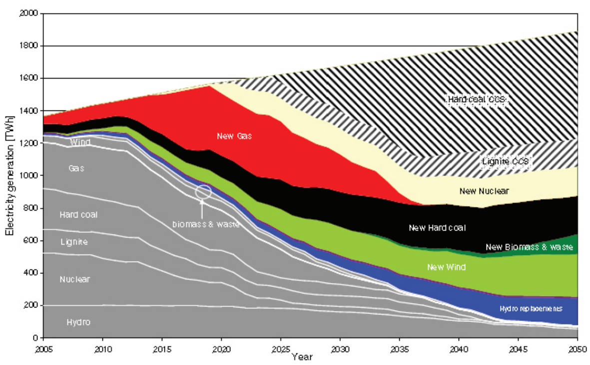

Figure 1: Electricity generation in the scenario including CCS aggregated from the Nordic system, Germany and the UK. Contributions from present generation capacities are represented by the grey field, where fuels/technologies are indicated by white lines.

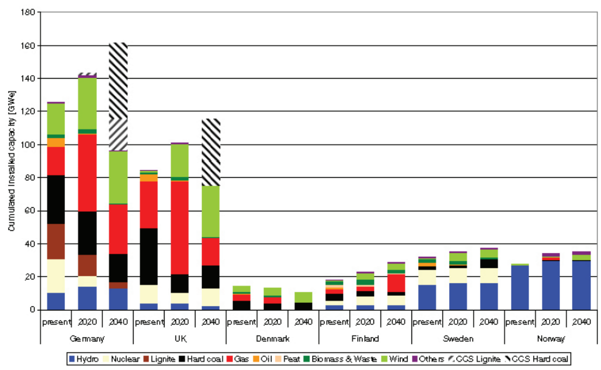

Figure 2: Cumulated installed capacity per region in the present system, in 2020 and in 2040 for the scenario including CCS.

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Development of a Liquid Fuel Non-catalytic Reformer based on Super-Adiabatic Combustion for Fuel Cell Applications

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The scarcity of fossil fuels and the increase in greenhouse emissions are driving the research and development of hydrogen utilization in association with fuel cells as a promising way to a carbon-free future. Since the production, distribution and storage of hydrogen is still not economically competitive, on-board/on-site reforming of hydrocarbon fossil fuels into syngas represents the initial step towards the "hydrogen economy" and the fuel cell market uptake. The availability of distribution plants for liquid fuels such as diesel and gasoline motivates research in compact fuel processors for these feedstocks.

The present project aims, initially, to develop a relatively inexpensive technique for fossil fuel reforming based on noncatalytic Partial Oxidation. At a later stage, to adapt this reformate with suitable clean-up stages for a PEM fuel cell. Among the various techniques for on-board hydrocarbon reforming to syngas ($CO+H_2$), Partial Oxidation (POX) presents the best features as compactness and quick response [1]. The reformate gas can then be used for fuel cell applications or for hydrogen enrichment of conventional combustion technologies. The University of Cambridge reformer is based on combustion inside an inert porous medium. The high conductivity and radiation of the porous matrix allows the recirculation of the post-flame zone heat to the region before the reaction zone, thus resulting in a socalled "excess enthalpy flame", also known as "super-adiabatic combustion". This allows a larger flame speed than a free flame of the same equivalence ratio, since the reaction zone is at higher temperatures higher than the adiabatic flame temperature of the initial fuel mixture [2,3,4]. It also allows the stabilization of very lean or very rich reaction zones, which hence can allow super-adiabatic combustion to be used as a reformer.

The experimental apparatus consists of a tube burner comprising a section for the atomization and evaporation of the fuel and a section for the reforming of the fuel. The first step is achieved by means of an air-assist atomizer where electrically-preheated air at 520 K and liquid fuel are mixed in a spray cone. Complete evaporation is achieved due to the small droplets achieved by the atomizer. The second step is carried out in a two-layer porous matrix. The porous matrix comprises Al_2O_3 beads of different size: a first layer with small particle diameters precludes flashback, allowing the reaction zone to be stabilised in a second layer with large particle diameters. This concept has been demonstrated at the University of Cambridge for gaseous fuels and its feasibility was examined for pre-vaporised liquid fuels [5].

Various porous materials (packed beds of ceramic beads and ceramic foams) were also tested [5]. In this work, more extensive experiments have been carried out with n-heptane and diesel, emphasizing the development of the burner for practical applications. Fig. 1 (n-heptane) and Fig. 2 (diesel) show the reaction zone during reforming at rich conditions: the high-temperature region (red hot) extends for several centimetres inside the large-particle porous medium, but does not penetrate upstream of the interface of the two layers. Gas samples downstream of the porous media layers were analysed with a Gas Chromatograph equipped with a FID and a TCD. The syngas obtained for n-heptane at a firing rate P of 4 kW and an equivalence ratio of $\varphi = 2.5$ contained 11.5% hydrogen and 18% carbon monoxide (by vol.) on a dry basis. Diesel fuel reforming at P=5 kW and $\varphi = 2.5$ gave a hydrogen concentration of 10.9% and a carbon monoxide concentration of 19.6%. Tests at constant firing rate exhibited a trend of increasing syngas yield against increasing equivalence ratios, as Fig. 3 and Fig. 4 demonstrate. Intermediate hydrocarbons (methane, acetylene, ethylene and ethane) were also detected in the products with a concentration connected to the equivalence ratio.

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The next steps involve reformer optimization and gas clean-up for a fuel cell application. In addition, modelling by a premixed flame code, suitably modified to include heat transfer to the solid phase [4], will be performed to understand better the effects of residence time and operating conditions on the composition of the reformed gases.

Figure 1: Photograph of n-heptane flame (P=4 kW, φ=2.5).

Figure 2: Photograph of diesel flame (P=4 kW, φ=2.5).

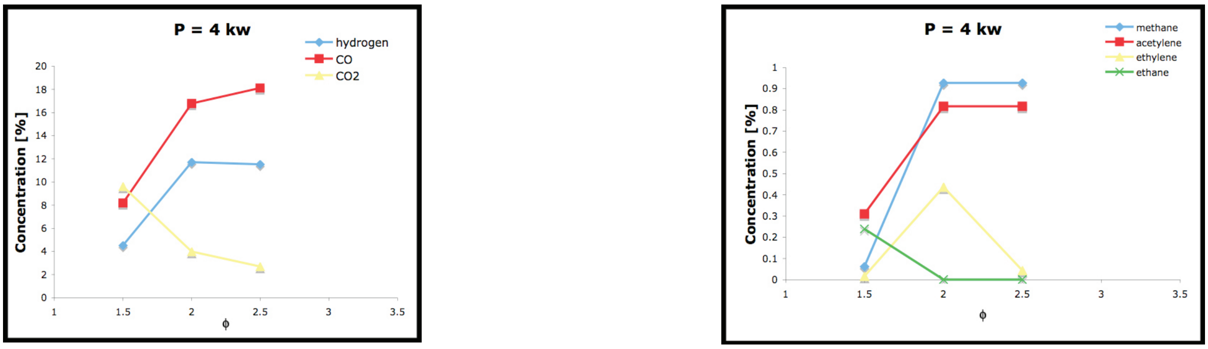

Figure 3: Mole fractions in reformate gas against equivalence ratio for diesel, P = 4 kW.

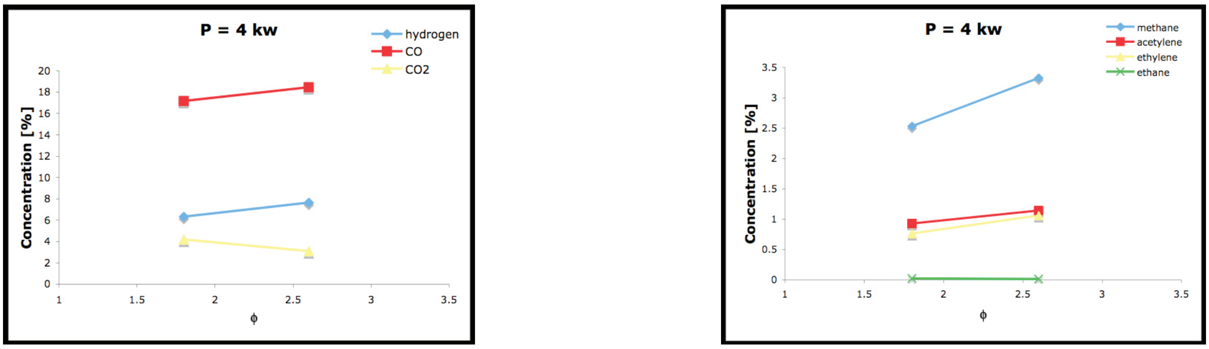

Figure 4: Mole fractions in reformate gas against equivalence ratio for n-heptane, P = 4 kW.

Acknowledgements

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Efficient Energy Conversion in a Sulfite Pulp Process

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Reducing energy consumption in the pulp and paper industry can lead to considerable cost savings. When implementing an energy efficiency program in a mill, the three main points to consider are the reduction of the energy requirement, the energy recovery and the efficient integration of the energy conversion system. This analysis leads to the definition of an energy efficiency road map with the evaluation of the energy savings and the related investment costs. Due to the high level of integration of a pulp and paper process, simple methods cannot be applied alone; computer-aided process engineering tools have to be used. In this poster, we present the application of a process integration methodology for energy savings options in the pulp and paper industry.

Energy efficiency enhancement options have been developed for the Borregaard Schweiz a.g. calcium bisulfite pulp manufacturing mill. This mill has the particularity that it does not only produce pulp but, also bioethanol and precipitated lignin. It is highly integrated and there are strong interactions between individual units (pulp making, lignin extraction, bioethanol production, chemical recovery and recovery boilers, etc.) (Figure 1).

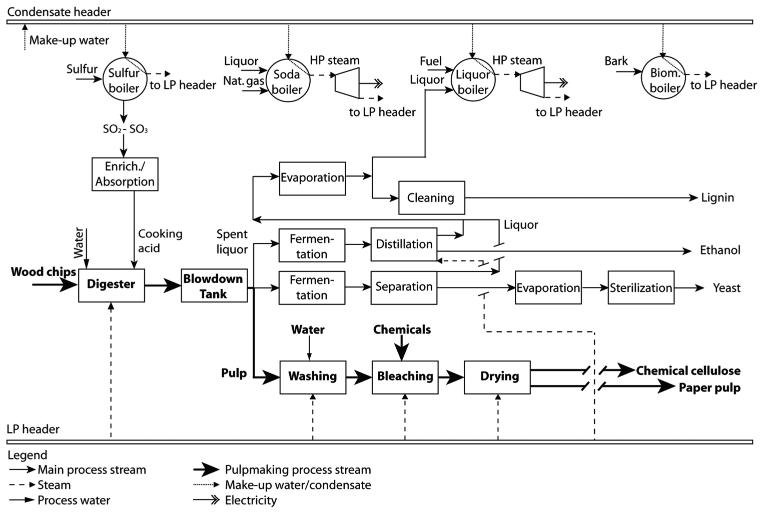

Figure 1: Simplified process diagram, Abbreviations: LP & HP: low and high pressure steam.

In this context, mill-wide process simulation combined with the application of process integration tools, such as pinch analysis, is the key for reaching the energy savings target. A comprehensive computer-aided methodology to analyse the integration of utility systems and energy conversion technologies in the mill has been developed. Its goal is the identification of energy savings options considering process integration and thermo-economic optimisation techniques.

Using data reconciliation models for the process and the energy distribution and conversion systems at Borregaard Schweiz AG, the process heat requirements have been defined. A top-down approach (Figure 2), starting from the actual energy purchased by the mill, the conversion technologies used to produce utilities and their distribution to the process, has been followed.

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A first analysis of energy savings achieved by means of energy conversion has been performed. It identifies energy saving measures such as recovery of the sensible heat of the boilers flue gas and increasing condensate returns. A systematic definition of the process heat transfer requirement defined as hot and cold streams in the process has been developed in order to compute the minimum energy requirement of the process. For the steam consumption sections, the process requirements have been defined considering the multiple representations concept: the energy requirement of the process unit operations are systematically analysed from their thermodynamic requirement, but also from the way they are satisfied by the technology that implements the operation and finally from the way they consume the distributed energy (Figure 3a). Defining a given process unit requirement from different temperature-enthalpy profiles gives an estimate of the energy efficiency of the heat transfer system in that unit operation and identifies possible energy savings. The analysis is completed by the identification of possible energy recovery from waste streams and from heat exchange between mill sections.

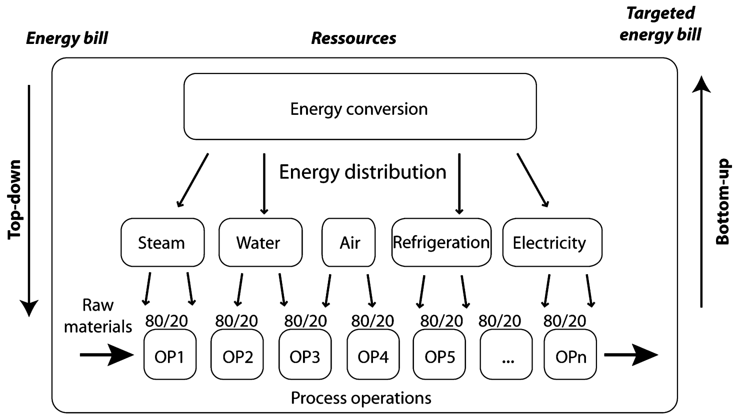

Figure 2: Systematic top-down and bottom up approach.

The systematic analysis of the minimum energy requirement of the process computed with the different requirement representations has been conducted and the analysis of the energy savings opportunities was done for each mill section (for example, the drying section in Figure 3b). Energy savings have been analysed considering the possible heat recovery within and between sections. In particular the analysis of the multi-effect evaporation section has shown that a reduction of 21% of the steam requirement is possible. Using heat cascade MILP models, the energy savings have been quantified in terms of fuel consumption and optimal combined heat and power production.

Up to 48% of the heat requirement could be saved by improved heat recovery in the process. Considering the combined heat and power integration, the energy bill could be reduced by 54%. Switching from utility to thermodynamic representation would require equipment modifications and investment. Therefore a systematic analysis of the required modifications has been done to identify the configuration that would have the higher impact on the energy requirement. The techno-economic evaluation of the most promising energy savings options in the process is being prepared and will constitute the last step of the methodology.

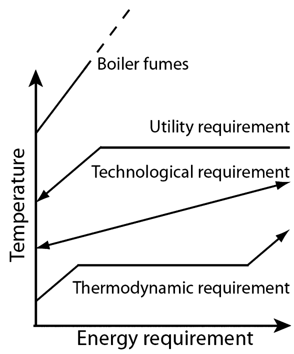

Figure 3a: Concept of multiple representation.

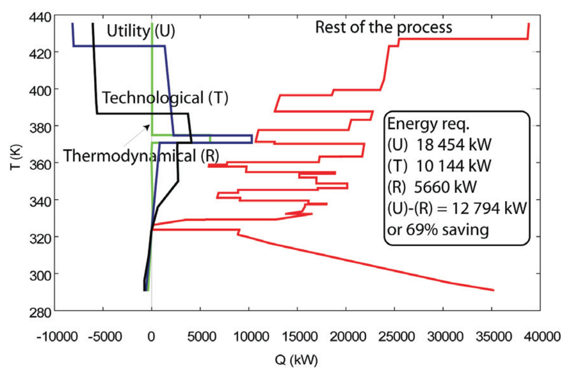

Figure 3b: Multiple representation of the drying section.

Promoting Crop-Based Biofuel Production in Switzerland – Sense or Nonsense?

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Introduction and research questions

The ongoing climate debate, (inter-)national efforts towards environment-friendly energy strategies and rising energy- and food prices have caused strong political discussions with regard to biofuel production. In this context, the aim of this article is to analyze the interactions between crop-based food and energy production from an economic point of view and to assess potential land use allocation effects in Switzerland that might be caused by rising fuel prices. Using a normative, economic modeling approach, we investigated the fuel price level at which crop-based biofuel production would become more profitable than conventional agricultural production. Assuming that fossil energy prices would reach or even exceed this critical level, the further research question is to evaluate the role of Swiss agriculture as biofuel supplier. Based on the model outcomes we answered the question if financial support of a crop-based biofuel production is justifiable in Switzerland or not.

Methods

To analyze these aspects of investigation, we applied the recursive-dynamic, agricultural supply model S_INTAGRAL. This is a normative, economic-ecological programming model, maximizing sectoral farm income (labor income plus land rents) subject to a Swiss-specific factor endowment and structural constraints. In order to analyze interactions between food and biofuel production, the model was extended by five biofuel crops, representing biodiesel (rape), bioethanol (corn, wheat, beets) and heat production (cereal, as a substitute for heating-oil). Furthermore we based our model calculations on two policy scenarios called “CH” (Switzerland) and “EU” (European Union), reflecting different degrees of market opening (“CH”: weak, “EU”: strong). Thus the “CH”-scenario covers a high farming price level for conventional agricultural commodities and the “EU”-scenario a low one. By increasing fuel prices stepwise from 1.0 to 3.7 CHF/l, we analyzed changes in land use allocation and assessed the potential of a crop-based biofuel production in Switzerland. Model calculations refer to the year 2015. Furthermore, model runs are subject to “best-case” conditions for a crop-based domestic biofuel production, assuming (i) a general mineral oil tax exemption for biofuels (ii) a fuel price increase which is not globally but limited to Switzerland (e.g. CO_2-tax) and (iii) an introduction of border protection with regard to cheap biofuel imports.

Results

Given a fuel price of 1.7 CHF/l, our model results in scenario “CH” show that – by 2015 – about 1.4% of the whole Swiss farmland could be converted into biofuel-cropland (cf. Fig. 1). That share increases to 7% if Swiss fuel prices would keep on rising to 2.7 CHF/l and even to 32% if fuel prices reach an exceedingly high level of 3.7 CHF/l. Low farming prices (“EU”-scenario) decrease opportunity costs for biofuel production and thus increase the biofuel-cropland share for all three fuel price levels up to 7%, 15% and 33%. According to these figures, more than 30% of the whole Swiss farmland (grass- and cropland) could be converted into biofuel cropland, given Swiss fuel prices of 3.7 CHF/l. However, even this remarkable acreage input would cover only about 8% of today’s Swiss fossil fuel consumption (cf. Fig. 2). This fact reveals the marginal energy-related significance of a domestic, crop-based biofuel production.

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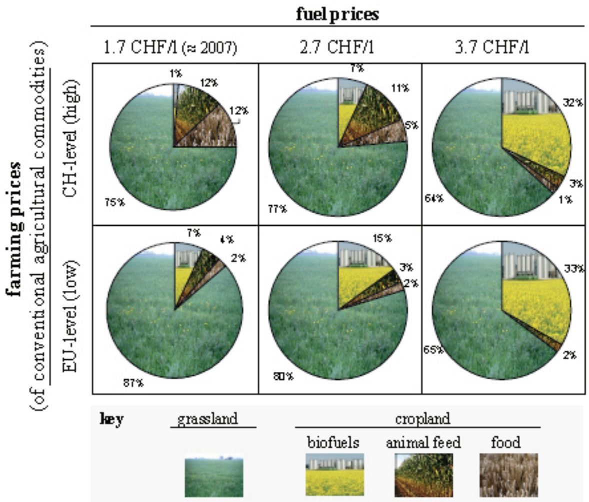

Figure 1: Estimated farmland allocation in Switzerland by 2015 (note: 100% =1.025 Mio ha).

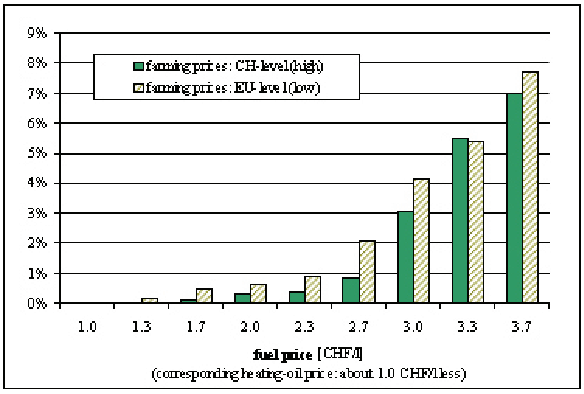

Figure 2: Estimated biofuel share in total Swiss fuel consumption (note: ‘05/’06 = 100% ≈ 10’500 kt).

