Project No 308329

ADVANCE
Advanced Model Development and Validation for Improved Analysis of Costs and Impacts of Mitigation Policies

FP7-Cooperation-ENV
Collaborative project

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Report from expert workshops

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 308329 (ADVANCE)

Report from expert workshops
Introduction

ADVANCE established a two-way dialogue with experts and stakeholders on specific topics covered by the project. The workshops involved the users of IAM results (e.g. policy makers and civil society organisations), the broader modelling community (e.g. as organized in the IAMC) as well sectoral experts with the main goal to get bottom-up feedback on the project work and validate the chosen approaches.

Initially it was planned to organize three workshops on the topics of (i) VRE system integration, (ii) drivers of energy demand and efficiency improvements, and (iii) innovation, technology diffusion and uncertainty. Eventually, the consortium had to conduct an additional workshop: in order to cover topic (ii) with the necessary level of detail, two workshops were organized, one on energy demand with a focus on the transport sector and one on energy demand with a focus on the buildings sector.

Also, in the course of project, the timing of the workshops was slightly adjusted in coordination with the scientific officer at the EU Commission. While the workshop on VRE integration was originally planned for month 8, it was anticipated to month 2 of project implementation, as timely feedback by experts as well as coordination with IRENA and NREL was considered of great value already at the very beginning of the project. This facilitated the decision on the direction of model improvements and early start of project activities on this topic. Also the other workshops were slightly anticipated or postponed in time in order to be in line with actual modelling priorities and project progress: the workshop on uncertainty was anticipated from month 24 to month 17; the workshop on energy demand planned in month 15 was split into 2 workshops conducted in month 11 and 25.

This report provides an extensive documentation of the following expert and stakeholder workshops conducted by ADVANCE:

- **JOINT ADVANCE-NREL WORKSHOP "Integration of Variable Renewable Energy" (20 Feb 2013, Potsdam)**
  This topic was chosen for workshop discussion as it is considered to be a top priority in IAM modelling: according to many climate change mitigation scenarios, the variable renewable energies (VRE) wind and solar are key options for mitigating greenhouse gas emissions. However, since their energy source fluctuates, they increase the challenge of matching load with electricity generation. Workshop participants discussed these challenges and ways to represent them in IAMs, including the need of consistent, up-to-date resource potential datasets. The workshop also served the purpose to bring together ADVANCE modelling teams with the Renewable Initiative coordinated by NREL and IRENA and allowed identification of synergies und planning of further cooperation.

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- **The JOINT IIASA-PBL WORKSHOP "Enhancing the state of transport modelling in IAMs" (19 Nov 2014, Laxenburg)**
  The driving force behind this workshop was the recognition that the transport sector represents a particularly important demand sector within IAMs, given that energy use and carbon emissions are increasing quickly and the mitigation of these emissions can be difficult to achieve. The workshop brought together transport experts from various areas in order to share their extensive knowledge on the sector and ultimately to provide guidance on how to enhance the state of transport modelling in IAMs. Topics covered during the workshop included data, behavior and infrastructure.

- **FEEM WORKSHOP "Uncertainty in climate change modelling and policy" (13-14 May 2014, Milan)**
  The workshop focused on uncertainty, as a key factor of climate change. In fact, to understand the problem of climate change and formulate appropriate policy responses, it is necessary to understand major uncertainties and provide related risk management strategies. The workshop discussed potential applications of uncertainty and risk analysis to IAMs as well as recommendations for modelling climate change policies under uncertainty.

- **PBL WORKHOP "Innovation in relation to building energy demand in IAMs" (20-21 Jan 2015, Utrecht)**
  The workshop aimed at filling a major gap in IAM modelling: generally, IAMs tend to focus on energy supply rather than on energy demand, however energy demand is a main driver of emissions and, related to this, energy efficiency is of major importance for mitigation strategies. The workshop looked into technological and behavioural options to increase energy efficiency in buildings as well as demand management options to support grid integration of VRE. By means of expert knowledge on these topics, participants could draw conclusions on how to represent these issues in integrated assessment models.

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JOINT NREL-ADVANCE WORKSHOP ON RENEWABLE ENERGY SOURCES

20 February 2013
Location: Potsdam, "Haus H" Telegrafenberg

AGENDA

Part I: Stock-taking (Chair: Elmar Kriegler)	
14:00–14:05	Welcome and short introduction
14:05–14:20	Goal and status of the Renewables Initiative (Doug Arent, NREL)
14:20–14:35	RES and IAMs: Lessons learned from EMF27 and plans for ADVANCE (Gunnar Luderer, PIK)
14:35–14:50	IRENA intentions (Asami Miketa, IRENA)
14:50–15:05	Discussion
15:05–15:25	RE resource potentials (short Input from NREL / DLR)
15:25–15:45	Representation of RE integration in IAMs (short input Patrick Sullivan and/or IAM teams)
15:45–16:00	Coffee Break
Part II: Planning the work ahead (Chair: Leon Clarke)	
16:00–17:00	Scenario work / model comparison Methodological development Scope for a special issue

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JOINT NREL-ADVANCE WORKSHOP ON RENEWABLE ENERGY SOURCES
An expert meeting carried out within the framework of the
European Commission FP7 ADVANCE project
Wednesday, Feb 20, 2013, Potsdam

REPORT

Objectives

According to many climate change mitigation scenarios, the variable renewable energies (VRE) wind and solar are key options for mitigating greenhouse gas emissions. Since their energy source fluctuates, they increase the challenge of matching load with electricity generation. Options for ensuring grid stability include storage, increased geographical averaging through increased transmission lines, or demand-side management.