Conclusions

In general, S_INTAGRAL outcomes confirm the well known fact that increasing fuel prices raise the competitiveness of biofuel crops. Our results show that a domestic biofuel production could indeed become meaningful and cover more than 30% of total Swiss farmland (which reflects more than 80% of the arable land). An exclusive support of a crop-based biofuel production could have similar effects. Promoting biofuels could “crowd out” conventional agricultural production and might cause an increasing dependency on food and forage imports. Therefore financial support of a crop-based biofuel production could cause a strong Trade-Off with constitutional food supply security. This aspect must be considered especially in Switzerland, due to the scarce farmland endowment and because currently no fallow land is set-aside (which could be converted into biofuel acreage without causing a competition with food production). Considering the small quantitative potential of a crop-based biofuel production with its – anyhow – strong implications with regard to food supply security, we can state that public support of a crop-based biofuel production is not justifiable in Switzerland. Neither in terms of substantial positive environmental impacts nor in terms of general energy supply security. However, there is one exemption: Given times with disturbed trade relations (e.g. a lack in food or energy imports), a biodiesel production on 6% of total Swiss farmland would be sufficient to cover entire *agricultural* fuel consumption (about 100 Mio liter diesel annually). This relatively small farmland input would already permit to reach (at least) an agrisectoral independency on fossil fuels, contributing substantially to ensure domestic food supply security.

CO_2 sequestration using an aqueous mineral carbonation process

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Carbon dioxide (CO_2) capture and storage (CCS) [1] is a set of technologies for the capture of CO_2 from its anthropogenic point sources, e.g., power plants, its transport to a storage location, and its isolation from the atmosphere. It is an important option to counteract the increase of atmospheric CO_2 concentrations and therefore to mitigate climate change, while at the same time allowing for the continued use of fossil fuels. Capture of CO_2, using existing separation techniques, can be applied to large point sources, i.e. power plants or industrial plants; CO_2 can be easily transported using pipelines; CO_2 storage can take place in geological formations, in the ocean, or by fixing it in mineral carbonates. In this last option, called mineral carbonation, captured CO_2 is reacted with metal-oxide bearing materials, such as silicates rocks (e.g., olivine, wollastonite and serpentine) or alkaline industrial residues, thus forming the corresponding stable carbonates (e.g., magnesium and calcium carbonate) and the solid by-product silica. The overall aqueous mineral carbonation reactions in the case of forsterite (magnesium rich end-member of the olivine family) and wollastonite are:

$$Mg_2SiO_4 + 2CO_2 \rightleftarrows 2MgCO_3 + SiO_2 + 89KJmol^{-1}_{CO_2}$$
$$CaSiO_4 + CO_2 \rightleftarrows CaCO_3 + SiO_2 + 87KJmol^{-1}_{CO_2}$$

Carbonation of silicates can be achieved in aqueous phase by dissolution of a metal-oxide bearing material followed by precipitation of the corresponding carbonate. The process feasibility has been so far demonstrated through lab-scale experiments performed at rather severe operating conditions. High forsterite conversion after 1 hour reaction was achieved operating in slurry phase (L/S=5) at T=185°C, P_{CO2} = 150 atm and using a make-up solution 0.64 M $NaHCO_3$ and 1 M NaCl [2]. Milder reaction conditions allowed fast and effective carbonation of calcium silicates (wollastonite) and alkaline residues such as steel slags [3]. Both costs and energy penalty connected to these operating conditions make mineral carbonation still not competitive with respect to other storage options. Thus, a further effort is required in order to improve the operating conditions so as to achieve high carbonation conversion at milder temperature and pressure.

Namely, our goal is to develop an aqueous mineral carbonation process that achieves a cost and an energy penalty, which are 50% lower than the best achieved so far. Besides, although lab-scale feasibility of the carbonation process has been demonstrated, the development of a CO_2 storage plant based on mineral carbonation requires the selection and design of the proper carbonation reactor and of all the ancillary equipments needed for the solid and water pre and post-processing. In this work, the first issue is approached through a fundamental study aimed to select the optimal operating conditions for the individual dissolution and precipitation processes. The results of a comprehensive study of olivine dissolution and carbonate precipitation are presented and discussed, together with those of the direct carbonation of wollastonite.

The development of the design criteria of the carbonation process is achieved by building and testing a pilot-scale carbonation unit, whose scheme is shown in Figure 1. The unit is composed of the following main unit operations:

- Milling and grinding units for the mineral pretreatment
- Pumps and compressors
- Mixer for slurry preparation
- On-line monitoring equipments for process control
- Reactor and separation units
- Treatment plants for wastewater and solid products

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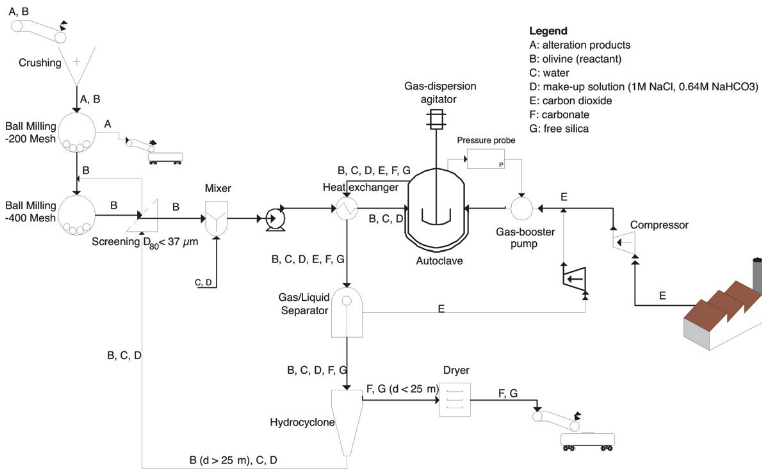

Figure 1: Layout of the mineral carbonation pilot plant.

The specifications of each unit operation are set, allowing for the selection and design of the corresponding equipment. This is done accounting for the following constraints: recovery of valuable materials, CO2 recycle, wastewater treatment and recycle within the process, carbonate separation from the solid product and recycle of the unreacted mineral.

The results of the pilot plant operation and optimization are intended to provide sound criteria for the design of a larger scale demonstration plant.

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Methodology and Technologies for Geological Storage of CO_2

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CO_2 emissions reduction can only be achieved by deploying a diversified portfolio of solutions: development of renewable energies, improvement of energy efficiency, nuclear energy, CO_2 Capture and Storage or CCS and other GHG emission reducing technologies. This CCS solution consists in capturing the CO_2 emitted by large-scale point emitters, such as coal-fired power plants, and transporting it through pipelines for storage in suitable geological formations.

The storage part of CCS, which we are interested in today, has to be looked at with a holistic approach and it needs to be based on a sound Performance & Risk Management Methodology. A typical CO_2 storage project is split in different phases: pre-operational, operational and post-injection, starting with preliminary studies such as site selection and pre-characterization, followed by detailed characterization of the potential injection site, including seismic surveys and data well drilling, and field design – e.g. injection and monitoring wells –. The operation phase starts with the drilling and completion of injection and monitoring well(s), and installation of surface facilities and infrastructures. It is followed by the injection of CO_2 and monitoring activities for: (1) monitoring the injection operation, (2) monitoring for verification and (3) monitoring of the environment. For each monitoring measurement, baseline conditions will be recorded before injection. At the end of the injection phase, the site will be prepared for closure and liabilities transfer.

The development of such an integrated approach requires a significant research and development effort. Over the last several years teams of researchers and engineers have adapted oilfield technologies and developed new tools and concepts applicable to CO_2 geological storage (monitoring measurements, modeling tools, well construction technologies). Experience is being gained by active participation in international collaborative research projects (GCEP, CCP-2, CO2SINK, CO2ReMoVe) and storage pilot projects such as Ketzin, Otway Basin and Illionois MGSC.

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Implementation of Multiagent Reinforcement Learning Mechanism for Optimal Islanding Operation of Distribution Network

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Background and Objectives

The Electric Power system of Denmark exhibits some unique characteristics. An increasing part of the electricity is produced by local generators called distributed generators DGs, and most of these DGs are connected to network through the distribution system. This situation has created an incentive among electric power utilities to utilize modern information and communication technologies (ICT) in order to improve the automation of the distribution system and to realize the vision of smart grid. In this paper we present our ongoing work for the implementation of a dynamic multi-agent based distributed reinforcement learning mechanism for the islanding operation of the distribution system. Purpose of this system is to dynamically divide the distribution network in different sections (islands), in a fault scenario when they are separated from main utility system, and make them survive on local DGs.

For this purpose intelligent agent technology is used for dynamic decomposition and adaptability of the distribution network, and distributed reinforcement learning is used for devising a control strategy of optimal islanding operation.

In the following sections we briefly describe our approach for utilizing intelligent agents and distributed reinforcement learning for this purpose. Also we give an overview of software platform which we are implementing in Java Agent Development Environment (JADE).

Intelligent Agents for Dynamic Islanding

Intelligent Agents are autonomous software entities encapsulated in a Belief, Desire, Intention (BDI) metaphor. Each Agent is integrated with a physical distribution system component, e.g switch, load, feeder etc.

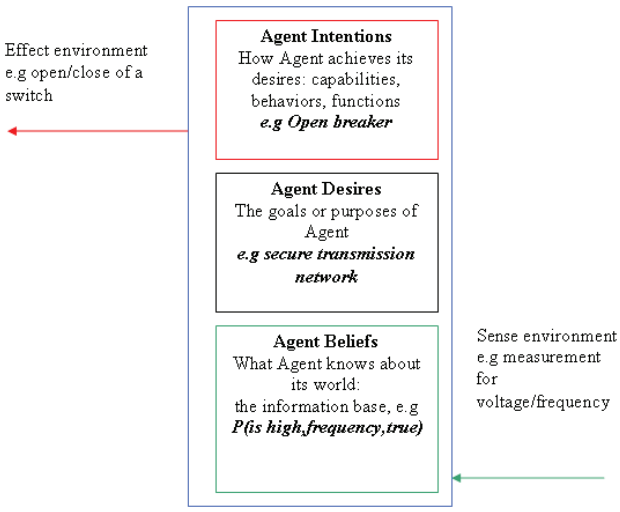

Figure 1: BDI architecture of Agents and Reinforcement Learning in Power systems.

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The capabilities of intelligent agents e.g. learning, intelligent decision making, communication with peers and adapting to new situations have been utilized. Figure 1. gives a symbolic explanation of how BDI architecture and reinforcement learning will be exploited for the operation of dynamic islanding.

Distributed Multi-Agent Reinforcement Learning

Several individual agents are made to first learn upon their local information and then communicate and cooperate with other agents in the network to achieve a coordinated final optimal control policy. In particular distributed reinforcement learning have been used because in this particular case there is no central control that has information about the complete state of the network, rather individual components (agents) have their local information, which they communicate and share in order to achieve a global operation policy.

Implementation of a Dynamic Multi-Agent Software Platform in JADE

A dynamic and flexible multi-agent platform is under development in JADE. The platform consists of one main container, and several sub containers, each representing an island in distribution network and consisting of one or more load agents. Both load and feeder agents can join and leave network dynamically according to the physical changes in network. Communication between this software platform and simulation of physical network in a simulation environment e.g. "Digsilent Power Factory" is to be done using OPC (open connectivity via open standards) server.

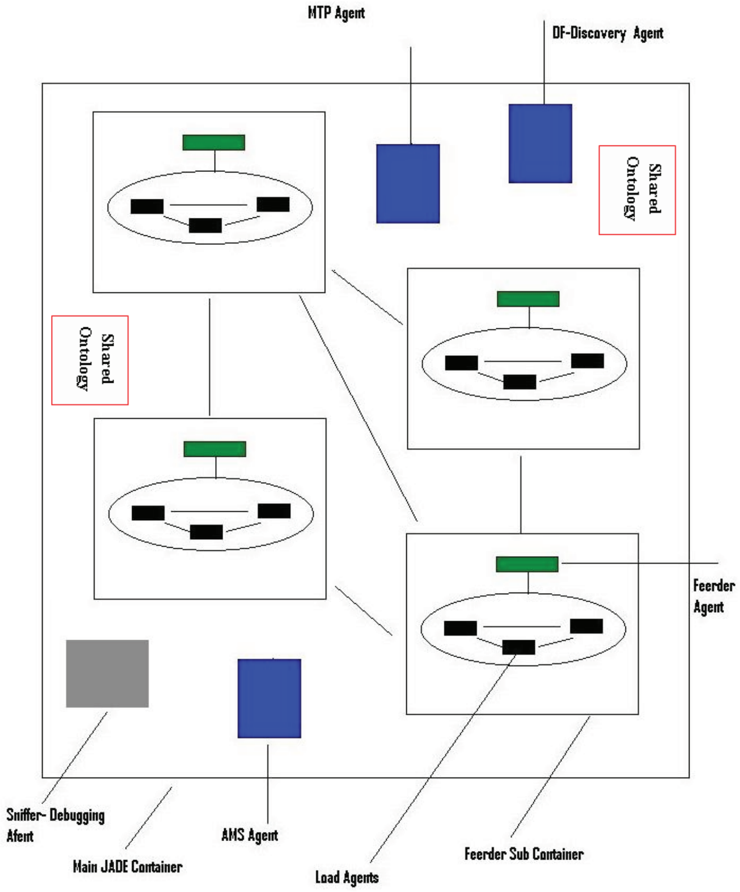

Figure 2: Multi-agent software platform in JADE.

Integrated assessment of Swiss CO_2 mitigation policies – focus on the residential sector

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1 Introduction

It is widely recognized that the residential sector in most of the developed countries presents a great potential for CO_2 mitigation. This is the case in Switzerland where almost a fourth of the emissions are due to the consumption of light fuel oil, mainly for space and water heating. We couple a CGE model with a residential energy model to perform an integrated assessment of the global, national and sectoral impacts of different CO_2 mitigation policies. The paper presents the models, the coupling methodology and assesses various policies using the coupled models.

The coupling procedure we have implemented allows for estimating a CO_2 tax corresponding to a national CO_2 emissions target. Furthermore, it allows for modeling technical regulations aimes at increasing the energy efficiency of the technologies used in the residential sector. Finally, the coupled model allows an integrated analysis of the implication of the policies on the Swiss and the global economy as well as on the Swiss residential sector energy consumption.

2 Methodology and results

In our coupling procedure, we use a six region dynamic-recursive CGE model (GEMINI-E3) representing the world economy as well as a Swiss residential sector's energy model (MARKAL-CHRES). Figure 1 presents the coupling schema.

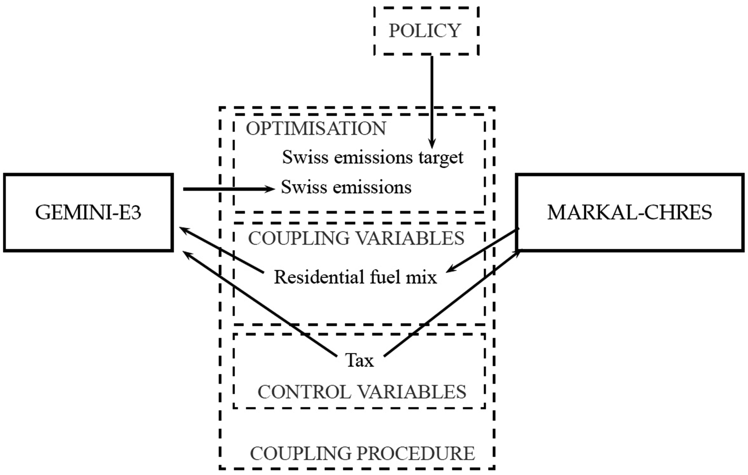

Figure 1: Coupling structure.

Figure 2 shows the additional abatement in 2020 and 2050 at various levels of tax for both the original GEMINI-E3 and the coupled model. It is interesting to note that a pure CGE model like GEMINI-E3 allows for stronger abatement than the coupled model when it comes to relatively small taxes. Nevertheless, it is not able to model the substitution to future efficient but expensive technologies when taxes over 100 USD/tCO_{2eq} are introduced.

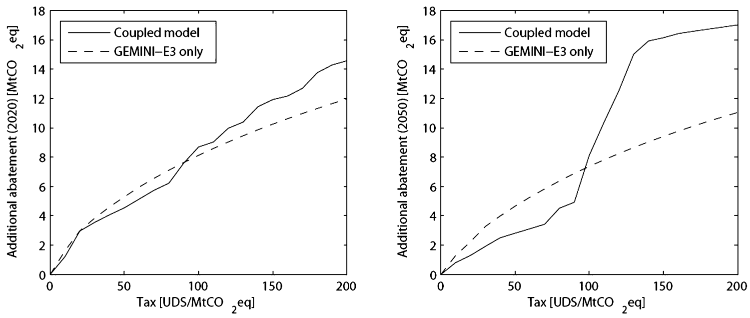

Figure 2: Comparison of GEMINI-E3 with the coupled model – Additional total abatement in 2020 (left) and 2050(right).

2.1 Policy assessment

In the framework of revision of the CO_2 law for the post 2012 climate policy, the Swiss federal council decided to follow similar targets as the European Union, i.e. a 20% reduction of GHG by 2020 and a 50% reduction by 2050.

In order to achieve the emission target various options are envisaged. First, we implement emission taxes applied across the whole Swiss economy, influencing both the production sectors and the households by changes in relative prices. We analyze two type of taxes, first a progressive tax that increases linearly up to the target year and, secondly, a uniform tax, which has a fixed value from 2008 till 2050. We also compare CO_2 taxes with a tax covering all GHG. Secondly, we implement technical regulation in the residential sector with the aim of restricting investments to energy efficient technologies. We compare the energy efficiency of each technology with the average efficiency of all technologies allowing for satisfying the same final energy demand. Then, as of 2015, we restrict households' investments to those technologies having an energy efficiency superior or equal to the average. Finally, we combine both instruments.

2.2 Results

We find that in Switzerland, without emissions trading mechanisms, the implementation of a progressive GHG tax reaching more than USD 200 per ton of CO_2 equivalent would be necessary in order to achieve a GHG abatement of 50% in 2050. With such levels of taxation, we also find that technical regulations do not bring additional incentives to abate emissions.

In the paper we also present the consequences of the implementation of such taxes on the Swiss economy and on the residential sector in particular.

Development of pre-combustion CO_2 capture techniques for IGCC plants

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The current emissions of Carbon Dioxide (CO_2) into the atmosphere, originating from the combustion of fossil fuels (e.g. coal) in power plants, represent a considerable problem from an ecological point of view. CO_2, as one of the most important greenhouse gases, contributes in a large part to climate change. On the other hand, a complete substitution of fossil fuels will not be feasible within the near future, because a change to other regenerative energy sources will take several years. Bearing in mind the increasing energy requirements worldwide, other solutions to reduce CO_2 emissions have to be found urgently.

One possibility, for instance, is to remove CO_2 from the flue gases of a power plant to avoid its release into the atmosphere and store it in a 'safe' way, e.g., in geological formations or in the ocean. This concept is generally known as CO_2 capture and storage (CCS). Moreover, increasing the efficiency of power plants to enhance the energy output per ton of CO_2 emitted is required to make these technologies profitable. Future legislation, limiting the allowed amount of greenhouse gases, will further strengthen the research and development in this field.

Based on the current power plant technologies, CO_2 can be removed basically in three different ways:

- Post-combustion capture added to a conventional power plant design
- Oxy-fuel combustion with subsequent CO_2 separation
- Pre-combustion capture

In the latter case, in a first step hydrocarbons are reformed or coal is gasified. The obtained gas consists mainly of hydrogen and CO, which is converted to CO_2 in a shift reactor and afterwards, i.e. before the combustion of this gas, can be removed leading to a relatively pure hydrogen gas stream, which is fed into a gas turbine. Integration of this process to a common power plant with coal or natural gas (NG) firing results in the concept of a so-called IGCC (Integrated Gasification Combined Cycle) plant, which is shown schematically in Figure 1.

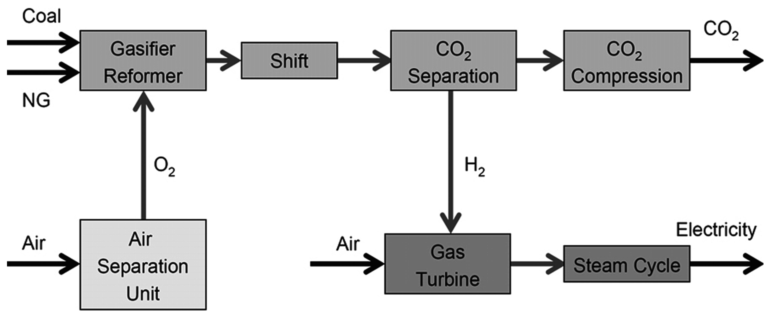

Figure 1: Concept and different parts of an IGCC plant.

The EU FP7 project DECARBit ("Decarbonise it", 2008-2011) aims at promoting the research and development in this field of pre-combustion CO_2 capture within an IGCC plant with the intention of further developing these techniques in order to build a wide base of data, knowledge and experiences as well as experimental and theoretical results to allow in a next step to demonstrate the process in a larger-scale plant.