Integrated Assessment Models (IAMs) are the main tool to analyze the long-term energy system transformation pathways needed for stringent climate mitigation, and are accordingly used to derive long-term targets for deployment of variable renewable energy technologies. IAMs face a considerable challenge concerning their temporal resolution: They have to span a whole century to cover the relevant long-term climate dynamics, while also representing the effects of very-short-term dynamics (down to hourly scale) on investment decisions in the power sector. Also, they require aggregated resource potential data sets to represent the regionally differentiated availability of solar and wind resources.

The aim of this expert workshop was to bring together IAM modelers and experts on variable renewable energies to discuss the development of consistent, up-to-date resource potential datasets, to explore the main characteristics of the VRE system integration challenges as well as ways to represent these integration challenges in IAMs. The agenda was organized around two main sessions, the first covering the existing knowledge and main insights from VRE experts, the second covering the IAMs and defining the interfaces and collaborations to transfer the expert knowledge into IAMs. The workshop connected the modelling efforts in the ADVANCE project with the existing Renewable Initiative coordinated by NREL and IRENA to maximize synergies between the two projects.

Part I: Stock-taking (Chair: Elmar Kriegler)

The workshop started with a welcome and short introduction to the workshop objectives by Elmar Kriegler, Coordinator of the ADVANCE project.

RE Working Group: Improving the Representation of Renewable Energy Technologies in IAMs for Climate Scenario Analysis (Doug Arent, NREL)
Doug Arent provided an overview of the work NREL has done on analyzing variable renewable energies in the US, including the Western Wind and Solar Integration Study and the Renewable Electricity Futures Study. Using detailed grid models and taking a systems perspective allowed to analyze both negative and positive system effects of increasing the share of wind and solar in power systems.

Arent stressed the importance of continuous interaction and exchange between IAM modelers and VRE experts working with more detailed models, and offered an intensive collaboration between NREL and the

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ADVANCE teams. In order to facilitate this interaction, the Renewable Initiative was created, which is a vessel for exchanging data and modeling approaches between different modeling and research teams.

A further focus point was the problem of resource potential dataset derived from coarse resource data. This was illustrated on the example of an NREL wind potential analysis for the US, where most of the good wind sites were overlooked when using reanalysis data on a 120km grid, compared to using reanalysis data derived from a more detailed grid level.

RES and IAMs: Lessons learned from EMF27 & plans for ADVANCE (Gunnar Luderer, PIK)
Gunnar Luderer presented insights from the previous modeling comparison study EMF 27 on the deployment of renewable energy in IAM scenarios. While a substantial increase of renewable energy is robust across most models, the size of this increase varies strongly between different models. Three main determinants for VRE deployment were identified in the course of the EMF27 study: resource assumptions, technology cost assumptions, and the modeling of VRE integration challenges.

Luderer then explored how WP5.1 of the ADVANCE project could contribute to reduce the uncertainties on these drivers, with a special focus on developing improved modeling approaches for representing integration challenges.

Objectives and Activities of the International Renewable Energy Agency (Asami Miketa, IRENA)
Asami Miketa presented IRENA's activities concerning analysis of VRE integration and capacity building on VRE modeling. With a membership of 160 countries, IRENA is uniquely positioned to take a country-by-country view on VRE integration and explore the similarities and differences between different countries' challenges. They especially focus on questions from emerging economies and less developed countries, having performed a study on VRE integration in Africa and planning to do a similar exercise in Latin America. IRENA thereby offers a complement to the US/EU-focused experts from NREL and DLR, and could help the IAM modelers to develop parameterizations for all world regions.

System integration – a bottom-up taxonomy (Falko Ueckerdt, PIK)
Falko Ueckerdt presented a categorization of integration challenges based on three distinct characteristics of VRE, namely that their output is variable, that their output is uncertain, and that VRE resources are location-specific. These three characteristics can lead to system integration costs, which can accordingly be classified as profile costs, balancing costs, and grid-related costs. Based on a substantial literature review and preliminary modeling exercises, profile costs seem to be substantial, grid costs are lower but still relevant, and balancing costs seem to be of a negligible size when taking an aggregated IAM viewpoint. Ueckerdt then elaborated options to reduce integration costs, and how they might be represented in IAMs

RE resource potentials (Patrick Sullivan, NREL, and Yvonne Scholz, DLR)
Patrick Sullivan presented ongoing work at NREL to create a new resource dataset for onshore wind, based on CFDDA reanalysis data from NCAR. Once finished, this dataset might be used and implemented by the ADVANCE modeling teams. He made a proposal for a suitable data format for exchange with the IAM teams, and a dataset vetting process was defined in the ensuing discussion.

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Yvonne Scholz discussed the global renewable data available at DLR, and proposed to create a dataset for the two solar technologies photovoltaics and concentrating solar power. Exclusion areas have a substantial effect on resource potentials, so it would be beneficial to either harmonize exclusion assumptions or allow resource dataset users to specify criteria for exclusion areas.

Representation of RE integration in IAMs (Yvonne Scholz, DLR and Patrick Sullivan, NREL)
Concerning the challenge of VRE system integration, Yvonne Scholz briefly presented the REMIX model and its main characteristics. REMIX is a Dispatch and Investment model that covers all European countries and covers a full year in hourly time steps. It therefore allows to analyze both the local integration challenges from wind and solar, as well as the benefit that improving the grid connection between different countries can have in smoothing VRE feed-in and thereby reducing integration challenges.