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Besides the research that is required in the areas of combustion or air separation to improve the efficiency of the whole process and to allow for combustion of a gas with a near 100% content of hydrogen, an important point is the development of advanced technologies for pre-combustion capture of CO_2, i.e., the separation of hydrogen and CO_2, with improved efficiency to decrease the energy consumption in this step. Different process concepts are possible. In the current project the following options are considered and analyzed:

- CO_2 removal by absorption
- CO_2 removal by a membrane process
- CO_2 removal by adsorption

Every alternative will be investigated in terms of their potential and applicability in a CO_2 pre-combustion capture process. Therefore, rather fundamental research, e.g., the development of adequate adsorbents or the measurement of adsorption isotherms for these adsorbents, will be complemented by the analysis of different possible processes, e.g., pressure swing adsorption, for a pilot plant. Among the different concepts and methods the most suitable will be selected.

Risk of Line Overloads in Power Systems with Stochastic Generation

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1 Introduction

The production of electrical energy from renewable sources has, in recent years, increased significantly with wind generation as the predominant technology. This development is expected to continue in the near future. However, the integration of such stochastic and intermittent power sources into the existing power system implies a higher ratio of non-dispatchable generation which, in turn, leads to less predictable and more volatile flows on the network. The intermittent nature poses a challenge for an adequate generation capacity planning, and the operational uncertainty of the time-varying load flow regime makes the anticipation of critical situations such as transmission line overloads highly complicated.

This extended abstract presents a hybrid modeling and simulation approach with the objective of assessing the impact of intermittent generation on the probability of thermal line overloads and of analyzing the time sequences of subsequent cascading line outages. Thereby, the power flow dependent, dynamic line temperatures are explicitly modeled in time. In order to overcome the problem of the slow simulation speed coming along with the continuous integration of the heat balance equation, we apply a technique for the fast simulation of rare events, called RESTART (REpetitive Simulation Trials After Reaching Thresholds) on the present problem. The modeling framework is applied to the IEEE Reliability Test System 1996 whereas the effect of different stochastic power injection patterns on the line outage probability and on subsequent cascading failures is analyzed.

2 Modeling Framework

2.1 Thermal Line Model

Each phase of a transmission line is heated by its temperature dependent resistive losses $L_\ell(T_\ell(t) = I_\ell(t)^2 R_\ell(T_\ell(t)$ and by the solar heat gain $Q_\ell^r(T_\ell(t)$, while cooling is due to convection $Q_\ell^c(T_\ell(t)$ and radiation $Q_\ell^s(t)$ [1, 2]. This heat balance yields the following first order nonlinear differential equation for the line temperature $T_\ell(t)$:

$$\rho_\ell \frac{d}{dt} T_\ell(t) = L_\ell(T_\ell(t)) + Q_\ell^s(t) - Q_\ell^c(T_\ell(t)) - Q_\ell^r(T_\ell(t)) \quad (1)$$

where P_{l} is the heat capacity of the line. During a simulation run equation (1) is integrated numerically using the RK4 algorithm.

2.2 Stochastic Power Generation Model

The output states of the individual intermittent generating units are represented by a simple two-state model according to figure 1. The power output, $P_g(t)$, is either at its maximum value, $P_g^{\max}$, or zero.

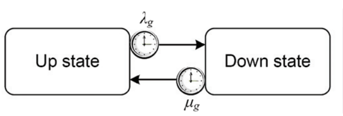

Figure 1: Two-state model for an individual intermittent generating unit.

The stochastic up-down-up cycle assumes constant transition rates λ and μ_g. Hence, this alternating renewal process is characterized by the cumulative distribution functions of the up state times, τ_g^u , and down state times, τ_g^d , respectively [3]:

$$F_g(t_u) = P\{\tau_g^u \le t_u\} = 1 - e^{-\lambda_g t_u} \quad (2)$$

$$G_g(t_d) = P\{\tau_g^d \le t_d\} = 1 - e^{-\mu_g t_d} \quad (3)$$

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where t_u and t_d are the time spans measured from the moment of entering the up state and down-state respectively. The average frequency of changing from the down state to the up state is called the renewal density, f_r, and is calculated by [3]:

$$f_r = \frac{\lambda_g \mu_g}{\lambda_g + \mu_g} \tag{4}$$

By increasing the renewal density of the individual generators a higher volatility of the combined power output of several units is obtained. Therefore, both transition rates are multiplied by the same factor in order to keep the value for the mean power output constant, see figure 2, upper part. Furthermore, by grouping different numbers of intermittent generators into a cluster, for which the same random generator holds during a simulation, a broad spectrum of different stochastic power injection patterns can be reproduced. Given a large number of small units being connected to one or several nodes, we denote the clustering factor *C* as the number of aggregated generators which change their output state simultaneously. The mean power output is independent of *C*. As depicted in figure 2, lower part, a small clustering factor is leading to more smooth power output time-series, while a high clustering factor implies a strong fluctuation around the mean value. According to [4], such a comonotonic behavior of a large group of strongly positively correlated units has more adverse effects on the frequency of line overloads, as the extremes of the combined power outputs are more frequently reached.

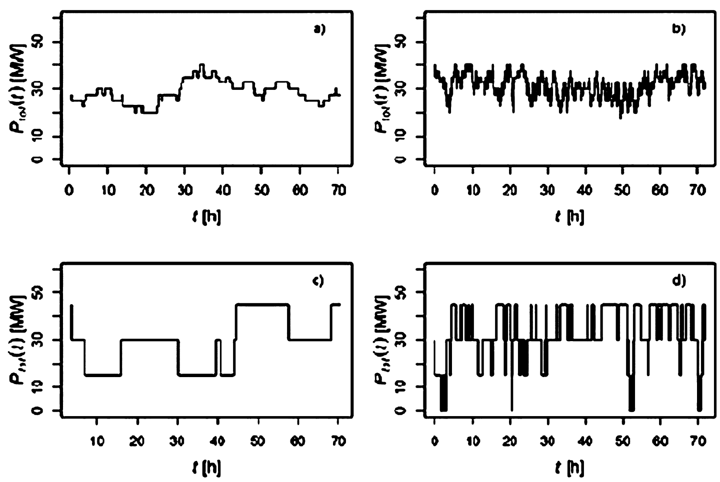

Figure 2: Different combined power injection patterns due to different renewal densities f_r and clustering factors C for 18 generating units with a capacity of 2.5 MW each.
a) f_r = 0.028h^{-1}, C = 1; b) f_r = 0.28h^{-1}, C = 1; c) f_r = 0.028h^{-1}, C = 6; d) f_r = 0.28h^{-1}, C = 6.

2.3 Simulation Speedup Applying RESTART

The continuous integration of the heat balance equation for the estimation of the transmission line overload frequencies by applying a crude Monte Carlo simulation would be highly time-consuming. In order to overcome this rare-event problem we make use of an accelerated simulation method, called RESTART [5]. Opposite to other variance reduction techniques such as importance sampling, the method has no influence on the time-sequence of the discrete events. Following, we introduce the informal basics of the method applied to our specific transitory state simulation problem. Suppose the objective of the study is to evaluate the occurrence probability of an event A within a predefined time period $[t_0, t_e)$ given a defined system state at t_0. In our case, the event A is the exceedance of the maximum tolerable temperature T^{max} on a specific line. A crude simulation would repeatedly simulate the system in the given period, whereas the line temperature would be significantly below Tmax most of the time. The basic idea of RESTART is to repeatedly perform simulation runs in those regions of the state space, where the event of interest is more often provoked. Therefore, the method divides the temperature state space $[T^0, T^{max}]$ into m intermediate intervals $[T^0, T^1)$, $[T^1, T2)$,…, $[T^{m-1}, T^m]$ with thresholds $T^0 < T^1 < ... < T^m = T^{max}$. The oversampling in the regions of interest is then achieved by splitting the simulation run into several retrials if the line temperature $T_l(t)$ reaches such a threshold.

3 Computational Results

3.1 Experimental Setup

The method is applied to the single-area IEEE Reliability Test System 1996 [6]. A single line diagram of the system is shown in figure 3. The conventional generation fleet has a capacity of 3405 MW. A total of 270 MW of intermittent power generation has been added to the system (i.e. about 7.3% of the total installed capacity), 90 MW to busbars 18, 21 and 22 respectively (see figure 3). The operational parameters are assumed to be the equal for all intermittent units, having a maximum capacity of 5 MW each. The average ratio of the operating times to the down times is set to $\mu g/\lambda g$= 2. All transmission lines are subject to the power flow limits specified in [6] with the exception of line 28 and the double line 25/26, which are subject to the thermal limit T^{max} = 373 K. These transmission lines constitute the only connection of the three busbars containing the intermittent generators to the main part of the network.

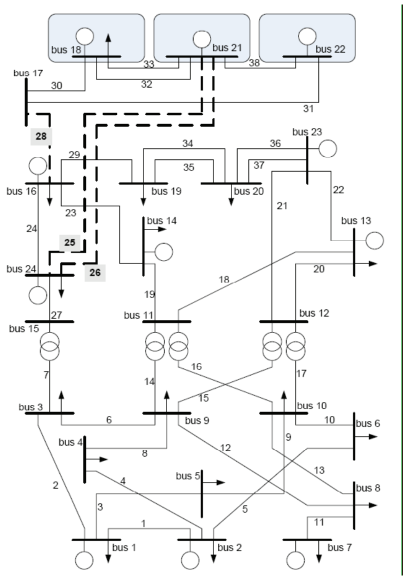

Figure 3: Single-line diagram of the one-area IEEE Reliability Test System 1996 indicating the thermally limited transmission lines (dashed lines) and the three busbars as the connection points of the intermittent generating units (rectangles).

3.2 Parameter Variation Studies

We define γ as the probability that line 28 reaches T^{max} and fails within the time span of a specific day, given that the total stochastic power injection is at its expectancy value at t_0. The influence of the renewal density f_r and the clustering factor C on the outage probability is shown in figure 4. Starting with a low value, an increase of the renewal density leads to an increase of γ. However, as f_r is exceeding a certain value, γ starts to decline again. This result can be explained by the thermal inertia effects according to equation (1). While the combined power output of the intermittent generating units reaches more often higher values, the average residence time of such combined states begins to fall below the critical time needed to heat the line up to T^{max}. With a high clustering the combined generator output is more fluctuating between the extreme values (compare figure 2). This, in turn, is leading to a higher probability to encounter a higher line temperature.

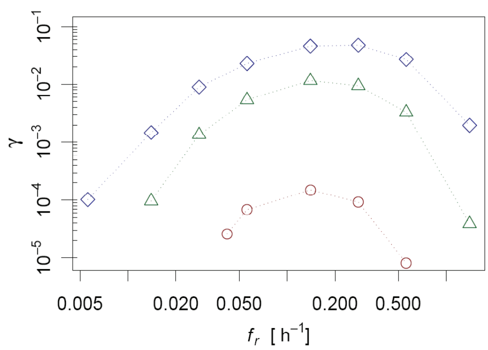

Figure 4: Outage probability γ of line 28 as a function of the renewal density f_r for three different clustering factors C=1,2,3 (circles, triangles and diamonds respectively).

The starting point for the second parameter variation study is the outage of line 28 due to reaching its maximum allowable temperature $Tmax$. This event immediately leads to an overload on the double line 25/26. Figure 5, left, shows the impact of the time needed to relieve this overload on the probability that the temperature reaches the maximum tolerable value which, in turn, would lead to the outage of the line and to the splitting of the network.Thereby, the action to relieve the overload consists of the disconnection of all intermittent power generators. The probability of the second line outage, $pout$, rises sharply after a time span of about

12 minutes after the outage of line 28. While this critical time is the same for the three chosen parameter combinations, the outage probability increases somewhat faster for a higher clustering of the intermittent generators. Given the short time span, the renewal density has only minor influence on the time dependence of $pout$. Figure 5, right, shows the decrease of the line outage probability while increasing the ratio of generators being disconnected after a reaction time of 10 minutes. For higher clustering factors, a higher number of generators have to be disconnected in order to decrease the outage probability. This result again confirms the adverse effect of a high stochastic dependence among the output pattern of different intermittent generating units.

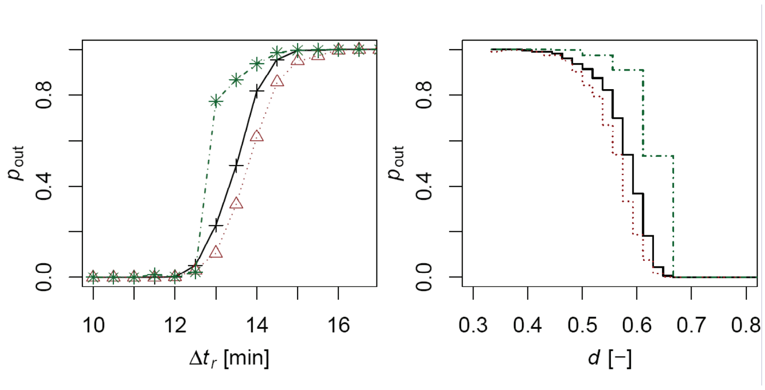

Figure 5: Outage probability p_{out} of line 25/26 as a function of the response time Δtr (left) and as a function of the ratio d of stochastic generators disconnected after Δtr = 10 min (right) for three different intermittent power generation patterns. Crosses / continuous line: C=1, f_r=0,14h^{-1}; triangles / dotted line: C=1, f_r =0.28 h^{-1}; stars / dashed-dotted line: C=3, f_r=0.28 h^{-1}.

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Emission Reduction Projects in Developing Countries
Assessing the performance of renewable energy technologies under the CDM

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Overview

The Clean Development Mechanism (CDM) is currently the only market-based mechanism aiming at triggering changes in the pattern of emission intensive activities in developing countries and is likely to play an important role in future negotiations on climate policy. Furthermore, CDM is seen as an instrument to push local sustainable development in the host countries. However, it is unclear how much impact the CDM really has on the profitability of different technologies in different countries and thereby contributes to the diffusion of these technologies. The literature has so far focused on studies of countries' aggregate CDM potentials without a technology focus (Jung 2006), case studies of one technology in one country (Kishore, Bhandari et al. 2004), studies of several technologies in one country (Ghosh, Shukla et al. 2002) or one technology in several countries (Georgiou, Tourkolias et al. 2008). Few studies attempt to evaluate various technologies in several countries (Diakoulaki, Georgiou et al. 2007), but typically focus on identifying the best technologies and countries. However, a systematic analysis of individual regional conditions and their influence on project performance and the interaction of these conditions with CDM from an investor's perspective is missing. Nevertheless, a precise understanding of these interactions and their effect on a project's profitability is necessary, in order to derive policy recommendations regarding the potential of a global carbon price and/or the necessity for regional policy measures.

Therefore, we developed a multi-level model for the systematic analysis of the economic and environmental performance of renewable energy technologies (RET) in different regional contexts. We first present the economic and environmental performance of six technologies (small run of river hydro, wind, photovoltaic, landfill gas to power, sewage gas to power, coal) in a hypothetical base case region with medium regional parameters. Then, we systematically vary these regional parameters (such as the electricity tariff) for the exemplary technologies wind and landfill gas. Based on this analysis and studies on interactions between CDM and RET support schemes (Brouns, Dienst et al. 2007; Del Rio 2007), we discuss policy recommendations for developing countries, which consider the integration of CDM into national energy and economic development planning. Finally, we outline a research agenda on how to improve the support for various RET in different countries.

Methodology

We use two indicators to measure economic and environmental performance respectively: Profitability index (PI, PI= Net Present Value/invested capital) and greenhouse gas (GHG) reductions over invested capital. The economic indicator is a function of investment costs, O&M costs, carbon price, energy density of the source (e.g. solar radiation), baseline, electricity price, and discount rate. We normalize the NPV by dividing it through the invested capital for a better comparability of the projects as the typical project size under CDM differs strongly for the selected technologies. The environmental indicator, a function of the baseline and the energy density of the source, is again normalized by invested capital and represents the amount of GHG emissions avoided per Euro invested compared to the business-as-usual grid emissions. The regional parameters are varied generically and the effects on both indicators are shown for wind and landfill gas technology.

Results

Figure 1 exemplarily depicts the base case. Each technology is represented by two areas: While for area 1 (continuous filling) we do not assume CDM participation we do so for area 2 (hatched filling). The areas are spanned by a range of the project-specific parameters such as investment, O&M costs, transaction costs, and the time-span of carbon revenues (area 2 only). The results show that photovoltaic power is not profitable and that its associated GHG reductions are very low. While wind and hydro power are profitable under several circumstances, the methane-to-power technologies become highly lucrative under the CDM. We present disaggregated and detailed results of the regional parameter variations.

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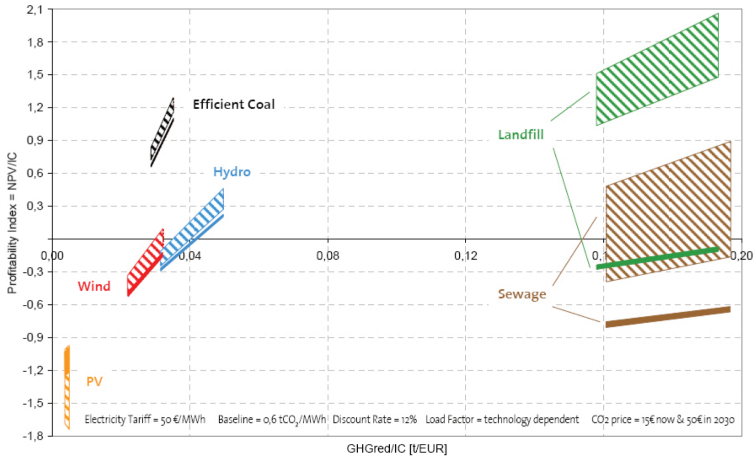

Figure 1: Base case of economic and environmental performance of analyzed technologies under a range of project-specific assumptions with and without carbon revenues.

Conclusions

While the carbon price is decisive for the profitability of certain RET, others depend much more on specific regional conditions. These results are supported by empirical data taken from the current CDM market, which show that investments in some RET such as wind are concentrated in few countries with favourable regional conditions, whereas others such as landfill gas to power are spread more equally over many countries. Our results show that the international carbon price on its own is not sufficient to increase the diffusion of all RET, but that complementary country-tailored policies are necessary. We synthesize our results to develop policy recommendations on how to proceed with a more disaggregated approach to foster the diffusion of low-carbon technologies with regard to their development potential, e.g. by a redistribution of carbon credits between technologies.

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A novel ICT-infrastructure for quasi-autarkic energy nodes in smart electrical distribution networks

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Description

The poster introduces the innovative S-TEN technology in the area of self-describing technical networks based on recent developments in the homonymous FP6-project.[6] The approach is capable for monitoring and operating flexible networks of distributed energy conversion plug & play units as well as loads and storages by using semantics for the identification of network elements as well as for the communication to the operator or even their autonomous operation. Thus, the network becomes more intelligent, hence, improving its management. Within the ICT-based project several prototypes will be developed addressing the field of generation and load management in electrical distribution networks.

Current EC policies as well as their national implementations in European countries claim for a significant share of renewable energy resources in the power supply in order to decrease greenhouse gas emissions. This implies a considerable increase of distributed energy resources (DER) with different characteristics to be integrated in the medium-voltage and low-voltage system posing new requirements to network operation such as becoming more flexible, more decentralised in its controlling processes and more intelligent. It is conceivable, that these units may show plug & play features. Moreover, the management of dispatchable loads offers additional benefit to network operation and market services. To put it in a nutshell, network operation has to become more active and to provide added value to all participating stakeholders.

A substantial step towards the intelligent integration of decentralised – and partly fluctuating – energy generation is made by the EC funded research project S-TEN (Intelligent Self-describing Technical and Environmental Networks). It applies Semantic Web technologies to efficiently monitor, operate and maintain self-organizing physical and technical networks like measuring stations or technical plants.The S-TEN technology will provide support to decision makers for operational and maintenance processes in a potentially continuously changing environment.

Based on the self-describing capabilities of network components this approach enables the monitoring and control of dynamic networks of various single, potentially moving, components with plug & play characteristics. Various applications in the field of energy systems are conceivable – some of them being analysed and demonstrated in detail within the S-TEN project.

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6 *FP6-027683 S-TEN - Intelligent Self-describing Technical and Environmental Networks; http://www.s-ten.eu*

The S-TEN ICT-architecture

Applying the S-TEN approach, the acquisition of distributed information and process control is assisted by self-describing devices, such as measurement sensors or further intelligent sub-S-TEN-systems. These devices announce their existence, their position in a network and their web services. As soon as they are in operation they register themselves in a registry and can be tracked by service consumers looking for a matching service. The ontologies for the definition of the required metadata are derived from international standards for engineering and will be enhanced as part of the S-TEN project. Using Semantic Web technologies implies that the computer does not only process but "understands" the data it handles. As a consequence it can operate on the data, that is, it is able to do inferencing and processing semantically defined rules which – up to now – is done by hard programming the logic within the software. Besides, best-practise support can be provided to decision makers offering a means to react adequately to critical situations.

The application to electrical distribution networks

Within the S-TEN project a showcase for demand side bidding and four prototype applications are developed evaluating the S-TEN technology, two of them addressing electrical distribution networks.

- The prototype application **"Control of distributed resources in electrical power networks"** developed and implemented by FGH is dedicated to monitor distributed resources within distribution networks (e.g. wind power plants, PV units and CHP units) and further components (e.g. energy storage devices, short-circuit displays and disconnectors) in order to improve the distribution system management in terms of remote control capabilities. Beside the monitoring functionality an event handling and rule handling package will be implemented. The event handling package allows the user to define events for which he wants to be notified, e.g. upper or lower threshold values can be defined issuing a warning or an alarm. The rule handling package lets the user define complex scenarios in the occurence of which an action is suggested to the decision maker or performed automatically by the system or the user will receive a notification that may be accompanied by best-practise support. In future, the prototype application will be enhanced with control mechanisms taking into account ecologic and economic parameters.
- The prototype application **"Secondary control of a Microgrid"** developed by LABEIN tries to manage the problem in a dynamic way taking into account the status of the different resources that are part of the network and their capability in certain instants of time. The self describing capability of the resources will allow the central controller to reconfigure the network and the role that each resource can play whenever a new resource gets connected to the network. In the same way the semantic knowledge, that the description of a resource carries with it, will allow the system to decide which resource has to be selected for playing the main role in controlling the Microgrid, depending on its described capabilities, its status and the role it is playing at the moment of time when the service is needed.

Thus, in combination with other S-TEN prototype applications on demand side bidding systems, the project provides a solid basis for a broad range of operational and / or business models in the field of electrical generation and load management. The further development of possible applications is granted by an S-TEN User Group established in November 2007 which is open to the interested public and comprises external representatives of grid operators, suppliers and research organisations.

Innovations

The Web enables the provision of data of distributed network resources at low cost independent of their location. Semantics are the key for an intelligent form of cooperation and process control. They ensure dynamic operation schemes and, hence, added value to all participating stakeholders like owners and operators with partly diverging interests. Up to now, in the field of electricity supply industry, concerns regarding the security and privacy of data as well as real-time requirements have postponed the use of Web technologies for network management. However, future networks with a high number of decentral energy resources require an intelligent network management and it is expected that the S-TEN technology will have an important impact on that. Using S-TEN technology within a network of a steadily rising number of decentralised generators such as private and commercial CHP plants and PV units on the one hand and dispatchable loads on the other hand would mean a crucial and cost effective contribution to an efficient network management. This benefit is even increased when regarding dynamic patterns of generation and/or storage units within the control area as presented in Vehicle-to- Grid applications.

Resume

The poster presents the S-TEN technology, describes its application to the above mentioned prototype and gives an outlook to further developments. Furthermore, the advantages of applications based on STEN technology in contrast to conventional applications are described and the innovations of the STEN technology are highlighted.

How to Make Private Households' Energy Demand Less Myopic – The Role of Discounting, Information and Incentives

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Quite often private households make decisions that appear rather myopic. They refrain from investments which in the short term imply high expenditures but in the long run – for example due to low running expenses – are very profitable. This is of special relevance for energy demand decisions since many efficient and smart energy technologies are characterized by the pattern "high costs in the beginning – low running costs thereafter". Energy saving bulbs as well as washing machines or refrigerators fulfilling the category A requirements of the Swiss energy efficiency label are typical examples.

Given the fact that future electricity prices will be higher than current ones, the pattern just described seems to gain importance over time. It is therefore crucial to identify the conditions under which private households are using sufficiently small discount rates so that their energy consumption decisions are rational with respect to energy efficiency especially in the long term. In addition, information and incentive structures should be identified which make private household's energy demand decisions less myopic and more oriented towards long-term energy efficiency.

With respect to private households' discount rates, empirical evidence is needed concerning the rates which are used in energy demand related decisions and their determinants. Empirical studies on discount rates are mostly based on survey studies (for instance Diekmann/Meyer 2007; Ruderman et al. 1987). According to these studies discount rates relevant when buying different electric appliances vary between 15 and 100% whereas market interest rates amount to an average value of around 4%. The survey studies also show that discount rates decrease with increasing educational level and with increasing income. Both effects are very plausible: The better educated people are, the more value they give to future outcomes and events. The higher their income is, the less are people forced to focus mainly on today's economic situation and the more they are inclined to also give a high value to future outcomes. In addition, the survey studies show that discount rates increase with age and that women have higher discount rates than men. Again these results are plausible: The older people are, the less value they give to future events. These value judgments seem to be based on rather selfish grounds and occur even if the survey participants have children. Women's higher focus on today's values and their devaluation of the future seem to have two key reasons. One is the lower income level which women experience as compared to men. The other is the fact that women are often very strongly involved in the raising of and caring for children. These activities require a high degree of orientation towards the present; future developments are also relevant but only to a small degree in everyday activities.

With respect to gender, several differences in energy demand related issues can be observed (Carlsson-Kanyama, Räty 2008; ISOE 2002; genanet 2003a; Scherhorn et al. 1997; Longstreth 1989). On average, men's energy consumption is significantly higher than women's, especially when it comes to transport. The biggest differences occur between single men and women. Men are driving more often and less efficient cars than women; women use more often than men public transport. Women are more afraid of nuclear energy than men and they have stronger preferences for "green" electricity. On average, women have a lower meat consumption and their general lifestyle is more sustainable. Women feel more stressed than men when energy prices increase. This may be due to their smaller incomes which limits their buffering possibilities. Women prefer a rather decentralized energy production whereas men are in favor of huge energy "factories". All these gender differences seem to turn women into smarter energy consumers than men are. However, although they have a "comparative advantage" also women are rather myopic energy investors so that long-term energy efficiency remains low.

In spite of a great number of survey studies on discount rates and in spite of a number of interesting results, the outcomes of these studies have to be used with great care. The problem of such survey studies is that individuals are confronted with merely hypothetical decision situations which cannot easily be used to learn something about factual decision making. Even worse, survey study discount rates are often elicited by using question on financial payments. The question whether discount rates resulting from financial decisions can be used without problem for energy demand decisions or other types of applied decisions remains totally open. Therefore, experiments to identify households' time preferences seem to be much more appropriate. They can be easily focused on the relevant field of application, e.g. energy demand decisions.

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Energy related experiments, however, are more or less missing until now. On a more general level, experiments focused on pure financial outcomes had been accomplished. During the last years, such experimental studies were dominated by the so-called "hyperbolic discounting effect" (Laibson 1997, Thaler 1981). Hyperbolic discounting means that individuals use a higher discount rate for events in the near future and lower discount rates for events in the far future (see Figure 1).

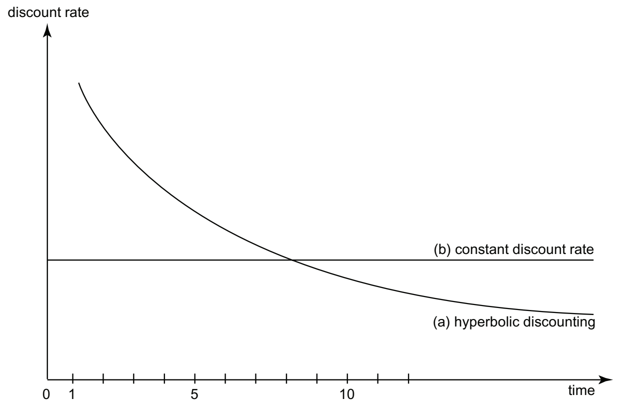

Figure 1: Time pattern for discount rates: (a) hyperbolic, (b) constant.

It seems that this pattern of discounting is highly relevant. Not only experimental studies but also survey studies yield this phenomenon. In a large representative study for Germany for instance more than 50% of the participants were classified as hyperbolically discounting persons (Dohmen et al. 2007), consistent with our own experimental findings.

The experimental and survey studies' evidence on the existence of hyperbolic discounting is often called into question since it is in contradiction to the economic standard model. This model assumes a constant rate of time preference (see Figure 1). Hereby, the rate of time preference is a purely theoretical concept which may be operationalized by the empirically testable discount rate. Recent approaches show that hyperbolic discounting may be the consequence of uncertainty and decision-makers' risk preferences (Walther 2007). If decision-makers are uncertain about future events and if they are prone to probability distortions, hyperbolic discounting may result even in case of a constant rate of time preference. Let's assume, for example, that a decision-maker is not sure whether his future supply with wooden pellets is guaranteed. In this case, the decision maker may tend to discount possible future cost reductions due to the use of such pellets much stronger than in a perfectly certain situation. In this sense, uncertainty and risk-aversion may not only yield high discount rates (as already classical investment theory says) but even be represented by a profile of discount rates that are decreasing over time.

With respect to energy demand decisions reliable experimental or survey information on discount rates is hardly available until now. Yet, further information will result from experiments and surveys run at the Chair of Economics at ETH in cooperation with the Federal Office for Energy (BfE). Here, the structure of the experiments is as follows: Subjects will be presented with a large number of decision situations involving real risky and delayed monetary outcomes. Each subject will be paid according to one of her decisions, which will be selected randomly after the experiment. There will be two treatment conditions: One half of the subjects will be confronted with neutrally framed decisions, the other half will face decisions embedded in an energy-demand related setting. These choice data will enable us to estimate individual risk attitudes as well as discount rates and to examine the influence of framing on individuals' decisions.

Given the knowledge from experiments in other domains than energy demand decisions we can assume that also for this type of decisions discount rates are relatively high and potentially decreasing over time. This means that on the one hand private households are rather myopic and on the other hand risk attitudes and risk perceptions have a decisive influence on energy demand decisions.

Key determinants of the absolute value of discount rates used in energy demand decisions are income, age, education, general environmental knowledge, energy specific knowledge, environmental preferences and gender. The influence of these determinants will be elicited and can hence serve as basis for the design of a regulatory framework for energy demand decisions.

The time profile of discount rates seems to be mainly dependent on risk attitudes and risk perceptions. With respect to risk attitudes and perceptions the psychological literature signals that mainly risk perceptions are highly context specific (Weber/ Milliman 1997). This strengthens the importance of conducting experiments that are directly focused on energy demand decisions. In the experiments we differentiate between different groups of participants, for instance groups with or without a specific knowledge in environmental or energy related issues, groups with or without the possibility of insurance against future risks, or groups that vary according to their socio-economic characteristics.

Given the results of our experimental and survey studies, we will be able to better understand the reasons why households' energy demand decisions reflect high and over the time decreasing discount rates. Based on these insights, recommendations for the design of information or incentive structures in the energy demand context can be derived.

Successful advice for making energy demand decisions smarter than they actually are has to be based on insights from behavioral economics. This means that, for example, one has to consider that potential losses typically have a bigger impact than potential gains of the same size (Kühberger 1998). Another effect is, for example, the controllability effect which means that risk are perceived lower if individual controllability is perceived to be high (Kahneman/Tversky 1979). Considering such effects, policies can help to make households' energy demand more long-term oriented and more efficiency oriented at the same time. This fosters smart energy demand decisions.

The following information and incentive structures seem appropriate to push energy demand decisions of private households into a smarter direction:

- Women esteem something as highly risky if they think that they do not have enough information (Gysler et al. 2002). Therefore it seems important to give consumers – and especially female consumers – more information about the consequences of different energy demand options and to make this information easily accessible as well as easily understandable.
- In many cases, energy demand options with high investment costs and low running cost are not chosen due to income constraints. Therefore, it seems appropriate to give economic incentives for those options that are desirable from a sustainability perspective and to give economic disincentives for all other alternatives. Given the fact that losses loom more than gains, a malus system for non-sustainable alternatives, making them much more expensive, seems to be especially effective. On the other hand, given the fact that a bonus system seems much more feasible from its political implementation perspective, subsidizing desirable energy demand decisions directly (for example via rebates when buying electric appliances) or indirectly (for example via tax reductions or reductions of health insurance fees) seems also appropriate. A smart mixture of bonus and malus structures will probably represent the most successful way – successful in the sense that energy demand decisions will become less myopic and more sustainable.
- High discount rates and hence myopic energy demand decisions are partly caused by uncertainties. With less uncertainty discount rates will decrease. Clear and stable regulations on the one hand side and innovative financial market products on the other side which may serve as some kind of insurance against undesired losses have to be considered and implemented in order to reduce uncertainty.
- The reasons for high discount rates in the context of energy demand decisions are not completely clear. Some key determinants like income, age, education, risk attitude or risk perception are known but little is known about their relative importance in general or for different groups of decision makers. Therefore, not only information and incentive structures are needed to make energy demand decisions less myopic. Additional research improving the basis on which information and incentive structures are designed is also important.

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Climate Policy Making for Enhanced Technological and Institutional Innovations (CLIMPOL)

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Bridging the Gap between the Availability and Implementation of Technologies and Institutions

A great deal of research effort has focused on understanding the causes and mechanisms of past and future climate change (IPCC, NCCR Climate). Based on these findings, numerous scientists are now modeling the ecological, economic, and social impacts of climate change (Stern Review, IPCC, NCCR Climate). Most scenario outcomes range from grim to devastating. Nevertheless, the business world, individual consumers and land users, and political decision-makers are showing surprisingly languid reactions. Effective climate policy in the sense of ensuring long-term global sustainable development is not prevailing, and the evidence suggests that it is very difficult to design and, more particularly, to implement such a policy at the global, regional and national levels. Given anthropogenic global climate change and increasing climate variability, the lack of appropriate policy endangers intergenerational equity. A main prerequisite for combating global climate change is the large-scale transformation of the technological systems and behavioral patterns that are largely determining anthropogenic climate influences. However, this transformation is not purely dependent on technological innovation and scientific knowledge; it also exhibits lengthy lead-times until appropriate climate-friendly technologies and behavioral patterns are implemented in society. The inertia of the technological system has its counterpart in the hysteresis of the earth's climate system which renders any increase in global mean temperature irreversible for hundreds of years. Hence, if no decisive measures are taken now, the resulting damages in the decades after 2050 could be tremendous. This seems to call for appropriate public policies to spur technological and behavioral changes towards low carbon emission solutions now. Otherwise, if the corresponding changes are to be postponed to a later point in time, convincing arguments for such a postponement must be given. The reasons for the lack of an adequate climate policy are numerous. However, there are some key determinants that seem worthy of a deeper analysis:

- The expected burden of anthropogenic climate change varies considerably among world **regions**, which is reflected, for instance, in different country positions in the Kyoto negotiations.
- The **time frames** of different decision makers involved in climate change and climate policy issues vary considerably. The time horizon for a politician is often only the period for which he or she had been elected, whereas all investment issues for firms and farmers have a much longer time horizon. From a normative perspective, inter-generational equity requires an even longer planning horizon. However, for the current generation, climate policy decisions will mainly result in costs; benefits (in the sense of avoided costs) or returns will occur only after decades.
- Given the long-term time horizon and the complexities of the technological and climate system, there are manifold **uncertainties** regarding the future costs and benefits of climate change and policy. Uncertainty appears on many different levels, e.g., on the scientific level (projections of future climate in different world regions as a function of human behavior), on the socioeconomic level (what will the future development of population structure, economic growth, social institutions, etc. look like?) or on the political level (which political forces will be in power and which policies will they be implementing? Which countries will be politically influential?). Of course, the above-mentioned uncertainties are not independent but instead influence one another. The high degree of uncertainty renders decision making on climate change-related issues fairly complex. Often, this uncertainty is not given adequate attention by decision makers.

Addressing Four Different Groups of Actors: Policy-Makers – Consumers – Farmers – Firms

Given the key determinants of the climate policy problem, it is obvious that the challenges to make and ensure the appropriate behavioral changes on all levels are huge. Thus, a scientific analysis of climate policy is to be guided by the following research questions: What are the major barriers that have prevented adequate climate policy from being designed and implemented until now, and which elements of current climate policies hinder the large-scale transformation of technological systems? What are the conditions under which 'good' (effective and efficient) policy could be designed and implemented while minimizing the presence of 'perverse' incentives? Which are the optimal time horizons of climate policy decisions?

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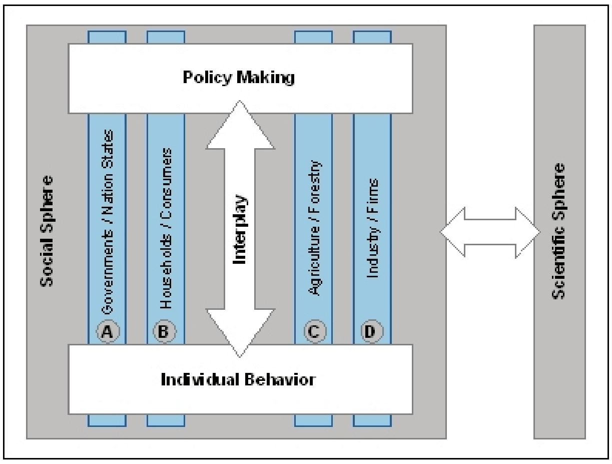
http://www.cces.ethz.ch/research/clench/clench_projects/approved_clench_projects/CLIMPOL*

In addition, there is a normative task to be addressed: by which criteria should policy decisions be made, and how can sustainability aspects be integrated effectively? How can climate policy overcome the problems of differential impacts, differing planning horizons, and the prevalence of uncertainties?

The field of research on climate policy, as defined by the questions listed above, is vast. The overall goal of CLIMPOL is to make a significant contribution to answering at least some of these questions through the application of a broad set of different methods without being hampered by disciplinary boundaries. In order to concentrate on the actuating and influenceable factors of climate policy, CLIMPOL's research strategy is based on three levels of analysis which are, in fact, interlinked: individual decision behavior, decision making at the policy level, and the interplay between the two (see Figure below). The choice of these **three levels of analysis** is motivated by the following basic hypotheses:

- There are numerous examples in which well-intended policies have failed because individual decisionmakers took decisions that were not anticipated or intended by policy-makers. Hence, a key factor when trying to answer the aforementioned questions on policy design is to gain a better understanding of the interplay between policy-bound and individual decision-making levels. The transformation of technological systems and behavioral patterns and the corresponding climate outcomes are strongly dependent on individual behavior (firms, consumers, farmers, land users). If inappropriate (e.g., too short) time frames are applied and information about future costs and benefits of climate change is lacking or misused, climate policy fails to give the necessary incentives for technological changes and results in insufficient mitigation and adaptation behavior.
- Individual behaviors of all types of decision makers are significantly influenced by institutions and policies that determine the incentives and constraints under which decisions have to be made. For some constellations of institutions and policies, individual behavior will be such that further climate change can be significantly mitigated, and adaptation to already-existing climate change will be adequate.
- Policy making is the result of the interplay between state policy makers and other actors (households, firms, NGOs, etc.). There are some constellations of the different actors' behavior that enhance the design and implementation of good climate policy. Command-and-control and top-down approaches rather seem to fail. Cooperative approaches and economic instruments bear opportunities but also risks, like the ineffectiveness of voluntary agreements or the watering down of policies through negotiation with companies.



In order to reach a high level of specificity with respect to the project's output and outreach, CLIMPOL is also structured according to the four **different groups of actors** involved (see Figure above): (A) Governments and Nation States, (B) Households and Consumers, (C) Agriculture and Forestry actors, (D) Industry and Firms' actors. The clusters chosen represent the major actors that are highly relevant for climate policies. Industry and households combined directly accounted for over 50 percent of greenhouse gas (GHG) emissions in 2003, while agriculture and forestry were responsible for approximately 30 percent (Stern, 2006). In addition, seeing as the chosen structure incorporates all levels of aggregation, CLIMPOL's different modules map a large part of those interactions within the social sphere that are influencing or that are being influenced by climate policy. These interactions are also driven by the knowledge generated in the scientific sphere (see Figure above), which in fact plays a decisive role for the resolution of the uncertainties that are constitutive to the climate change problem. Given the fact that many different levels, actors and cross-cutting themes are dealt with, CLIMPOL can launch a broadly based, long-term oriented Center that bundles the activities of various researchers and institutions like NCCR Climate or OcCC.

Extensions to the Energy Hub Model

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History

Measuring is the backbone of electrical engineering. From measurements one obtain data to build models and with these models one can predict various new conditions. Strategies developed in this manner will be used to improve the current situation, in terms of efficiency, reliability and/or costs. But what happens when the object of interest itself represents a limitation?