Patrick Sullivan then discussed NREL work on VRE integration and emphasized the offer to directly assist with implementing new modeling approaches in IAMs. During a research stay at IIASA, he had integrated new constraints into the MESSAGE model to better represent additional requirements for power system flexibility arising from VRE additions. The MESSAGE parameterization was based on a large number of runs with a more detailed power system model by NREL.

Part II: The way forward (Chair: Leon Clarke, PNNL)

Exchange on the different IAMs current integration approaches
In the following, each of the participating IAM teams briefly presented the approach currently implemented in their IAM, envisioned improvements in the process of the ADVANCE project, as well as needs in terms of resource potential data, time series or technology parameterizations.

Leon Clarke, GCAM (PNNL)
GCAM takes a two-pronged approach. For the US, the model encompasses 4 time slices to which VRE contribute differently, and the model can trade between different load segments with the help of a storage technology. For the rest of the world, electricity is a homogeneous good, and integration costs are added as VRE-shares increase.

Shinchiro Fujimori, AIM/CGE (NIES)
Due to its CGE nature, AIM does currently not have a detailed technology representation of VRE integration challenges, but rather relies on the substitution stiffness of the CGE formulation.

Tobias Wiesenthal, POLES (JRC)
POLES recently increased the number of renewable technologies included in the model. Concerning VRE integration, it requires back-up capacity when VRE-shares increase, and there is a region-specific hard upper bound on VRE shares. The POLES team is working on introducing storage, and thinking about adding a dispatch sub-module with hourly resolution to better represent the challenges of VRE integration.

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David Gernaat, IMAGE (PBL)
IMAGE has a number of explicit VRE integration challenges, but the parameterization is outdated and was based on very coarse data. Also, the interaction between the back-up capacity constraint and the investment algorithm creates an implicit upper bound for VRE deployment.

Nils Johnson, MESSAGE (IIASA)
MESSAGE is working on the introduction of explicit equations for capacity adequacy and system flexibility together with NREL. Further plans for ADVANCE work include the addition of concentrating solar power as well as regionally differentiated parameterizations of the integration equations.

Giacomo Marangoni, WITCH (FEEM)
WITCH contains an aggregated wind/solar-technology, with integration challenges implicitly represented in the limited substitutability of the CES production function. Plans for ADVANCE work are to split the VRE technology into explicit wind, PV and CSP technologies, as well as adding explicit integration constraints.

Robert Pietzcker, REMIND (PIK)
REMIND currently contains explicit wind, photovoltaics and concentrating solar power technologies. AS VRE shares increase, the model requires storage to be built and also curtails some of the produced electricity. Plans for ADVANCE are the introduction of residual load duration curves to better represent the interaction between VRE and the rest of the power system.

Main points raised in the discussion about the way forward:

Doug Arent, NREL: It would be good to have diagnostic scenarios from all the IAMs to allow judging the realism of the currently implemented approaches. Questions to ask are “do you get a realistic amount of VRE?”, “can you do 450 without nuclear and CCS?”, “what is the impact of the new resource dataset?”.

Elmar Kriegler, PIK: What is the added value of running the new scenarios? We already have the EMF27 scenarios. The main difference between the models will be the difference in integration modeling.

Leon Clarke, PNNL: Scenarios would help to do fingerprinting of the models. We shouldn’t see the scenarios as “results”, rather as “development work”, or as part of the stock-taking/ diagnostics.

Gunnar Luderer, PIK: As ADVANCE is more about modeling than about scenarios, we should try to have a limited number of scenarios. Next steps should be: taking stock of the integration approach, tailor the VRE potentials, clear up problems with the reporting template, run the scenarios.

Patrick Sullivan, NREL: We need to start improving the IAMs – let us not waste time on more scenarios when the main task is modeling.

Robert Pietzcker, PIK: To start working on the IAMs, we first need the diagnostic scenarios to show us where the main problems lie, and how to prioritize. With IAMs, it is not possible to “add every realistic constraint there is” – IAMs are too numerically demanding. You need to identify the most important constraints.

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Tobias Wiesenthal: To test the limits of the integration challenge: try to force the models into very high RE shares. Shouldn't we also think about renewable heat?

Gunnar Luderer: WP5.1 focused on power system. RE heat would be interesting, but only if all other power sector aspects are covered.

Asami Miketa, IRENA: It would be good to have some IAM scenarios with high VRE shares to allow analyzing what would be the impact of high VRE deployment on climate mitigation and economic development.

Robert Pietzcker, PIK: To improve VRE modeling in IAMs, it would be extremely useful to have a large number of scenarios with different wind and solar shares calculated by a more detailed, hourly power sector model. These scenarios could then serve to parameterize IAMs, validate existing modeling approaches or assist the creation of new algorithms.

Yvonne Scholz, DLR: Currently, REMIX is mostly used in "validation mode", where we check if a set of VRE and conventional capacities can meet load in each hour of the year in the EU. It could probably be improved to a "greenfield investment mode", where optimal capacities for different VRE shares are calculated. This might then be used to create a number of scenarios to which IAMs could be compared.

Gunnar Luderer, PIK: Given the number of IAMs and bottom-up experts contributing to this WP, it might be useful to publish the results and findings together in a Special Issue in a suitable journal.

Doug Arent, **NREL**: A special issues sounds like a promising idea to have a wide visibility of the results. Possibly, John Weyant would be willing to host the Special Issue in "Energy Economics".

Next Steps

1. Finish wind potential data set (NREL)
2. Iterate with IAM teams (NREL, PIK, all teams)
3. Do stock-taking of integration approaches (PIK)
4. Define scenario matrix: (PIK/NREL)
    a. old/new resource potentials
    b. high/low integration costs
    c. high/low technology costs
    d. no Nuclear, no CCS
5. Define reporting template (PIK)
6. Run scenarios (All teams)
7. Organize an ADVANCE WP5.1 meeting at the SNOWMASS workshop, where the scenarios can be discussed with VRE integration experts from NREL (NREL/PIK)

The next months will be used to collect in-depth information on both the current implementation of VRE Integration in the models as well as the approaches envisioned by the pioneer models MESSAGE, REMIND and POLES to start content-based interactions between the teams. Furthermore, possibilities for the interface and information exchange between the DLR and the large-scale IAMs will be developed until the next meeting. Also, a cooperation with the Renewable Initiative was started that could lead to improved renewable data input to the IAMs.

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JOINT NREL-ADVANCE WORKSHOP ON RENEWABLE ENERGY SOURCES
Wednesday, Feb 20, 2013, Potsdam

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NETHERLANDS ENVIRONMENTAL ASSESSMENT AGENCY (PBL) AND
INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS (IIASA) WORKSHOP ON

ENHANCING THE STATE OF TRANSPORT MODELING IN IAMS

AN EXPERT MEETING CARRIED OUT WITHIN THE FRAMEWORK
OF THE EUROPEAN COMMISSION FP7 ADVANCE PROJECT
(WODAK ROOM, IIASA, LAXENBURG, AUSTRIA – 19 NOVEMBER 2013)

8:15	*Departure with shuttle bus from hotel to IIASA* ***Grand Hotel Mercure Biedermeier*** *(Landstraßer Hauptstraße 28, 1030 Vienna)*
9:00	**Opening remarks** (10 min) *Welcome from host:* Keywan Riahi *Objectives of the meeting:* David McCollum, Detlef van Vuuren
9:10-10:30	**Session 1: What is the current state of transport modeling in IAMs and where should it go?** To advance the state of modeling, it is important to understand the current 'lay of the land' and how the integrated assessment modeling community arrived at this point. This session will provide an overview of the present state of transport modeling within IAM frameworks, as well as the challenges that lie ahead. The evolution of these models will be discussed from both present-day and forward-looking perspectives. What criticisms have been made of IAM transport models in the past? How have IAMs responded to these criticisms? Which models include which features? How do scenario results compare across models for key transport metrics, and are these results easily explained by the parametric assumptions and structural frameworks of the models? How do IAM transport results compare to more focused sectoral studies? In what ways are the IAM teams in ADVANCE hoping to improve the representation of transport in their models in the foreseeable future? ***Chair: David McCollum***

Bastien Girod, ETH-Zurich & PBL Netherlands Environmental Assessment Agency (20 + 10 min)
Global transport modeling in IAMs: past experience, pitfalls, and paths forward; comparison of results across models

Tom Longden, Fondazione Eni Enrico Mattei (15 + 5 min)
Comparing IAM results for transport and embedding them within the wider sectoral study context

Oreane Edelenbosch, PBL Netherlands Environmental Assessment Agency (10 + 5 min)
Areas of planned/desired IAM transport modeling improvement, as identified by the transport stocktaking exercise in the context of ADVANCE

Group discussion (15 min)

10:30-10:45	**Coffee Break**

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10:45-12:00	**Session 2: What transport data is available and what more do we need for IAM work?** Model results are driven in large part by input data and assumptions: this is as true for transport modeling as for any other energy sector. Various sources of transport data exist, but where are the best places to find it? Are there any centralized repositories of combined country-global data? Are particular data sets better than others? How similar or different are they? Are there any known caveats? How certain or uncertain are the numbers thought to be? What do we do about gaping holes in the data for particular countries and transport modes? Is it possible or useful to construct an historic database for common use throughout the research community? What is the best way to harmonize data across models? ***Chair: Detlef van Vuuren***

Detlef van Vuuren, PBL Netherlands Environmental Assessment Agency and Utrecht University (5 min)
Introduction into the session: What is it that we want to achieve in ADVANCE with respect to data collection and organization? What will we use it for? What kind of product (e.g., database) might emerge from ADVANCE?

Lew Fulton, University of California, Davis (15 + 10 min)
State of global/national transport databases; caveats and known issues; how can improved data resolution also increase the resolution of scenarios

Jari Kauppila, International Transport Forum (OECD) (15 + 10 min)
State of global/national transport databases; caveats and known issues; what data is best to use for transport modeling within IAMs?; is it possible or useful to construct a common database?

Group discussion (20 min)

12:00-13:30	**Lunch (sandwiches will be provided outside meeting room)**

13:30-15:00	**Session 3: Key determinants of mode choice and service demand - how can IAM transport models be improved to reflect heterogeneous behavior and consumer choices?** Capturing consumer choice and behavior in numerical models is an acknowledged challenge, especially in the transport sector, given the myriad market imperfections. This session will discuss key determinants of mode choices driving transport energy demand, and how these vary within a population, over time, and spatially. Best-practice modeling examples from the community will be noted, and experiences shared. What vehicle and mode choice algorithms can be feasibly incorporated into IAMs? What do we know about modeling price-induced demand responses and how are these affected by consumer preferences and choices? Are different modeling paradigms required for developing vs. industrialized countries? How demand-influencing policies (e.g., 'fee-bates', public transit and land use, road and parking pricing, etc.) be represented in IAMs? ***Chair: Charlie Wilson***

Mark Jaccard, Simon Fraser University (20 + 10 min)
Determinants of modal choice and service demands, including examples of how to model transport-sector policies?