A energy supply containing electricity, natural gas and district heating, treats these different energy carriers separately, as if they don't conduce to the same business: satisfy the needs of producer and consumer. New emerging technologies like hybrid vehicles, heat pumps and micro turbines point to more interaction between different energy carriers and the use of synergetic effects. So why only look at the electricity grid, even with a "smart" view?

Recognizing the trend toward energy carrier integration the "Vision of Future Energy Networks (VoFEN)" research project launched at the ETH High Voltage and Power Systems Laboratory faces incoming challenges from the transmission and supply side. Based on a Greenfield approach, which breaks infrastructural limits, and a multi-energy system optimization could lead to a higher value of sustainability. The modeling framework is already established [1] [2], only the implementation is missing. The case study at Baden in cooperation with a municipal utility in Switzerland started in 2007 [3] shall give answers about open questions.

Practical Experience

A case study for the city of Bern tries to reveal potential benefits of the integration of different types of technology (conventional power plants, CHP, solar energy, etc.) into the grid. For this purpose and for the sake of clarity the city will be divided into districts-hubs according to each of its areas' load characteristics (industrial, household, commercial consumers) and geographical factors. Each hub will be described with its respective energy flows (electricity, district heat), its production, conversion and transmission capacity. This way the whole city will be described as a network of energy hubs.

Thus the model of the city will take as inputs the consumption profiles of the city districts, production profiles of the supplying plants and its emissions, given electricity and fuel prices, distributed generation and energy saving related trends in construction and consumption. Any parameter change will show its effects on a particular hub where it is introduced and on the entire network. Such a model allows medium term improvements of the city's energy supply in terms of costs, emissions and reliability to be studied.

In the near future the city's energy supply will undergo a considerable change as the replacement of the old incineration plant by a modern polygeneration plant running on waste, gas and wood incineration to provide the city with district heat and to a large extent electricity. Its introduction into the grid will serve as a verification of the model's usefulness. The plant will be modeled as simply as possible with a variation in production and costs being the decisive parameters. This will be done using linear or if it is possible fixed conversion coefficients of the plant's internal processes.

As a result of this analysis the range of each technology to be used can be determined. Moreover, possible useful benefits for the consumers (e.g. daily consumption distribution) and ever more as energy producers (e.g. solar energy) can also be recognized. In the following phases, a longer term prospects for the city will be evaluated with a complete Greenfield approach with the objective to minimize emissions and maintain or improve reliability at reasonable cost.

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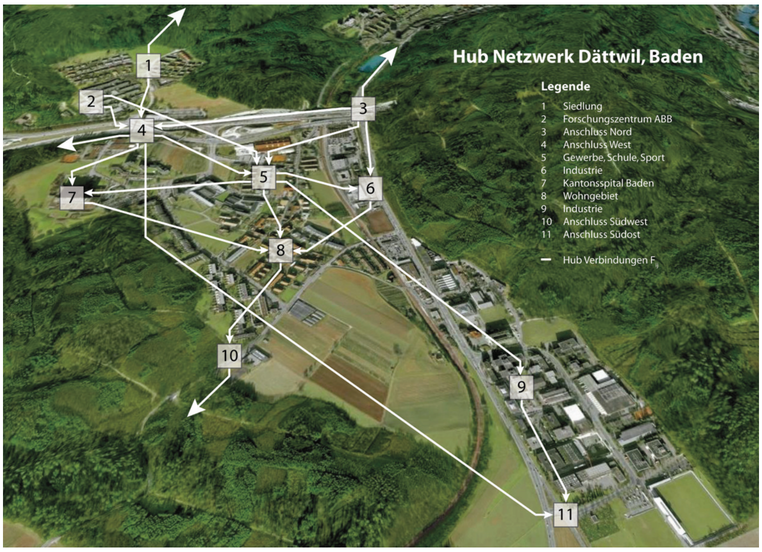

Figure 1: Borough of Dättwil modeled as an Energy Hub.

In Fig. 1, a part of Baden is illustrated as a network of interconnected Energy Hubs. There are eleven Hubs, four of them behave only as network nodes because they lack of load demand. The remaining seven are chosen by:

- load characteristics, kinds of energy carriers used
- the type of area; commercial, settlement, industrial or single object
- the natural or topological boarders.

White lines in Fig. 1 apply to the medium voltage electricity network, showing today's interconnections between the Energy Hubs. They symbolize the energy exchange and summarize each of the multiple power cables. Note that the Greenfield Approach will later on ignore these lines. Measurements were taken to get information about the load flow in Dättwil, for electricity, district heating, natural gas and fuel oil. All energy carrier except the fuel oil are bounded to lines, the latter will be feed to the user directly from outside the region. Energy storages are include in the modeling, especially the district heating pipeline and the natural gas pipeline can be discussed as shared storage between neighboring Hubs.

Some difficulties came up in [3] when the Hub #7, a hospital with an independent energy supply, was modeled. Decentralized generation leads to more infeed at a low power level, and with a new biomass power plant realized in the investigation area of the case study these power flow become negative. Hence one need an infeed from the Energy Hub into the grid, conditions for solving and optimizing have to be changed.

Synthesized examples of former research only regards a small number of Energy Hubs for power flow optimization problems, like [4]. Also the hubs act in a conservative manner, thus load consuming in total and per carrier more energy than local generated. Net the power flow from the grid to the hub is positive.

Advanced Modeling

On a previous model (see Fig. 2) the output vector (e.g. load) was a given fact and the input vector (from the grid to a hub) was searched for, one now break with this strict separation. For instance a solar cell can only produce what the sun delivers, not what one would like to have. Because infeed and load of the same energy carrier mostly are related to different costs, some problems with the hub marginal objectives, respectively the costs, occur as well.

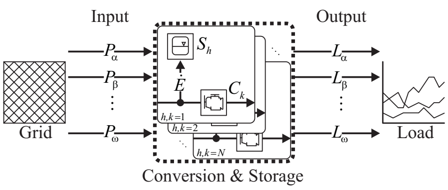

Figure 2: The standard Energy Hub concept.

As a melioration the Energy Hub concept will be advanced by splitting the input and output vectors in two different vectors each. The input is now one part from the attached grid and the other from a local energy source connected directly at the Energy Hub. The energy coming out of the hub is split into load and grid infeed. For calculating costs a new variable representing the infeed remuneration is introduced. Objectives for the optimization will be now: minimize costs and coevally maximize income. Thus modeling a Energy Hub based on a more local generated energy than the load demand present yield to a success.

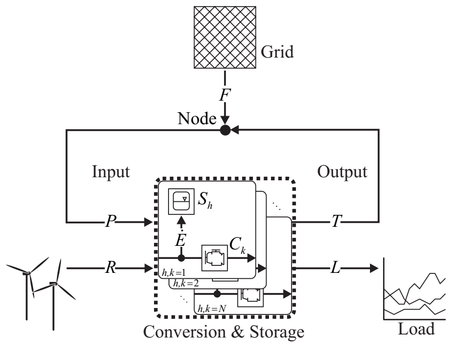

Figure 3: The Enhanced Energy Hub concept.

An optimization can now be formulated in the following way:

$$\text{Minimize} \quad \mathrm{F}(\mathbf{P}, TC)$$

$$\text{Maximize} \quad \mathrm{F}(\mathbf{T}, TB)$$

$$\text{subject to} \quad \begin{aligned} (\mathbf{L}+\mathbf{T})-\mathbf{C}(\mathbf{P}+\mathbf{R}) &= 0 \\ \mathbf{h}(\mathbf{P},\mathbf{T}) &\leq 0 \end{aligned}$$

where **R** represents the input of local produced energy, **P** the supply from the grid, **L** the demand of the load, **T** the infeed to the grid, **C** the coupling matrix, *TC* the total costs and *TB* the total benefit. **R** and **L** are treated as given values. Inequality constrains *h(x)* will additionally come from boundaries related to a certain maximum of transferable energy, performance of conversion components and dispatch factors correlated to the input. Energy storage can be include, as it is done in [1].

Conclusion

The theoretical framework presented by the VoFEN's project in combination with a real and now existing facility, modeled as an Energy Hub, leads to various difficulties. By altering the input and output parameters of the existing Energy Hub model, solving the optimization process is still possible. On the other hand, one abandons the universal validity of the model. Some extensions of the Energy Hub concept are presented in this paper in order to keep clarity and solvability within theory and practice. A second case study with the city of Bern, in addition to the ongoing case study Baden, ought to show strengths and weaknesses of the Energy Hub concept.

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A Receiver-Reactor for the Solar Thermal Dissociation of Zinc Oxide

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An improved engineering design of a solar chemical reactor for the thermal dissociation of ZnO at above 2000 K is presented. It features a rotating cavity-receiver lined with ZnO particles that are held by centrifugal force, Fig. 1 and Fig 2. With this arrangement, ZnO is directly exposed to concentrated solar radiation and serves simultaneously the functions of radiant absorber, chemical reactant, and thermal insulator. The multi-layer cylindrical cavity is made of sintered ZnO tiles placed on top of a porous 80%Al_2O_3-20%SiO_2 insulation and reinforced by a 95%Al_2O_3-5%Y_2O_3 ceramic matrix composite, providing mechanical, chemical, and thermal stability and a diffusion barrier for product gases. 3D CFD was employed to determine the optimal flow configuration for an aerodynamic protection of the quartz window against condensable Zn(g). Experimentation was carried out at PSI's high flux solar simulator with a 10 kW reactor prototype subjected to mean radiative heat fluxes over the aperture exceeding 3000 suns (peak 5880 suns). The reactor was operated in a transient ablation mode with semi-continuous feed cycles of ZnO particles, characterized by a rate of heat transfer – predominantly by radiation – to the layer of ZnO particles undergoing endothermic dissociation that proceeded faster than the rate of heat transfer – predominantly by conduction – through the cavity walls. A typical experimental run is depicted in Fig. 3.

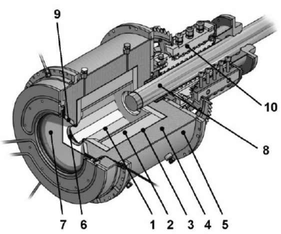

Figure 1: Schematic of the solar chemical reactor configuration:
1 = rotating cavity lined with sintered ZnO tiles
2 = 80%Al_2O_3-20%SiO_2 insulation
3 = 95%Al_2O_3- 5%Y_2O_3 CMC
4 = alumina fibers
5 = Al reactor shell
6 = aperture
7 = quartz window
8 = dynamic feeder
9 = conical frustum
10 = rotary joint.

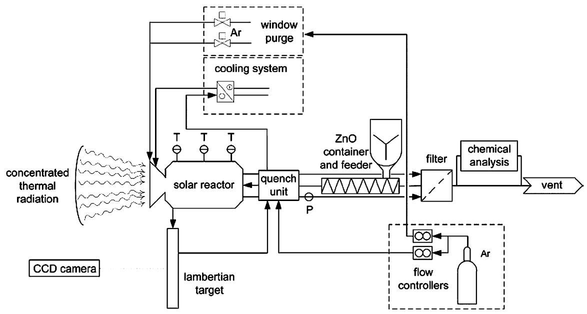

Figure 2: Experimental set-up of the solar reactor and peripherals at PSI's High Flux Solar Simulator.

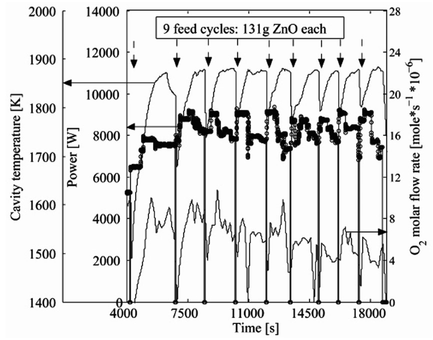

Figure 3: Radiation power input, cavity temperature, and O_2 molar flow rate in the product gases measured during run No. 8, with nine feed cycles of 131 g ZnO each.

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Nanostructured thin-film tungsten trioxide photoanodes for photoelectrolytic production of hydrogen from sea water

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We report here some progress on the development of materials for photoelectrochemical water splitting with respect to solar hydrogen generation – a CO_2 neutral, clean energy technology (Figure 1).

Template-assisted sol-gel synthesis offers attractive possibilities of the controlled production of microporous and mesoporous oxide films, which are mandatory for photoelectrochemical applications. We prepare mesoporous tungsten oxide films based on the sol-gel method involving ultrasonic stirring step as the main improvement of the previously established procedure1. Investigation of solar-light-driven photo-electrolysis cell employing such a WO3 photoanode shows that the amount of the delivered steady-state photocurrent is increased by some 20%. This improvement is likely related to optimization in the morphology of the nanostructured films shown in Figure 2 consisting in a marked decrease in the particle size and, apparently, also in the film porosity.

Inspection of photocurrent-voltage curves, recorded under simulated AM 1.5 solar illumination, shows that stable photocurrents of the order of 3 mA/cm2 are attained in a 0.5 M solution of sodium chloride (Fig.1).

The latter solution, which is a composition close the lly occurring sea water, does not require any preliminary acidification as the formation of chlorine sets locally the solution pH to ca. 2. It should be noted that, although in 0.5 M NaCl ca. 20% of chlorine is formed at the WO_3 photoanode, oxygen remains the main photo-electrolysis product. Extended electrolysis experiments demonstrate perfect stability of the WO_3 photoanodes under conditions of mixed chlorine/oxygen evolution which allows anticipate its suitability for the sea-water photo-electrolysis2. The sea water is an abundant, non-toxic electrolyte suitable for massive hydrogen/production via photo-electrolysis.

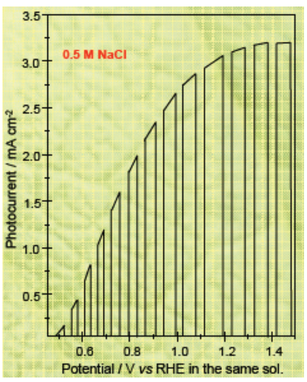

Figure.1: Schematized photoelectrochemical cell for solar water splitting.

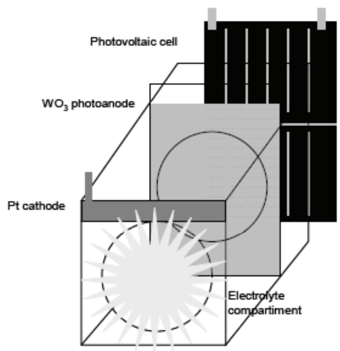

Figure.2: Photocurrent – voltage curve for sea-water splitting (recorded in a 0.5 M NaCl solution) at a semi-transparent WO3 photoanode obtained through the sol-gel route modified by ultrasonic stirring. Simulated solar AM 1.5 irradiatio.

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Smart Online Congestion Diagnosis Tool for Enhancing the Security of Power Grids

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Introduction

The security of electrical power systems is the main objective of system operation besides economy. Security thereby is understood as a deterministic concept as compared to reliability [1]. Security and congestion management are not only in the interest of local operators but are now in the focus of international organizations. Together with regulators they have obliged transmission system operators (TSOs) to adhere to rules and measures against deficiencies of system security, as the UCTE agreement [2] indicates. The related inter-TSO Multilateral Agreement (MLA) constitutes a legal instrument providing a substantial contribution to the active and adequate security of supply in the interconnected UCTE system.

As security monitoring is in the foreground of these principles the tool and software system presented in the following is in line with this agreement. What is remarkable is the present state-of-the-art, the refinement and perfection leading to an industrial application in an Energy Management System (EMS) of a large interconnected transmission system.

Objectives of the Transmission System Operators

It is the objective of system operation to maintain and preserve the transmission function of the system. The (n- 1)-security concept has been introduced and forms the basis of security and congestion management. Thereby for every single element in the system, a power flow simulation is calculated assuming the element being out of service.

The basic objective is the assessment of consequences of outages and disturbances in the overall system. Since the disturbances are accidental, the analysis has to be performed in the sound operational state of the system in regular intervals. A few minutes are considered as a practical interval. Due to the existence of extended interconnections consisting of networks operated by several independent organizations it is required that a transmission system operator (TSO) is able to assess his own network with the neighboring networks attached carrying loads and flows such that his own system is correctly modeled.

Congestion Diagnosis Needs

A network controlled by a TSO and surrounded by several networks under the control of other independent TSOs is the configuration of an interconnection which is of interest and which is quite common in Europe and on the American continent.

In order to perform a security analysis for the network as well as for the neighboring zones the following processes, actions and steps are necessary and feasible:

- processing of measurands of the TSO’s own transmission system
- processing of measurands in the neighboring zones (1 to 2 tiers away)
- performing state estimation for the online system (TSO’s own system and neighboring zones)
- matching the neighboring zones based on the exchange programs and the measurands of the neighboring zones (also an estimation process)
- performing a load flow calculation comprising the complete UCTE system (base case)
- checking of a large number of predefined outages (order of a few thousands)
- obtaining the results within several seconds
- presentation of the results in categories of critical elements, i.e. degree of loading and overloading in numerical, graphical, topological form (user oriented)

Solution

The core software system is ISPEN/OCD (**I**nstant **S**ecurity **P**robing of **E**lectrical **N**etworks/**O**nline **C**ontingency **D**iagnosis) which is normally integrated into a SCADA system.

ISPEN runs on computers with standard operating systems (Windows XP, Windows 2003 Server, Linux) or otherwise on control computers usually found together with SCADA systems.

ISPEN itself is a high-performance and very accurate power flow program that solves outage cases in very large interconnected transmission systems and generates security relevant information for the TSO. The online network monitored via the SCADA system is estimated and converted, balanced and integrated into the adjacent systems by means of the UCTE network. The overall system created this way is subjected to the base case power flow and the outage cases. The last step deals with extracting key features, which characterize the security of the system.

After the actual flow situation has been established, outages of system components or disturbances can be investigated according to a predefined list (composed according to multiple criteria – single, double, common mode, bus bars). Results are presented according to the degree of severity measured in terms of the proximity to current limits or exceeding defined limits.

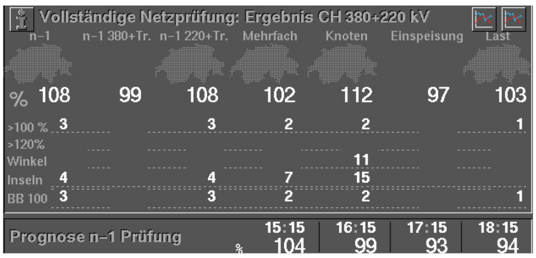
Assuming that ISPEN is to be used in an online process within an Energy Management System it is the SCADA system of the proper network (own supervised network) which provides analogue data of flows, voltage magnitudes and topological data. The result of state estimation of these data is then converted to a standardized format (UCTE-DEF=UCTE data exchange format). Thereby it is assumed that an actual network model of the surrounding system in the UCTE format (DACF files = day ahead contingency files, reference case) is available. The estimated network is integrated or inserted into the UCTE network whereby a balancing process for the boundary zone takes place. The result is an estimated state of the overall system, which is subjected to the subsequent power flow analyses. With the available common data, the integration is simple and evolves automatically. It requires no special efforts.

The ISPEN/OCD is designed as a ‘plug-in’ application that can be used in any SCADA/EMS system having a state estimator. It is so fast that the N-1 security diagnosis can be carried out in real time and displayed as a SCADA measurement in the ‘alarm list’. An integrated part of ISPEN/OCD is ISPEN/MERGE that embeds the TSOs own estimated network in a real external network to get a high quality network model for the N-1 diagnosis.

When inter-TSO cooperation involves the exchange of estimation results, the ISPEN/MERGE can be used repeatedly to embed the own network in the estimations of the neighboring TSOs. Thus, a real wide area estimation is obtained without any extension of the own SCADA system.

The standard output from ISPEN/OCD is given below:

1) Max. loading [%]
2) Number of objects with n-1 loading > 100%
3) Number of objects with n-1 loading > 120%
4) Re-closure angle > 100%
5) Max. re-closure angle [°]
6) Number of isolated injections
7) Number of network split
8) Number of cases not solved



Performance – Response Time

The challenge of the problem is the handling of the large number of nodes and achieving fast convergence both in the base case as well as in the outage cases. Hence, state-of-the-art techniques for sparse matrices and step size control are being applied. In a reference installation an outage list of 2000 cases (single, double line out-ages, etc.) for the entire UCTE reference network having 6’000 nodes and 9’000 branches is processed in about 15 seconds.

Conclusion

A versatile software tool for security monitoring and congestion management has been described, which fulfills the requirements as they appear in today's EMS systems operated in extended interconnected networks under the supervision of several independent TSOs. The special feature is the treatment of a system under the control of a TSO together with the surrounding network whereby the system is integrated and matched at the boundaries. This process does not require any special effort by the TSO. The tool has been implemented in one of the EMS systems of the UCTE network where it can be demonstrated on demand.