Jillian Anable, University of Aberdeen (20 + 10 min)
Modeling of transport demand, behavior and consumer choices – present practice and challenges?

Group discussion (30 min)

15:00-15:30	**Coffee Break**

15:30-17:00	**Session 4: How can transport infrastructure be better modeled in IAMs?** The complex networks supporting person and freight mobility are fundamental elements of the transport sector, even if they are not fully represented in many IAMs. This session will reflect on which of these elements are most critical to model and how best to model them. For advanced vehicles and fuels this potentially includes representing pipelines, refueling stations, and fast-chargers, among others. How are infrastructures supporting fossil liquids, biofuels, electricity, and hydrogen different in this context? The 'chicken-and-egg' dilemma is well known, but can it be satisfactorily modeled in IAMs? How should models treat the different actors involved in making these decisions: public vs. private; society vs. individuals? How far should the IAM system boundaries be extended along the infrastructure dimension – all the way to network capacity issues and the construction of roads, bridges, rail lines, ports, airports, bike lanes, etc.? ***Chair: Robert Pietzcker***

David Greene, Oak Ridge National Laboratory and University of Tennessee (20 + 10 min)
How can fuel delivery and infrastructure decisions be captured in IAMs? Is it possible to model the "chicken and egg" dilemma? How do biofuels, electricity, and hydrogen compare in this context? How might infrastructure issues influence energy transition dynamics?

Hannah Daly, University College London (20 + 10 min)
Infrastructure decisions in energy systems and integrated assessment models

Alexander Körner, International Energy Agency (10 min)
Estimating road and railway infrastructure capacity and costs – lessons learned from IEA analyses

Group discussion (20 min)

17:00-18:00	**Discussion Session: Where do we go from here?** Wrap-up of the meeting. What follow-up activities can we imagine? Which areas are the most feasible? Which are of the highest priority (for policy, for the IAM community, for other research communities, etc.)? ***Chair: Keywan Riahi***

18:00	*Departure with shuttle bus from IIASA to hotel* ***Grand Hotel Mercure Biedermeier*** *(Landstraßer Hauptstraße 28, 1030 Vienna)*

NETHERLANDS ENVIRONMENTAL ASSESSMENT AGENCY (PBL) AND
INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS (IIASA) WORKSHOP ON

ENHANCING THE STATE OF TRANSPORT MODELING IN IAMS

AN EXPERT MEETING CARRIED OUT WITHIN THE FRAMEWORK
OF THE EUROPEAN COMMISSION FP7 ADVANCE PROJECT

Background of the meeting
Research within the FP7 ADVANCE project strongly focuses on enhancing the representation of energy demand in integrated assessment models (IAMs), both by improving the description of energy services and end uses (WP2) and by better capturing spatial, social, and policy heterogeneities, including consumer behavior and preferences (WP3). Transport is a particularly important demand sector within these models, given that energy use and carbon emissions are increasing quickly and the mitigation of these emissions can be difficult to achieve. The purpose of this joint PBL-IIASA workshop was to bring together transport experts from various areas in order to share their extensive knowledge on the sector and ultimately to provide guidance for how to enhance the state of transport modeling in IAMs. Topics covered during the day-long meeting included data, behavior and infrastructure.

Opening remarks
Keywan Riahi, *International Institute for Applied System Analysis, Austria*
As the co-host, Riahi welcomed all workshop participants and gave a short introduction to IIASA and the town of Laxenburg. He also described how one of the first transport innovations of the modern era (train travel) contributed to the town's development.

Detlef van Vuuren, *PBL Netherlands Environmental Assessment Agency, the Netherlands*
van Vuuren, one of the workshop co-organizers, explained that IAMs tend to include more technological detail on the energy supply side than on the demand side. Many studies show that there is great potential for reducing greenhouse gas emissions from energy supply. In contrast, fewer analyses have explored the potential for energy efficiency; the ones that have (e.g., the Global Energy Assessment) indicate that efficiency can be a key mitigation option in achieving long-term low temperature goals. Therefore, for the IAM community it is a high priority to enhance the representation of energy demand in their models, and specifically within the transport sector.

Session 1: What is the current state of transport modeling in IAMs and where should it go?
To advance the state of modeling, it is important to understand the current 'lay of the land' and how the integrated assessment modeling community arrived at this point. This session provided an overview of the present state of transport modeling within IAM frameworks, as well as the challenges that lie ahead. The evolution of these models was discussed from both present-day and forward-looking perspectives.
Chair: David McCollum, International Institute for Applied System Analysis, Austria
Speakers: Bastien Girod, Tom Longden, Oreane Edelenbosch

Bastien Girod, *ETH-Zurich & PBL Netherlands Environmental Assessment Agency, Switzerland & the Netherlands*
Girod presented his comparison study of five IAM transport models. A key finding was that projected service demand growth drive total emissions in all models (annual growth of service demand is 2.1 to 2.9 % for travel, 1.8 to 2.8 % for freight, compared to 1.1% to 2.2 % for direct CO_2 emissions). The main transport modes for global GHG emission are: cars, air travel, and heavy trucks. The share of air travel in total emission is poised to increase in future, which is most pronounced in models that consider the increasing value of time costs for travel mode choices. There are other modes (e.g. rail) that would be relevant for mitigation (mode shift), but little change in mode split is observed even at high carbon prices (200 USD/tCO2). To improve the IAM transport models, the following is needed: a better understanding of potential transport development pathways in transitional and developing countries; an enhanced representation of the response to a carbon tax (with respect to service demand, mode shift, efficiency, fuel mix); and improved modeling of alternative fuels and fuel prices.

Tom Longden, *Fondazione Eni Enrico Mattei, Italy*
Longden focused on four major areas that are important for modeling transport: fuel mix and carbon reduction potentials, fuel efficiency and technical change, demand for travel and freight, and modal shifts. Scenario projections of IAMs were compared and embedded within a wider sectoral study context, based on the work that was done for the IPCC AR5 report. In terms of fuel mix and carbon reduction potentials, IAMs show results that are similar to non-IAM transport model results. Fuel efficiency and technical change are areas where details should be clarified and refinements should continue to take place. In addition, freight was highlighted as a particularly challenging sector to model in IAMs. Unresolved issues include how to represent sea and air, and should demand be linked to GDP or can industrial composition be taken into account. Finally, Longden suggested that modelers should start thinking about how IAM outputs can be maximally effective for consumers of such information. This includes making divisions in and/or reporting variables based on: public/private personal transport, road/rail freight, and sea and air.

Oreane Edelenbosch, *PBL Netherlands Environmental Assessment Agency, the Netherlands*
Edelenbosch summarized one of the first major activities within the ADVANCE project: taking stock of the current representation of energy demand models within the IAMs involved and attaining an overview of their ambitions for improving these models. Edelenbosch focused her talk on the transport sector stock-taking, of which results from eleven models were available. She noted large variations in technological detail across the models – in terms of the number of modes and technologies considered, which costs are taken into account, how efficiency is represented, and the relationship between demand and its drivers. The modeling ambitions of the teams could be categorized into four categories: improving technology representation, improving the historical and calibration data, more heterogeneity, and including infrastructure cost.

Discussion and questions from the audience
Andre Lucena (UFRJ, Brazil): The global "bottom-up" transport models are quite detailed, but are they detailed enough? City-scale models can be more useful for informing policy on the ground.

Felix Creutzig (MCC, Germany): Regarding the discussion of infrastructure (road/rail networks, etc. vs. new refueling systems), he would add a third type of infrastructure that models could/should consider: the built environment. It could be a fruitful exercise to couple global IAMs with local models for the built environment.

Robert Pietzcker (PIK, Germany):
The question is, what for do we try to improve the IAM transport models? We should only put in more details if these improvements actually influence the aggregated results, not only for detail's sake. We also have to think about how to design new model comparison scenarios that make explicit the newly-introduced range of policies and options beyond "one carbon price", such as policies to change infrastructure/city design, or travel behavior.

Lew Fulton (UC DAVIS, U.S.A.): Regarding the practice of applying transport metrics developed for one region to other regions, Fulton would argue that this does not work in many cases. For instance, people in developing countries probably have higher price elasticities than their counterparts in the US and EU, so we cannot simply use the numbers calculated from US/EU data.

Session 2: What transport data is available and what more do we need for IAM work?
Model results are driven in large part by input data and assumptions: this is as true for transport modeling as for any other energy sector. Various sources of transport data exist, but where are the best places to find it? Are particular data sets better than others? How certain or uncertain are the numbers thought to be? What do we do about gaping holes in the data for particular countries and transport modes? Is it possible or useful to construct an historic database for common use throughout the research community? What is the best way to harmonize data across models?
Chair: Detlef van Vuuren
Speakers: Jari Kauppila, Lew Fulton

Detlef van Vuuren, *PBL Netherlands Environmental Assessment Agency, the Netherlands*
van Vuuren stressed that an essential element of transport models is data, in terms of activity levels (e.g. pass-km by mode), energy use per service unit (e.g. energy use for cars), energy use for different technologies (e.g. gasoline vs. electric vehicles), relevant prices and taxes, and a variety of cost information. Several modeling teams are in the process of collecting their own data to support model development. Yet, these parallel activities are not the most efficient use of constrained resources across the IAM research community. Sharing data between the ADVANCE teams would not only save time, but also present the opportunity to check the data on inconsistencies. This could be done in a database, similar to the GTAP database, or alternatively in a meta database, where the available data would be summarized and direct links to the providing institution would be available. In the latter case the data would continue to reside at the organization that originally provided it.

Jari Kauppila, *International Transport Forum (OECD), France*
Kauppila described how the ITF continuously collects a large amount of transport data at the country level (e.g. ton-km, pass-km, investment in infrastructure, CO_2 emissions, road safety). This data, much of which is freely available online, is based on surveys and cooperation with other organizations. For example, the ITF/Eurostat/UNECE questionnaire contains 800 transport variables, however, this is not online yet. ITF publishes a "Glossary for Transport Statistics", which provides a basis for international comparability in data reporting and measurement. One of the ITF's goals is to ensure that data collected across countries is somewhat harmonized. Kauppila then put forward the challenges in transport data collection and analysis:

- Achieving a common understanding across countries on what data should be collected and how. Comparability is affected by lack of data collection criteria and definitions.
- Good information on origin-destination pairs, non-motorized transport, and differentiation between rural, inter-urban, urban transport data is at this moment difficult to find.
- Continuity is a problem: some data collection activities are started but then later discontinued.
- Responsibility for collecting data is often fragmented, and global data initiatives are often not integrated with domestic data activities. No global mandates exist for data collection.