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CLean and Efficient VEhicle Research (CLEVER)

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There are many scientific studies showing relationships between global CO_2 emissions and the climate change. One major source of CO_2 emissions is the transportation sector since it, in general, relies heavily on fossil fuel and in particular on refined oil products. There are growing concerns that the transportation sector, in particular vehicles for individual mobility, will continue to expand throughout the world, not only in traditional industrialized markets like Europe and the USA but also in highly populated emerging markets like China and India, and cause even further CO_2 emissions. These concerns put emphasis on policy makers, researchers and industry to develop new technologies for transportation propulsion.

The amount of CO_2 emissions is directly related to the amount of burnt hydrocarbons. The overall fuel efficiency of the system is therefore of importance as well as developing new fuels and new fuel infrastructure.

One way of dealing with the problem in traditional gasoline combustion engine based systems is to optimize the engine and improve the overall powertrain configuration to allow for fuel consumption reduction. This can be done by hybridizing the powertrain i.e. including an electric motor and an electric energy storage. Hybridizing the powertrain allows for several new, efficiency improving, operating modes such as brake energy recuperation, start-stop operation, and engine operating point shifting.

Another way of reducing CO_2 emissions is to change to a fuel with less CO_2 emissions compared to gasoline. There are several different fuels which have lower CO_2 emissions than gasoline however most alternative fuels have limited or non-existent fuel infrastructure and availability. Therefore these aspects are extremely important to consider when changing fuel. Compressed natural gas (CNG) is a possible alternative fuel with existing infrastructure, which offers additional benefits when combined partly with or replaced by biogas produced from waste.

The CLEVER project combines both powertrain configuration optimization through hybridization and fuel change to lower CO_2 emissions of a midsized passenger vehicle. Within CLEVER a compressed natural gas (CNG) parallel hybrid electric powertrain is developed and optimized. The goal is to reduce the CO_2 emissions by 40% compared to a conventional gasoline powertrain with similar performance and to fulfill the future EURO-5 emission standards.

Hybridization optimization includes both component dimensioning, i.e. electric motor/storage and combustion engine sizing, and energy management strategy optimization. The energy management strategy refers to the control problem of determining the power distribution between the motor and engine.

To eliminate the influence of the energy management strategy on the powertrain component size optimization an optimal control approach is used. The optimal control problem is solved numerically using a dynamic programming algorithm. By using an optimal control method each configuration is compared based on its optimal performance on a given drive cycle. Therefore no configuration will benefit from a “biased” control strategy.

To fullfill the ambitious targets of the CLEVER project, an optimized combustion engine for the given application is required. The combustion engine of the CLEVER powertrain is based on a series production, naturally aspirated direct injection gasoline engine. The use of turbocharger makes it a classical downsizing concept. This adaption and optimization, of the basis engine, for natural gas poses many challenges, like the optimization of compression ratio, combustion chamber geometry, valve timing, combustion process itself, and the exhaust gas aftertreatment. One of the major issues is the realization of direct injection of gaseous fuel, which puts high requirements on combustion process and injectors.

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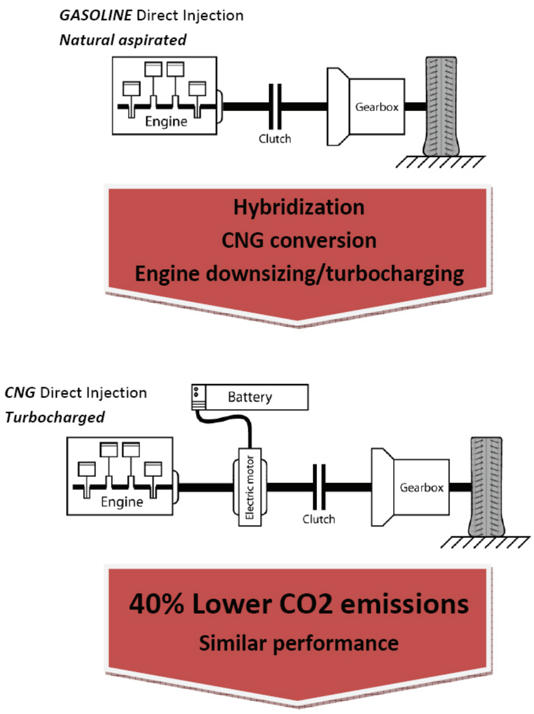
First measurements with a naturally aspirated direct injected natural gas engine, at low engine speed and torque range, on the test bench show a good stability of the combustion process. However, the combustion process stability is highly dependent on the reproducibility of the injection process.

A 1D simulation model has been build up which represents the entire engine from the intake to the exhaust. Validation by test-bench measurements shows good accuracy on gasoline operation for the model. In a second step, the model runs with methane as fuel and helps designing and optimizing the engine by reducing the needed amount of test bench measurement. First results show that with the given concept an increase of efficiency can be realized by increasing the compression ratio or by the use of miller cycle (closing the inlet valve early). Further it was shown that the desired maximum power can be be reached by using a standard serial production turbocharger.

Results show that the proposed powertrain optimization will reach the goal of lowering the CO_2 emissions by 40%.



Emissions' reduction of a coal-fired power plant via reduction of consumption through simulation and optimization of its mathematical model

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Global climate change is the main issue of discussion among scientists throughout the world. The effects are beginning to become obvious as sudden changes of the weather conditions in many regions have been occurred the last years. Greenhouse gases, including carbon dioxide, are responsible for this change. One of the main sources of carbon dioxide emissions is the electrical power generation from fossil fuels (coal). Additionally the operation of this kind of power plants results to Nitrogen Oxide (NOx) and Sulphur Oxide (SOx) emissions which are also harmful for the environment. 84% of the electrical power generation in Greece is produced from lignite combustion and thus optimized operation of the conversion system will result in higher efficiency of the whole process, with the same electrical power generated consuming less fuel and producing lower emissions.

That forms our motivation for the modeling, simulation and optimization of a lignite fired power plant. An electrical power production unit, with 300MW maximum output, has been chosen to model, (similar to units operating in the Ptolemais region in northern Greece). For this purpose, two software, using iterative method solvers, have been used. One is the open source code DNA (Dynamic Network Analysis) and the other is the gPROMS by the Process System Enterprise. The advantage of the former is that it consists of a library with the models of the components of a power plant and the steam/water properties but it does not include an optimizer, while in the latter, the user has to code the component models and the steam/water properties but it includes a nonlinear optimizer.

D.N.A. uses a Newton method for the solution of the non-linear problem for the simulation. gPROMS has a variety of solvers for the simulation as well as the optimization of a given model. In this case, which is a steady-state one, use of the solver "SPARSE" which is a Newton method-based solver is used with the "MA48" linear solver and both are included in the DAE solver "DASOLV" which uses a variable time step BDF method (Backward Differentiation Formula). For the optimization, gPROMS makes use of the "CVP_SS" (Control Vector Parameterisation – Single Shooting algorithm) solver which is capable of solving steady-state problems. "CVP_SS" includes the "DASOLV" solver as well as the Mixed-Integer non-linear solver "SRQPD" which uses a Sequential Quadratic Programming (SQP) method.

The components of the electrical power production unit that have been modeled in gProms were the following:

- Feed water Pumps
- Valves
- Boiler (simplified as Superheater and Reheater)
- Generators
- Extraction Splitters from the turbines
- High Pressure, Intermediate Pressure and Low Pressure Turbines
- Condenser
- Feed heaters
- Deaerator

A schematic of the unit chosen to be modeled is shown in Figure 1. We have reduced the components of this unit as shown in Figure 2 and this does not consist the spraying but we are in the process of adding this component.

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For the modeling of the unit, use of conservation of mass and energy equations was applied at each component and each node that connects them. Additional, use of characteristic equations of individual components were applied in order to give a more realistic expression of the unit. Therefore:

1) A pressure drop equation is applied to the boiler (simplified as a reheater) and the feed heaters

2) An overall efficiency equation is applied to the pumps and the generators

3) An isentropic efficiency and a Turbine Constant (C_T) equation were applied to the turbines. A polytropic efficiency equation has also been applied to an alternative model as a replacement of the Turbine Constant equation. The Turbine Constant was defined as follows

$$C_T = \frac{\dot{m}_1 \sqrt{T_1}}{\sqrt{P_1^2 - P_2^2}}$$

where:

m_1 is the inlet steam flow rate in kg/s
T_1 is the inlet temperature in K
P is the pressure in bar. 1 expresses the input, while 2 the output.
and the polytropic efficiency

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\eta_{pol}\frac{\gamma-1}{\gamma}}$$

where additional:

γ is the ratio of specific heat C_p / C_v

We assume that all parameters enter a component are positive and all parameters exiting a component are negative.

Finally, the thermal efficiency of the unit, which is our objective function for the optimization was defined as follows

$$\frac{\sum E_1 - \sum E_3}{\sum Q_3}$$

where:

E_1 is the produced electrical power from the generators
E_3 is the consumed electrical energy from the pumps
and Q_3 is the heat consumption

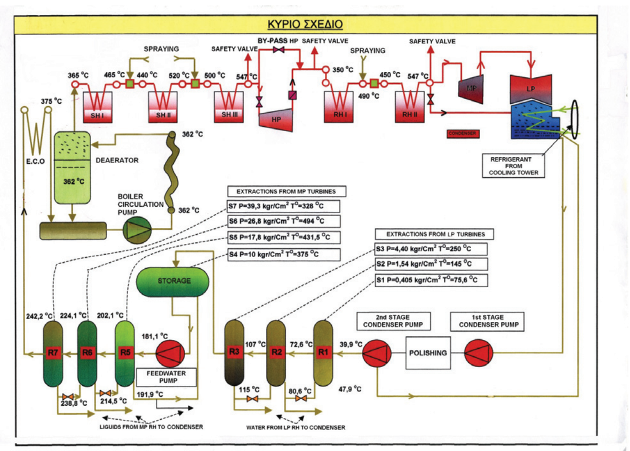

Figure 1: Schematic of the examined lignite fired electrical power production unit.

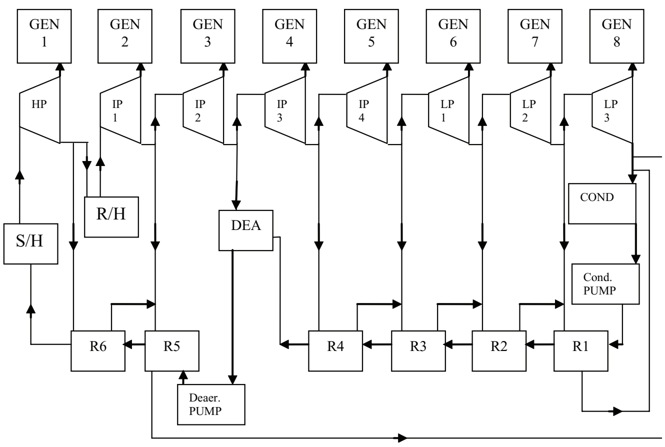

Figure 2: Flow chart of the Simulation of the examined lignite fired electrical power production unit (GEN: Generator, HP: High Pressure Turbine Stage, IP: Intermediate Pressure Turbine Stage, LP: Low Pressure Turbine Stage, DEA: Deaerator, COND: Condenser, R: Feed Heaters, S/H: Superheater, R/H: Reheater)

Simulation showed a satisfactory agreement between the measured data (in the control room of the examined unit) and the calculated data of D.N.A. for the steady state operation scenario of power output of 300MW. Table 1 compares the simulated results for D.N.A. and the gPROMS's model using the C_T equation. The results using the polytropic efficiency of the turbine are similar.

	D.N.A.	gPROMS	Difference [%]
Generator	Electric Power Production [kW]		
GEN1	-80760	-80527	**-0.29**
GEN2	-30400	-30353	**-0.15**
GEN3	-30880	-30770	**-0.36**
GEN4	-24190	-24245	**0.23**
GEN5	-39380	-39352	**-0.07**
GEN6	-29530	-29515	**-0.05**
GEN7	-33560	-33527	**-0.10**
GEN8	-22040	-22117	**0.35**
Pump	Electric Power Consumption [kW]		
Cond. Pump	420	420	**0.00**
Deaer. Pump	5521	5522	**0.02**
Heater	Heat Consumption[kJ/s]		
S/H	603800	603523	**-0.05**
R/H	105700	105502	**-0.19**
Condencer	Heat Losses [kJ/s]		
Condencer	-421700	-421628	**-0.02**
Unit	Thermal Efficiency [-]		
H	0.4014	0.4012	**-0.05**

Table 1: Simulation results of D.N.A. and gPROMS and% deviation for operational scenario of 300 MW.

	Simulation	Optimization	Difference	Optimization	Difference
D.N.A. model		gProms with C_T		gProms with polytropic eff.	
Unit	Thermal Efficiency [-]				
H	0.4012	0.42954	0.02834	0.41077	0.00957
Extraction	Turbine extraction mass flow rate [kg/s]				
HP	-23.29	-23.2896	0.00040	-21.714	1.57600
IP1	-15.41	-15.4098	0.00020	-17.597	-2.18700
IP2	-5.02	-5.0204	-0.00040	-7.207	-2.18700
IP3	-14.91	-14.9095	0.00050	-17.067	-2.15700
IP4	-5.78	-5.78009	-0.00009	-8.696	-2.91600
LP1	-10.55	-10.5503	-0.00030	-14.195	-3.64500
LP2	-0.47	-0.470532	-0.00053	-1.308	-0.83800
Generators	Electric Energy Production [kW]				
GEN1	-80527	-80527	-0.01	-79976	551
GEN2	-30353	-30354	-0.27	-30404	-51
GEN3	-30770	-30771	-0.92	-30680	90
GEN4	-24245	-24247	-1.96	-23844	401
GEN5	-39352	-39367	-14.53	-38441	911
GEN6	-29515	-29576	-61.15	-28260	1255
GEN7	-33527	-34450	-922.85	-31107	2421
GEN8	-22117	-57160	-35042.63	-20719	1399
Pump	Electric Energy Consumption [kW]				
Cond. Pump	420	420	0.00	420	0
Deaer. Pump	5522	5522	0.00	5588	66
Heater	Heat Consumption[kJ/s]				
S/H	603523	640977	37454.00	569637	-33886
R/H	105502	105502	0.00	105736	234
Condencer	Heat Losses[kJ/s]				
Cond	-421628	-422539	-911.00	-395087	26541

Table 2: Optimization results of DNA and gPROMS and difference for operational scenario 300 MW.

Since simulation results are similar to the measured results the optimization tool of the gPROMS could be used for an estimation of the parameters that can improve the conversion process. The variables that initially have been chosen to be examined are the mass flow rates of the steam extracted from the turbines (Table 2).

The optimization results gave significant differences between the two models. In the model using the C_T, insignificant changes to the mass extracted from the turbines resulted to a great increase of the thermal efficiency of the unit. The reason is the accumulated difference of the pressure, which appears as a second order variable in the C_T equation, and gives a nearly zero pressure at the low pressure turbine exit, which results in very low enthalpy and an increased power production at this stage.

With the polytropic efficiency model significant changes in the mass flow rates of the extractions resulted to an increase of 1% to the efficiency of the steam/water cycle of the unit. The increase of the thermal efficiency by using the polytropic efficiency model for the turbines is due to the lower amount of energy that is necessary to be given to the water in the S/H component (Superheater) as a result of the optimized preheating of the water, thus lower fuel consumption.

Further work for this project includes the extension of the model with the addition of a complete boiler model, which will include burners, furnace, superheaters and reheaters as well as more advanced equations which will take into consideration fouling of the heat exchangers' tubing. Also the expansion of the control parameters which can be used for optimization of the unit, e.g. fuel flow rate and air/fuel ratio, is subject of current work.

With the completion of this work we aim to create a smart control tool for the energy conversion system of an electrical power production unit that will help the control engineer to set the parameters of the operation of the power plant at an optimized point which will result in the reduction of fuel consumption and carbon dioxide emissions.

Acknowledgements

The authors would like to acknowledge financial support from the General Secretariat of Research and Technology, of the Ministry of Development in Greece.

Towards Future Electricity Networks – Meeting Strict CO_2 Targets

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This paper discusses challenges and possible pathways for the electricity networks up to the year 2050, assuming that strict CO_2 emission targets are to be met. The analysis is based on input from an energy systems model which gives the development of the power generation system until the year 2050, meeting the EU 2020 CO_2 target and a 60% CO_2 reduction until the year 2050. The development of the power generation system is modeled by means of a techno-economic energy systems model which gives the technology mix until the year 2050 under assumptions on cost for various technologies and applying specific CO_2 emission targets. Yet, for such modeling, the possibilities and barriers imposed by the electricity network is seldom included. This paper discusses a methodology to analyze the pathways for the electricity networks using the modeled pathways for the power generation system as input. The focus is on EU27.

The emission reduction target and the generation plan up to 2050

The goal of the project “Pathways to Sustainable European Energy Systems” (hereafter called the “Pathways-project”) is to investigate possible pathways for the stationary energy sector which can meet strict requirement of CO_2 emission targets in line with what has been proposed by the EU and the International Panel of Climate Change (IPCC). Typically, the stationary energy system (electricity and heat) contribute to at least a third of the CO_2 emissions. At the same time a large fraction of the power is produced in large centralized units which may constitute cost efficient opportunities for reducing CO_2 emissions such as fuel shift (e.g., coal to gas), application of CO_2 capture and storage and introduction of renewable energy technologies (e.g. wind power and biomass). Another option is introduction of poly-generation plants for co-production of power, heat and transportation fuels. It also seems possible to electrify the transportation sector by applying plug-in hybrid cars which seems to be a cost efficient way to reduce CO_2 emissions from the transportation sector. Thus, the two latter options represent technologies which increase the integration between the transportation sector and the stationary sector (heat and power). Finally, there are also more decentralized technologies being proposed such as small scale combined heat and power (CHP) schemes and photo-voltaic power generation.

Increased integration of the power generation system and the transportation sector as well as an increased use of intermittent power generation (most notably wind power) imposes new challenges on the electricity network.

A central part of the Pathways-project is to analyze development paths for the power generation sector under various constraints and targets such as targets on renewable energy based power generation and targets on CO_2 emission reduction.

The analysis is typically carried out by so called techno-economic modeling which gives the mix of technologies until the year 2050, minimizing the overall systems cost fulfilling the targets specified. An example of such result is given in Figure 1 [1].

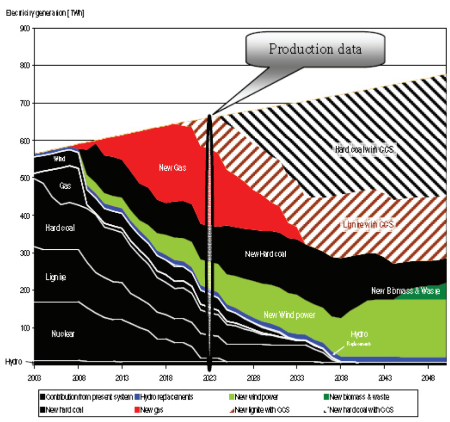

Figure 1: An example of output from one of the energy systems models which are used in the European Pathways project – example is the German electricity generation: 75% Reduction in CO2 by 2050, relative to 1990.

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The example shown is from the German power generation system as modeled by Odenberger et al. [1]. Results from such modeling give valuable information on the overall possibilities for developing the power generation system. However, the techno-economic modeling applied does not include any detailed analysis on the requirements imposed by the electricity network and what investments in the network which are cost effective. This paper discusses a methodology to include the electricity network in the overall analysis of the development of the power generation system. Examples of important questions which such a methodology should help to answer include:

What new network solutions are available to meet requirements for the different pathways to sustainable energy system?

What are the requirements on the transmission system for “key” technologies and systems on the generation side as identified in the Pathways project?

What is the critical timing for decisions to ensure that the electricity network can be developed in line with a pathway to a sustainable energy system?

The following briefly outlines the proposed methodology to address above questions.

Evaluation of existing electricity networks

The black areas in Figure 1 represent the existing power generation system. The data are taken from the Chalmers Power Plant Database which contains all power plants in EU27 with an installed capacity exceeding around 10 MW. For each power plant, the database gives information such as installed capacity, fuel, technology, age and location of the plants. Thus, the location is important information when it comes to the network issues. In this work, existing electricity networks (i.e., mainly the high voltage transmission systems) are simulated. The network representation can be implemented using any standard power flow software.

However, in this work, GAMS software [2] is used, since it will connect to the second part where network planning optimization will be performed. The system can only be solved using a dc load-flow (DCLF). A full ac load-flow would not be possible due to large uncertainties in voltage levels and reactive power sources and reactive power demand by the loads. With the existing systems simulated in the software, it is then possible to identify the physical transmission capacity limit, transmission bottle necks within the country and within countries. Once the long-term bottle necks are identified, the electricity networks need to be reinforced. This is the task of the network planning, which is discussed next.