In terms of solutions to the above challenges, coordinated efforts are needed (e.g., SLoCaT, ITF, IEA, UN-DESA) to reduce fragmentation. Also, using data collected by public authorities for other purposes (e.g. customs data) could provide a solution to overcome the limited data availability.
Finally, Kauppila suggested that there could be ways for ITF and ADVANCE to work together in these data collection exercises.

Lew Fulton*, University of California, Davis, U.S.A.*
In Fulton's opinion, the problem is not only that we lack data, but also that there are often multiple data sources. When different modeling groups use different sources, this results in different starting points in scenarios. It is especially difficult to collect the number of km that vehicles travel per year (especially in non-urban areas). IEA derives these numbers through using other data.
The International Energy Agency maintains the IEA Transport Database, which covers 33 single countries and 8 aggregate regions and tries to harmonize bottom-up and top-down data. Besides national statistics, which do not always contain consistent data, potential data sources are industry/consulting firms (e.g. Marklines, POLK, Walsh), the ORNL Transportation-Energy Data Book and GIZ (Germany). Alternative ways of data collection could be via vehicle registration data, vehicle OBD (on-board diagnostics) systems, household surveys, logistics and trucking company surveys or new data collection technologies. Fulton commented, however, that it is generally not the job of the transport modeling community to go out and collect this fundamental data; instead, we have

to rely on what is already out there.
With an eye toward improving data availability and accessibility, Fulton differentiated between different milestones that could be achieved by the transport research and statistics communities:

- Short term: Working together and sharing data among individual groups/teams
- Medium term: More structured sharing and working together between countries to improve their data collection systems. Notable in this respect is the Asian Development Bank's (ADB) "Global Transport Intelligence" initiative.
- Long term: Develop a common international framework/methodology for cost-effective, ongoing data collection systems that countries could adopt. Fulton noted that the United Nations' forthcoming Sustainable Development Goals might list transport as a goal, if it does, then transport data collection may form a major part of this effort.

Discussion and questions from the audience
Jari Kauppila: Often discussions on future transport systems largely focus on building new infrastructure and the transition process. But what about managing existing infrastructure better? It is surprising how little transport ministers think about this question.

Bas van Ruiven (NCAR, USA): IAMs only really need a few transport data variables for their work, so a role of ADVANCE could be to prioritize what exactly we need in terms of data. We don't need all 800 variables that ITF produces.

Bastien Girod: The integrated assessment modeling teams are mainly interested in time series data. What is your experience with these types of data?

Alexander Körner (IEA, France): A good place to look for transport data is the Global Fuel Economy Initiative. They have generated a time series of fuel economy from 2000 to 2011 for 26 countries (both OECD and non-OECD countries; major data effort especially for non-OECD countries), and it is publicly available. This would be a great place to start for IAMs for getting fuel efficiency of vehicles in our models.

Lew Fulton: There are very good opportunities for low-cost surveying exercises to collect data. An example is a 5-minute survey at fuel stations which was performed in Mexico.

Jari Kaupila: A different approach would be to look at so-called "big data", which is becoming increasingly available in different areas. However, it takes a lot of time and effort to clean this data, and complex algorithms are needed for data processing.

Session 3: Key determinants of mode choice and service demand - how can IAM transport models be improved to reflect heterogeneous behavior and consumer choices?
Capturing consumer choice and behavior in numerical models is an acknowledged challenge, especially in the transport sector, given the myriad market imperfections. This session discussed key determinants of mode choices driving transport energy demand, and how these vary within a population, over time, and spatially.
Chair: Charlie Wilson, University of East Anglia, Tyndall Centre, United Kingdom
Speakers: Jillian Anable, Mark Jaccard

Jillian Anable, *University of Aberdeen, United Kingdom*
Anable expressed concern that, with exceptions, the classical rational agent approach is still dominant in modeling transport. This is surprising, she said, given all the research that has been carried out in the behavioral economics and sociological domains. Anable listed the many determinants of travel behavior and stressed that it is impossible for a single model to include everything, simply because it would be too complicated to do so. Moreover, modeling behavioral changes is broader than just mode switching. How cars are driven and how much they are used are important aspects that are affected by behavior as well.
Recently a mostly unpredicted phenomenon known as "peak car" has been observed in the transport sector of developed countries, where especially in higher-income groups the levels of private auto transport have fallen.

Whether this is due to saturation, a real turning point in behavior, or just a temporary blip, remains an unresolved debate.
Anable ended by discussing two studies that she performed, where including behavior aspects to the scenarios created, resulted in a better understanding of the transport system and choices made.
Some conclusions and challenges for IAM transport modeling include the following:

- Doing "off-model" scenario work has a lot of value (i.e., developing scenarios outside the model and then feeding them in), as there are too many behavioral features to include in IAMs.
- Data does not readily exist on these behavioral features in different choice / national contexts.
- The best transport modelers are the ones who are interested in the entire transport sector (and all the related complexities), not just in modeling per se.
- It is important to look at non-cost factors and segmentation.
- Systems thinking is important. Many influences on transport service demands do not come from the transport sector (built environment, ICT, retail patterns).
- Including policy diversity in the scenarios is necessary.
- Be realistic about what IAMs can do: "IAMs will simply be an aid to (some) thinking – nothing more."