Future electricity network: An iterative approach

In an electricity network planning (ENP), the task is to determine when and where new network facilities should be installed so that the system can deliver the electrical energy from the generators to the loads in a reliable manner. Of course, other constraints such as financial and environmental issues are also of important considerations in ENP. In this work, we assume that the electricity network planning exercise is carried out with perfect foresight. Under such an assumption, power system data required for expansion planning, such as demand forecasts, existing generators, fuel prices, existing and planned power plants and the level of return on investments are known. It is, however, not the case in the deregulated environment where the new power plants are entirely up to the decisions of private investors. The idea here is that we want to analyze how the generation system planning is affected when considering the transmission systems. We however do not consider simultaneous optimization of both generation and transmission systems at the same time since the problems would become extremely complex. The approach used is of iterative nature as discussed next.

With the existing system, the transfer capability limits within countries and between countries can evaluated. We assume the peak load situation, which normally gives the highest power flows in the network. This information will serve as constraints (boundary conditions for power transfer from one area to the other) in generation planning module which determines the generation scenarios for the future years. With the generation system scenarios, production data will be taken for some selected years (e.g., 5 years at a time). These data will contain the estimated dispatched generation schedules of the power plants. The DCLF developed is used to check whether the system is feasible in terms of physical loadflow with these generation schedules. The calculated power flows can be checked against the actual limits of the transmission lines (i.e., the thermal limits). The load level has been taken into account when generating the scenarios. In this paper, the proposed methodology is applied to the case of Nordic countries.

If the transmission system is not feasible, which means that that the grid is not sufficient to accommodate new generation and load (e.g., there appear new bottle-necks). In this case, network reinforcement and/or development are expected. The DCLF model is used to identify those grid development needs. Once these needs are identified, the model to evaluate different options of transmission system upgrades (e.g., new lines and upgrades) is used to arrive at the “least cost” plan. This model is basically the augmented DCLF with the objective function and additional power flow constraints (i.e., the thermal limits of transmission lines or region). The objective function is the total investment costs in new transmission options plus the applicable environmental costs. The model will identify the optimal decision on new transmission lines and their placement and timings. Once the network is modified, it will again affect the generation system scenarios. The process will go on until no further changes identified in both generation and electricity networks. At this point, the pathways are accepted. The challenges poses by the development of the power generation system are that the new generation capacity will change the requirements of the network, with examples of new generation being intermittent generation (e.g. wind power), poly-generation of electricity and transportation fuel and plug-in hybrid vehicles.

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Guiding citizens' choice towards smart energy technologies

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The transformation process towards energy efficient technologies and a carbon constrained energy system implicitly requires that consumer choices are not only influenced by individuals but also by ocietal objectives such as mitigating climate change. Such a "smart" purchase decision is seen as a citizen choice process, also including societal and ecological aspects in the decision function. Hence, the challenge is to convey a new social norm for appropriate energy technologies that are guiding citizens' choices.

A transition framework for citizens' choices

Based on theoretical and empirical evidence this contribution proposes, a conceptual technology transition framework explaining changes in citizens' choice process.

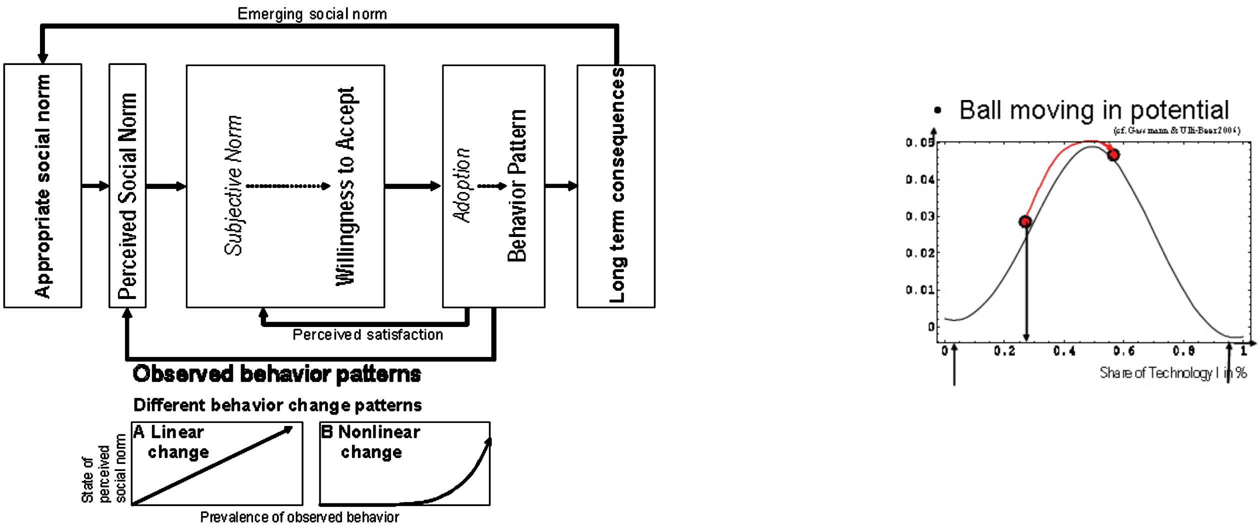

Figure 1: Citizens' technology transition framework: Undesired long-term consequences are provoking the emergence of a new appropriate social norm. Hence, pioneers and first movers induce slowly a new behavior pattern that may be perceived as a new social norm by following adopter categories leading to a linear change pattern if perceived proportional to the number of adopters. The more realistic case would be a nonlinear relationship between the prevalence of a new behavior pattern and the perception of a new social norm leading to nonlinear change. In this case a social lockin effect exists as long as the new norm is not strong enough. Policy measures are required in order to build up a critical mass till the new norm is guiding the mass-market towards a new equilibrium – policy measures would be the force that pushes a ball over the hill (see small illustrative figure).

Reference points setting the transition pace

The technology transition framework highlights the relevance of different adopter categories for the emergence of a new social norm and the technology transition process, respectively. Given a continued succession of the adoption along the categories from innovators, early adopters, early majority, late majority and laggards driven by a new emerging appropriate norm, we can guess a first reference point for the length of the technology transition process; e.g. the average life of cars may indicate how long it will take to replace the old technology within one adopter category. Having only the social norm building process as the guiding social policy, it may take three times the average life span till half of the car drivers have adopted the alternative technology (see Figure 2/3).

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The penetration within pioneers may be the legitimizing process of an alternative drive-train technology offering first decision cues to early adopters that this technology may become an appropriate solution for sustainable road transportation. The early adopters may form significant decision cues to the early majority. This group is learning that a new social norm is evolving. As soon as the early majority has adopted the alternative drive-train technology, this technology may now be prevalent enough within the car fleet to form the dominant social norm. Then, it can start guiding the decision of the late majority and the laggards.

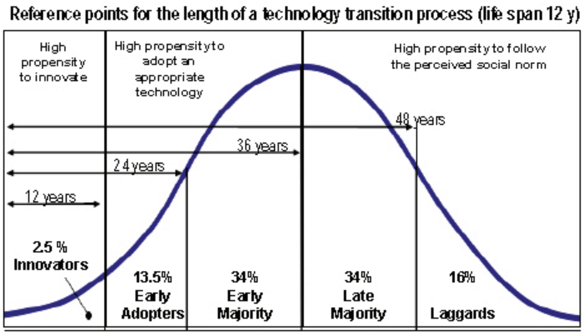

Figure 2: The average life span of the product becomes a first reference point indicating how long it will take an alternative technology to pass through the different adopter categories. In the case of alternative drive-train technologies it may take up to 36 years till half of the drivers may be driving it, if the transition process is primarily moderated by a social norm.

In order to reproduce the corresponding adoption curve representing s-shape growth (Figure 3), the ideal typical adoption succession along the categories can be translated in required market share ranges. The market share graph has a skew bell-shape, highlighting the long lead-time to massmarket (up to 36 years). Over time the stock of potential new adopters gets depleted, meaning that the technology transition has reached its new equilibrium. At this point the market is again mainly driven by repeated purchase decisions guided by the satisfaction loop.

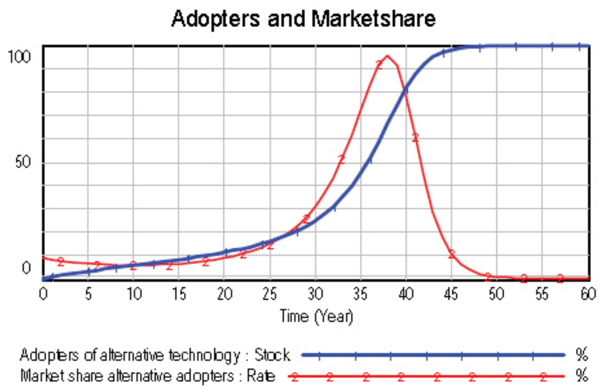

Figure 3: Adoption curve and market share development: Showing the level of adoption with its specific adoption rate or market share, respectively.

Policy deliberations

A nonlinear social norm building process can be absorbed by introducing bridging technologies that foster a more continuous change process. However, also these technologies may have a very long lead time due to other nonlinearities stemming from the supply side. Even worse, it could happen, that bridging technologies could lock the system into an inferior state, without being able to reach the policy goals such as CO2 reduction targets. Hence, a critical condition for promoting this strategy would be the existence of decisive technical spillovers between the bridging technology and a more promising one. For example, since, the automobile industry has very strong inertia, it may be more efficient and effective to follow an aggressive change strategy by fostering a radical change in order to build up a sustainable road transport before fossil fuel prices are disruptively high.

SunCHem – A smart strategy to produce biofuels and capture CO_2 using an algae-based process

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Bioenergy appears to be one of the most cost-effective options for substituting fossil fuels and reducing the net emissions of CO_2. However, the use of bioenergy requires land to intercept incoming solar radiation, and the total amount of energy that can be obtained from these sources is limited. Compared to other biomass types, microalgae are very interesting as they can be grown in reactors and offer the opportunity to utilize land resources that are unsuited for any other use. Productivity in terms of annual biomass yields per area are reported to be in the range of 45-256 tons ha^{-1} year^{-1} for microalgae [1,2,3]. In comparison, sugarcane yields 16-112 tons ha^{-1} year^{-1} [4,5] and corn ca. 9 tons ha^{-1} year^{-1} [6].

Microalgae cultures have been proposed for some years as a method for production of bio-energy and for fixation of CO_2. At present, sustained efforts are being made worldwide for the development and demonstration of the use of (micro)algae for energy and biofuel (biodiesel) production and CO_2 fixation. One of the key technical challenges that needs to be overcome before the large-scale introduction of microalgae technology for fuel production and greenhouse gas mitigation is the efficient conversion of biomass to fuels. We propose an innovative process (**SunCHem)** for the production of bio-fuels (methane and optionally hydrogen) via hydrothermal processing of algal biomass, which uses mainly sunlight energy and fossil (or atmospheric) CO_2 (see Fig. 1). Valuable chemicals produced by the algae (e.g. oils, pigments) could be separated before hydrothermal processing. The goal of our work is to demonstrate the technical and economical feasibility of this innovative process.

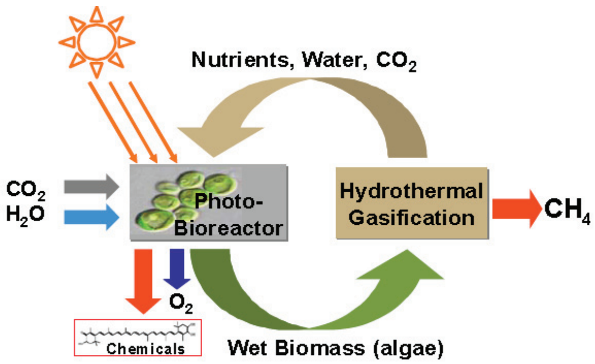

Figure 1: Simplified sketch of the SunCHem process.

The process consists of five steps. The first step is concerned with the production of biomass in efficient photobioreactors. The biomass growing in photobioreactors fixes CO_2 (e.g. from exhaust gases of a cement kiln or from a fossil power plant) and transforms it into biomass and O_2 by photosynthesis. In the second step the surplus biomass is dewatered mechanically to ca. 15-20 wt% dry mass. In a third step, the biomass sludge is then liquefied hydrothermally by heating it up under a pressure of 30 MPa, and salts are separated from the liquefied slurry for reuse as nutrients. In the fourth step CH4 (Bio-SNG) is catalytically produced under hydrothermal conditions (ca. 400°C and 30 MPa) as the major product. In a last step, CO_2 is separated from the product gas and recycled to the photobioreactor. This process is a closed-loop system with respect to all nutrients including nitrogen, and CO_2 produced in the process is also recycled to the algae.

The hydrothermal gasification and methanation process has been the focus of our research activities for the last five years. We have demonstrated that even highly concentrated wood slurries can be completely gasified to methane, CO_2, and H_2 in supercritical water [7]. Currently, we operate a 1 kg/h development unit at PSI. Recent efforts have addressed two important questions for the proposed cyclic process: (i) what is the level of dissolved heavy metals tolerated by certain algae?, and (ii) what is the performance of our current catalysts and of modified ones for the hydrothermal gasification of algae?

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For answering the first question, screening studies using both eukaryotic and prokaryotic microalgae (e.g. spirulina platensis, chlorella vulgaris), growing in Ni and Ru containing solutions were performed. Algae growth could be observed below ca. 25 ppm of Ni. Question (ii) was answered using batch reactor experiments with glycerol, spirulina platensis, and phaeodactylum tricornutum with and without added salts. A modified Ru catalyst exhibited a high tolerance towards sulfate, a well-known catalyst poison at hydrothermal conditions. A demonstration experiment in the continuous hydrothermal gasification plant with a throughput of 1 kg/h is in preparation.

Microalgae can be produced at high specific rates in photobioreactors, surpassing the area yield of crops and other plants. A high thermal efficiency for the production of Bio-SNG in the range of 60-70% is expected if the wet algae slurry is processed under high pressure to avoid evaporation of the water (hydrothermal conditions). Nutrients can be separated and recycled provided that they are not contaminated with heavy metal ions (e.g. from corrosion or from catalyst leaching), which would impede algae growth.

If proved feasible, the **SunCHem** process would offer a very attractive way of producing clean fuels for electricity generation or transportation using sunlight and CO_2 in a carbon-neutral process thus providing a means to store solar energy for use at any time. We are currently working towards demonstrating the technical and economical feasibility of the above described process for the sustainable production of Bio-SNG for power generation or transportation. In this paper we will present the concept of the **SunCHem** process, and we will give an overview about the potential and the technical challenges to be tackled.

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A smart concept for a gasoline hybrid powertrain with zero local emissions

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In order to reduce local emissions (excluding CO_2) to a virtually "zero"-level accuracy and simultaneously lower the fuel consumption, a combination of H_2-enriched fuel, reformed from gasoline on-board, together with a serial hybrid powertrain, is a new promising concept. The presence of hydrogen in the combustion process leads to a substantial reduction of the raw emissions of the engine. Together with a 3-way-catalyst a zero-emission level can be achieved [1]. In combination with a serial hybrid powertrain, the dynamic operation requirements of the internal combustion engine and of the reformer can be limited and partially substituted by the electric path. In addition, shifting the operating point of the engine to higher load can be used to significantly lower the fuel consumption, and braking energy can be recuperated at least in urban driving patterns. The configuration of a hybrid powertrain can be optimized for specific applications (specified vehicle and range of different driving profiles) in terms of cost, but also performance and fuel consumption.

In this collaborative project within the Competence Center Energy and Mobility of the ETH domain, an engine-catalyst system, including an on-board reformer for commercial gasoline, is developed to achieve a zero-emission level combined with a high efficiency. This concept will be demonstrated on a full-size engine in an emulated hybrid powertrain. This emulation can be used as a base for the decision to realize a specific concept as demonstrator in a successor project.

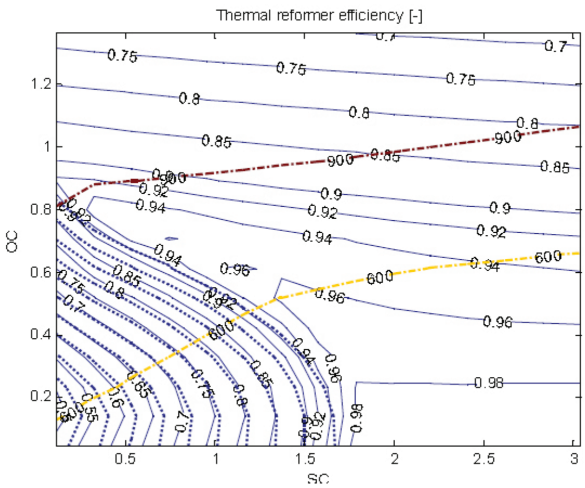

Figure 1: Contours of the thermal reformer efficiency as influenced by the S/C and O/C feed ratios (chemical equilibrium assumed; adiabatic reformer; The yellow and the brown dashed lines represent the 600°C and the 900°C reformer outlet temperatures, respectively; the blue dotted lines in the lower left corner represent conditions for coke formation).

One of the challenges is the proper choice of the reforming strategy. Using steady-state modeling of different reformer technologies (dry partial oxidation, autothermal reforming, exhaust gas reforming), a map of possible operating conditions and performances was obtained. As an example, Figure 1 shows contour plots of the reformer efficiency as a function of the steam-to-carbon (S/C) and the oxygen-to-carbon (O/C) ratios at the reformer inlet [2]. Based on this analysis and a multi-criteria assessment, the best suited reformer technology was selected. Reforming catalysts were then tested for their sulfur tolerance and long-term stability at the selected reformer conditions.

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Heat and Mass Transfer Analysis of a Suspension of Reacting Particles subjected to Concentrated Solar Radiation – Application to the Steam-Gasification of Carbonaceous Materials

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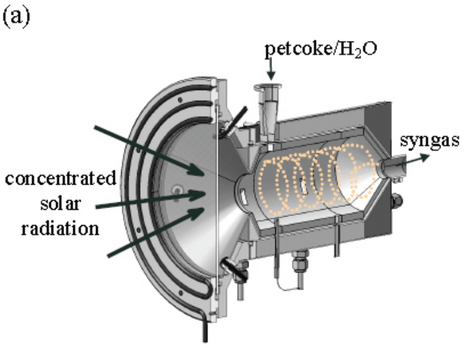
A chemical reactor for the steam-gasification of carbonaceous materials (e.g. coal, coke, biomass) using high-temperature solar process heat is modeled by means of a two-phase formulation that couples radiative, convective, and conductive heat transfer to the chemical kinetics for polydisperse suspensions of reacting particles. The governing mass and energy conservation equations are solved by applying advanced Monte-Carlo and finite-volume techniques with smoothing and underrelaxation. Validation is accomplished by comparing the numerically calculated temperatures, product compositions, and chemical conversions with the experimentally measured values obtained from testing a 5 kW solar reactor prototype in a high-flux solar furnace. A unique feature of the reactor concept is that the gas-particle flow is directly exposed to concentrated solar radiation, providing efficient radiative heat transfer to the reaction site for driving the high-temperature highly endothermic process.

A scheme of the reactor configuration is depicted in Fig. 1a. It consists of a well-insulated 24 cm-length 9.7 cm-diameter cylindrical cavity-receiver, made of Inconel and lined with Al_2O_3, that contains a 5 cm-diameter circular opening – the *aperture* – to let in concentrated solar radiation through a transparent quartz window. Petcoke-steam or petcoke-water slurry is injected at the front of the cavity and forms a particle-gas flow that progresses towards the rear of the cavity. Two experimental campaigns at a power level of 5 kW were performed: 1) "campaign 1", where petcoke particles and steam were injected separately; 2) "campaign 2", where petcoke particles and water were injected together as a liquid slurry. The model domain and the main boundary conditions are shown in Fig 1b.A two-phase fluid flow with neglected circumferential and radial components of the velocity vector is assumed. This simplification enables to better elucidate the physical phenomena involved in the interaction of radiation with the chemical reacting flow.



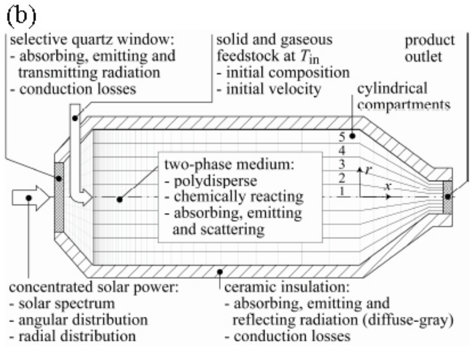


Figure 1: (a) Scheme of solar chemical reactor configuration for the steam-gasification of carbonaceous materials (e.g. petcoke), featuring a continuous gas-particle vortex flow confined to a cavity receiver and directly exposed to concentrated solar radiation. (b) Axissymmetric model domain, featuring five concentric cylindrical compartments. Indicated are also the boundary and inlet conditions.

The simulated progress of the chemical reaction is shown in Fig. 2, where the variation of the chemical composition (molar fractions) is plotted along the reactor at two radial positions: center (r=0 m) and close to the wall (r=0.025 m). Main product gas components are H_2 and CO, with less than 5% CO_2, as predicted by thermodynamic equilibrium. The steam and carbon conversions are significantly lower close to the walls that those obtained at the center line as a result of the relatively low temperatures existing there. In addition, reaction rates decrease towards the exit of the reactor, primarily because of the lower temperatures attained for a decreasing radiation source, as indicated in Fig. 2b. As expected, the gasification proceeds at a higher rate in campaign 1, due to the higher temperatures and particle effectiveness of the feedstock (smaller more reactive particles). This is also corroborated in the 2D contour maps of Fig. 3, showing the reaction rate $\partial X_C / \partial t$ and the carbon conversion X_C in the upper plot – normalized with its maximal value – , and the corresponding temperature profiles in the lower plot. In campaign 1, the peaks for the temperature (>2050 K) and for $\partial X_C / \partial t$ (1.4×10^5 s^{-1}) are pronounced and located in the first centimeters after the inlet plane, followed by a decrease to 1800 K and 6×10^{-6} s^{-1} , respectively, towards the exit of the reactor. In campaign 2, a more uniform temperature and reaction rate field is observed, with maximum values attained 5 cm after the inlet plane. The difference between the two campaigns is attributed to the differences in the particle sizes of their feedstock.

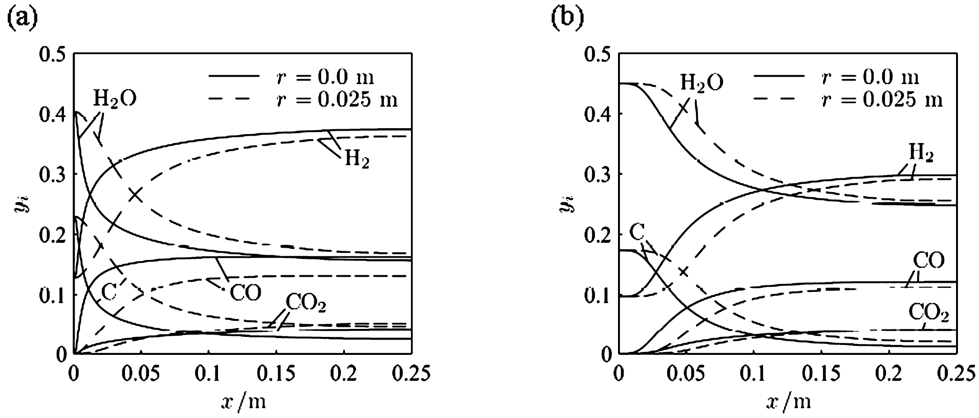


Figure 2: Variation of the chemical composition (molar fractions) along the reactor at two radial positions: center (r=0 m) and close to the wall (r=0.025 m). The baseline parameters of two typical experimental runs were employed for (a) campaign 1; and (b) campaign 2.

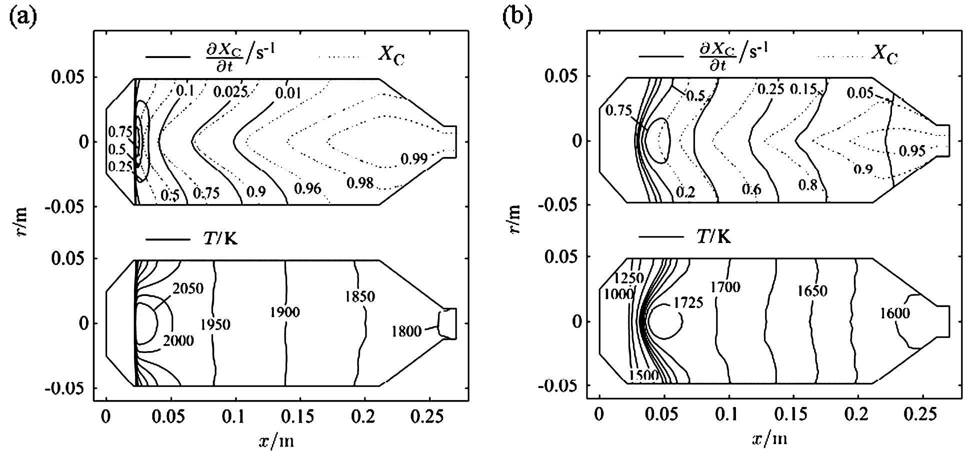


Figure 3: 2D contour map of the carbon conversion X_C and reaction rate $\partial X_C / \partial t$ (upper plot) and corresponding temperatures (lower plot). The baseline parameters of two typical experimental runs were employed for (a) campaign 1; and (b) campaign 2.

A Miniature Turbocompressor System

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The trend in compressors for fuel cells, heat pumps, aerospace and automotive air pressurization, heating, ventilation and air conditioning systems, is towards ultra-compact size and high efficiency. This can be achieved by increasing the rotational speed and employing new electrical drive system technology and materials. This paper presents a miniature, electrically driven turbocompressor system running at a speed of 500 000 rpm. The design includes the thermodynamics, the electric motor, the inverter, the control and the system integration with rotor dynamics and thermal considerations. In the experimental setup, the specified pressure ration of 1.6 is achieved at a speed of 550 000 rpm, which is slightly higher than the design speed.

1 Introduction

In future cars and airplanes more and more hydraulic, pneumatic and mechanical systems, also compressors, will be replaced with electrically driven systems: this leads to more-electric aircrafts and vehicles. Examples are the compressors for heating, ventilation and air conditioning (HVAC) or air pressurization for aircraft cabins. The power levels of these compressors are from about 100 watts up to a few kilowatts. Additionally, several car manufacturers have research projects or even prototypes on fuel cell propulsion systems. Also in trucks and aircrafts, fuel cells are planned to be used as auxiliary power units. These fuel cells usually need an air compressor, which consumes around 10-20% of the output power of the fuel cell, and the pressure levels are usually between 1.5 and 2.5 bar [1]. The air compressor should be small, lightweight and efficient. Another application of compressors are heat pumps. Also there, the trend is to more compact and systems with a higher efficiency. Furthermore, distributed systems could be realized with smaller compressors.

All of these applications need ultra-compact, high-efficient, electrically driven compressor systems, where the preferred type is the directly driven turbocompressor. Power density in both turbomachinery and electrical machines increases with increasing rotational speed [2], [3]. Therefore, these systems can have a rotational speed between 100 000 rpm and 1 Mrpm at power levels of up to several kilowatts.

In this paper, a miniature turbocompressor system with a rotational speed of 500 000 rpm for a calculated pressure ratio of 1.6 and a mass flow of 2 g/s at standard conditions for temperature and pressure is presented. It is built as a first prototype for the cabin air pressurization system for the Solar Impulse airplane [4], but the technology developed during the project will be used in all the other applications.

The system is shown in Fig. 1 and it comprises of a radial impeller, a permanent-magnet (PM) motor and the power and control electronics. The paper starts with the main scaling laws and then describes the different parts as well as the system integration. Finally, measurement results are presented.

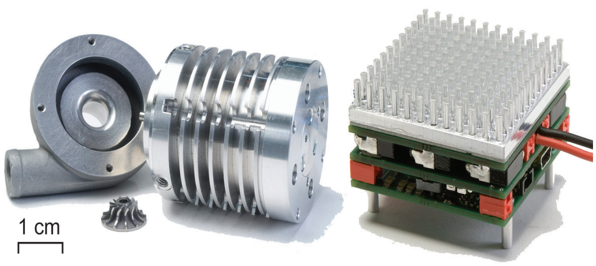

Figure 1: Miniature turbocompressor hardware: inlet, impeller, electrical drive system including stator and rotor, and electronics including control system.

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2 Scaling Laws

There are two reasons for downscaling turbomachinery. Firstly, in high power applications the power density can be increased with modularization and secondly, new emerging applications demand compressors with lower mass flow at constant pressure ratios.

2.1 Power density increase with modularization

In [2] is shown that the power density *(P/V)* of turbomachinery is inversely proportional to the rotor diameter D of the turbomachinery:

$$\frac{P}{V} \sim \frac{1}{D} \tag{1}$$

This implies that a conventional turbomachine with a certain output power can get replaced with a number of smaller units which have all together the same total output power but a smaller overall volume. This scaling implies constant surface speed, which means, that the rotational speed scales inversely proportional with the diameter D, shown in (4). However, this is not fully accurate, as a mayor condition for scaling of turbomachinery is a constant Reynolds number, which is also proportional to the dimension of the flow channel and the height of the air flow channel dh, shown in (2). This dimension also decreases with miniaturisation, and therefore the proportional scaling of speed with $1/D$ is an approximation.

$$\mathrm{Re} = \frac{cd_h}{\nu} \tag{2}$$

As an example, one large turbocompressor can be replaced with 16 compressors, each with a volume of 1/64 of the conventional compressor, which together have the same output power but need just a quarter of the volume of the conventional compressor (Fig. 2). The diameter of the small units would be ¼ of the original one and the rotational speed would therefore increase by a factor of at least 4.

2.2 Downscaling of mass flow

The requirements for turbocompressor, like the Solar Impulse cabin air pressurization system, but also the other mentioned applications such as heat pumps and fuel cell compressors, demand low flow rates (e.g. 1 g/s to 20 g/s) at high pressure ratios (e.g. 1.3 to 3). The characteristic parameters volume flow $\dot{v}$, specific pressure head Y and rotational speed n can be compiled in the similarity parameter specific speed σ

$$\sigma = \frac{n \cdot \sqrt{\dot{V}}}{(2 \cdot Y)^{3/4}} \cdot 2 \cdot \sqrt{\pi} \tag{3}$$

Downscaling of a macro turbomachine for constant specific speed and lower volume flow therefore leads to an increase in rotational speed.

2.3 Electrical machine and power electronics

The power density in electrical machines scales with speed (4),

$$\frac{P}{V} \sim n \tag{4}$$

Therefore, the overall volume of the electrical machines in the example is also ¼ of the original one. In contrast to electrical machines, the size of the power electronics mainly scales with power rating and is minimized by choosing the correct topology through efficiency improvements and the use of high switching frequencies. For systems with high power ratings, the size of the control electronics is negligible compared to the power electronics. However, for ultra-high-speed machines with low power ratings (e.g. 100 W), the control electronics size becomes significant. Generally, the size of the control electronics scales with the complexity of the control method selected and the complexity depends on the topology and the modulation schemes used.

3 Electrical Machine and Electronics

The rotor of the PM motor consists of a diametrically magnetized cylindrical Sm2Co17 permanent magnet encased in a retaining titanium sleeve. The stator magnetic field rotates with high frequency (8.3 kHz), it is therefore necessary to minimize the losses in the stator core by using amorphous iron, and the eddy-current losses in the air-gap winding by using litz-wire (Fig. 3). The machine efficiency at rated power is 87% including air friction and ball bearing losses. A detailed description of the machine has been presented in [5]. The bi-directional power electronics consists of an active 3-phase inverter and an additional buck converter, and a DSP-based control system. The block diagram is depicted in Fig. 4 and the topology has been analyzed in [6]. The power electronics have an efficiency of 95% at rated power. All data is summarized in Table I.

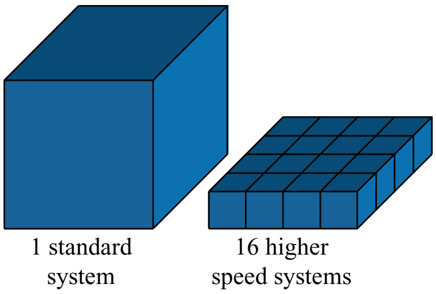

Figure 2: Scaling of turbomachinery: 1 large system can be replaced with 16 higher speed system with only ¼ of the original volume.

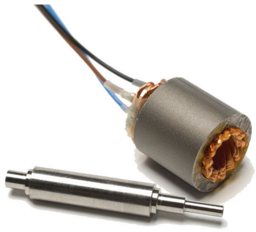

Figure 3: 150 W, 500 000 rpm machine: rotor with permanent magnet encased in titanium sleeve, stator with amorphous iron core and litz-wire air-gap winding.

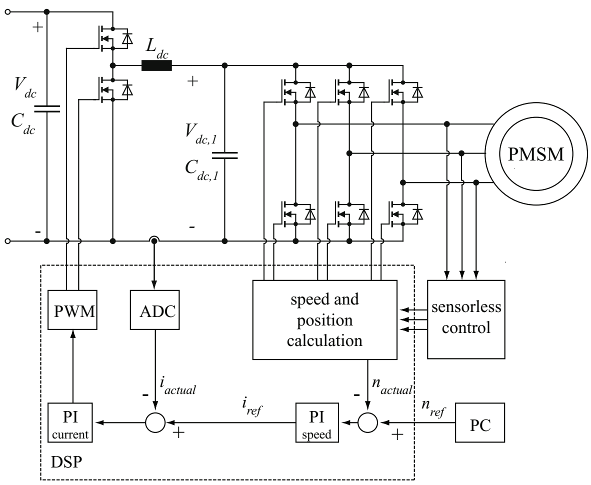

Figure 4: Power electronics and control system for driving an ultra-high-speed permanent-magnet machine.

Table I	
electrical data	
rated speed rated electric power machine efficiency power electronics efficiency dimensions power electronics (b x l x h)	500 000 rpm 150 W 87% 95% 45 x 45 x30 mm

4 Turbomachinery

A single-stage, radial compressor was chosen, because this type of compressors can generate high pressure ratios with a single stage. The biggest challenge is the manufacturing of the impeller and the fitting between the different pieces, especially impeller and casing. This is because the manufacturing tolerances cannot be decreased proportional with the scaling and therefore the leakage losses become more dominant for small compressors. This means that the chosen tip clearance (0.1 mm) is rather high. The impeller consists of 12 blades (no splitter blades) and has a mean streamline diameter at the inlet of 5.28 mm, while the outlet diameter is 10.5 mm. After the flow leaves the compressor, it enters the vane less diffuser and then gets collected in a volute and thereby guided into the exit flange. The compressor is directly mounted to the motor rotor shaft shown in Fig. 1. The design is for a pressure ration of 1.6 and a mass flow of 2 g/s, which is calculated to be achieved at a rotational speed of 500 000 rpm, and a power consumption depending on the mass flow and the inlet temperature of the air. The compressor data is compiled in Table II.

Table II

turbomachinery data	
rated speed	500 000 rpm
pressure ratio	1.6
mass flow	2 g/s
compressor efficiency	72%
turbocompressor lenght	53 mm
turbocompressor diameter	33 mm

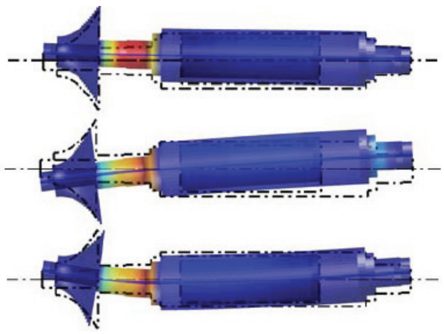

Figure 5: Bending modes of the miniature turbocompressor rotor. First (2.94 kHz, 176 krpm), second (4.59 kHz, 275 krpm), and third bending mode (14.3 kHz, 858 krpm). The color shows the bending and therefore indicates the area of highest mechanical stresses.

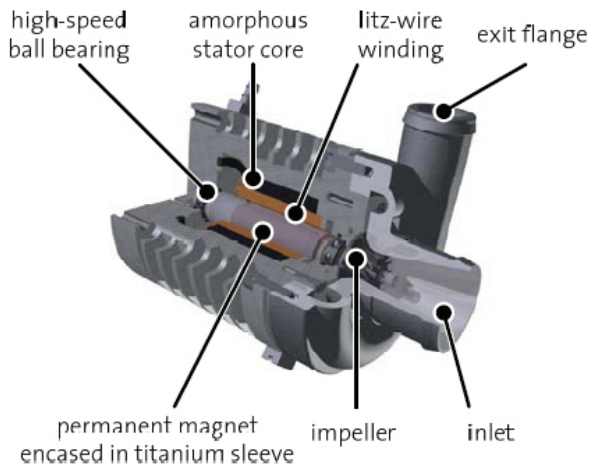

Figure 6: Cross section view of the integrated turbocompressor system.

5 System Integration

Beside the design of the individual components, an analysis of the mechanical stresses and rotor dynamics, and a thermal design is needed. The bending modes of the rotor are depicted in Fig. 5. The length of the shaft is adjusted such that rated speed falls between the second and the third bending modes. A cooling sleeve guarantees safe operation under laboratory conditions (ambient temperature 20 °C), the most critical spot is the ball bearings which produce high losses and have a maximal allowed temperature of 200 °C. On cross-section view of the integrated system can be found in Fig. 6.

6 Measurements

An experimental test bench is built in order to verify theoretical considerations and the feasibility of such ultra-compact ultra-high-speed turbocompressor systems. Therefore, a valve is connected to the compressor outlet, in order to art as a variable load. Between the compressor output and the valve a pressure sensor and a thermocouple is placed. Also at the compressor inlet a pressure sensor, a thermocouple and a mass flow sensor are used. Additionally two thermocouples are used to monitor the electronic and motor winding temperature. Due to the fact that the motor is of synchronous type, the speed has not to be measured separately.

First, the motor has been tested without load up to a speed of 550 000 rpm and the total rated losses in the stator core (0.5 W), the copper losses in the winding (5 W), air friction losses (6 W) and the ball bearing friction losses were measured (8 W).

In a second step, the impeller and inlet housing are mounted and the compressor map depicting the pressure ration versus mass flow for different rotational speeds is measured. In Fig. 7 it can be seen that the specified pressure ratio of 1.6 is achieved, but with a 10% higher rotational speed as designed. One main factor for this difference is the mechanical tolerances in the manufacturing which are not sufficiently small yet, which results in leakage air flow. Due to the same reasons, the measured efficiency (63%) is slightly lower than calculated. In Fig. 8 the electric power consumption of the turbocompressor system is shown. The mass flow at 550 000 rpm is only limited to 1.75 g/s by the electric power input limitation.

7 Conclusion

This paper presents the design of a miniature, electrically driven turbocompressor for various applications in area of renewable energy and heating, ventilation and air conditioning systems. The manufacturing of such miniaturized compressors represents difficulties due to smallest contours and desirably small tolerances. However, measurements show that despite this difficulties the system has a performance close to the specified design operating point, and turbocompressors with speeds up to 500 000 rpm are feasible.

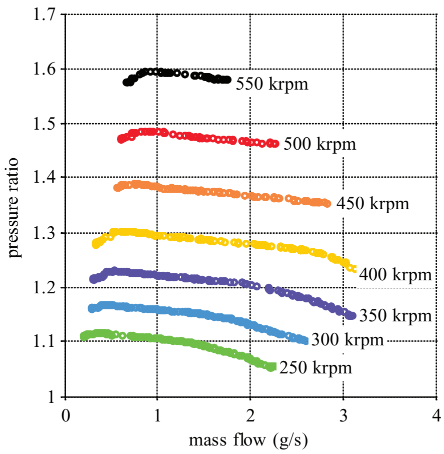

Figure 7: Measured compressor map (pressure ratio versus mass flow for different rotational speeds) of the miniature turbocompressor.

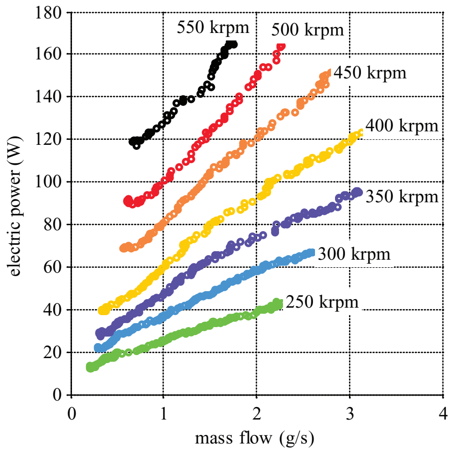

Figure 8: Measured electric power consumed by the high speed electric drive system of the miniature turbocompressor.

This first prototype fulfils the specification regarding the mass flow and the rotational speed, but it does not yet achieve the necessary pressure ratio. One next step in the project include a two stage version of the compressor for an increase in pressure ratio. This is necessary because the maximum flying altitude will be around 12000 m, and therefore a compressor ratio of approximately 3.6 is needed. Furthermore, magnetic and gas bearings are under investigation in order to realize an oil-free compressor system.

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