David Greene (Oak Ridge National Laboratory and University of Tennessee, USA): How well do you think we can put a dollar value on the willingness-to-pay for new vehicle technologies?

Jillian Anable: For the 2% of the market who are innovators, perhaps we can do this. For the majority of the market however, it's much harder. The late-adopter is much harder to predict. It is quite possible, for instance, that the types of people who are at present very averse to adopting new technologies (e.g., EVs) might be the same group that very quickly switches to wanting them in the future. In this and other cases, it's about more than just costs, at least much more than the manner that models tend to treat behavior and choices.

Mark Jaccard, *Simon Fraser University, Canada*
Jaccard described a set of approaches for modeling transport behavior. He and his team have worked for many years on the hybrid energy-economy model, CIMS. The transport part of this model includes three key behavioral parameters:

- Discount rate (r)
  - Jaccard's goal is to unpack the discount rate and explicitly model certain behavioral aspects.
  - This requires empirical research to separate these out.
- Intangible costs (i)
  - Technology-specific decision factors, especially differences in quality of services and risks
- Market heterogeneity (v)

The parameters for these behavioral aspects are estimated based on discrete choice surveys for modal choice, with both stated and revealed preferences. In addition discrete choice surveys for commuter modal choice have been performed. The hybrid model is used to estimate key parameters in aggregate models by (1) introducing a price-shock in the model in order to test the response surface, (2) taking this pseudo data for estimating parameters of production function (CES, Translog), (3) generating energy-capital inter-fuel elasticities of substitution, and (4) feeding these elasticities into a CGE model.

Discussion and questions from the audience
Keywan Riahi: What do you think about using intangible costs calculated for one region and applying those to another region? During the GEA we had difficulties with this for energy access.

Mark Jaccard: This can indeed be a challenge. There is no perfect way to do it.

Jillian Anable: Perhaps this can be done in certain instances. After all, behavioral assumptions in models should not necessarily be held to a higher standard than all the other technological assumptions that are in the models. Modelers routinely use technological parameters developed for one regional context and apply them to another.

Detlef van Vuuren: In ADVANCE WP2 and WP3 our plan is to do something similar as Jaccard and colleagues have done with CIMS and their CGE. Using certain more detailed IAMs to run a variety of price-shock scenarios and then taking the elasticity results and applying those to other models. van Vuuren proposed that to Jaccard and

his team to be involved in this effort.

Mark Jaccard: A question to Jillian Anable: When creating behavioral scenarios, how do you take into account feedback effects such as much less driving, thus less road congestion? Doesn't this argue for endogenizing certain relationships in models?

Jillian Anable: It depends on the scenario design and the question of interest.

Bas van Ruijven: What is your experience with how much consumers differ across countries? At the end of the day, we are all human; we are not completely irrational.

Mark Jaccard: Many things have to be done exogenously – he agrees with Anable on this point.

Jillian Anable: There are so many types of variability. We are just now at the point of accepting the fact that there is a large amount of variability in any one single population. We need to better understand (1) how behavior changes amongst small groups of people (cross-sectional studies), and (2) how behavior of individuals changes over time (longitudinal studies).

Volker Krey (IIASA, Austria): It would be nice to come to a place where we can divide up behavioral issues into (i) things that *can* be influenced by policies, and (ii) things that *cannot*. This could help us to prioritize what types of things we try to endogenize in our models.

Jillian Anable: Models are very important in policy making, whether one likes it or not. Because costs are at the core of all models, we end up with policies that are largely economic and based on fiscal instruments. The first step is getting people/policymakers to start thinking in a different mindset. There is plenty of evidence to suggest that there are many other non-cost factors at play.

Jillian Anable: Important final point: Don't forget non-modelers in modeling work. Don't just treat non-modelers as an add-on to your work. There's a lot that we can learn from the work they are doing (e.g., social science).

Session 4: How can transport infrastructure be better modeled in IAMs?
The complex networks supporting person and freight mobility are fundamental elements of the transport sector, even if they are not fully represented in many IAMs. This session reflected on which of these elements are most critical to model and how best to model them. For advanced vehicles and fuels this potentially includes representing pipelines, refueling stations, and fast-chargers, among others.
Chair: Robert Pietzcker, Potsdam Institute for Climate Impact Research, Germany
Speakers: David Greene, Hannah Daly, Alexander Körner

David Greene, *Oak Ridge National Laboratory and University of Tennessee, U.S.A.*
Greene stated that many studies quantify the costs at different scales of alternative energy infrastructures. The real difficulty lies in modeling the transition towards these new infrastructures, which might require a new public policy paradigm. Greene's opinion was that it may not actually be necessary to model these transitions entirely within the frameworks of IAMs; however, it is important for IAMs to include transition costs. The question then becomes: Is the goal to model the causes or consequences of the transition? This has implications for the modeling approach: endogenously or through scenarios.
Greene's previous work for the U.S. National Research Council indicates that in the long term the benefits of sustainable transport outweigh the costs. Model runs have shown that there are tipping points for the penetration of advanced vehicles and their accompanying infrastructure. This makes initial investment subsidies an important policy tool. The overall cost of a transition to either hydrogen or electric vehicles could be fairly sizable in the near term, but is probably quite small in the long term. Because of this, it is probably enough for IAMs to account for transition costs simply through long-run average costs. More detailed scenario modeling tools can then be used to understand the transition dynamics.

Mark Jaccard: PHEVs do not see much penetration in the NRC studies, but they do very well in consumer surveys that he has performed. In these surveys, people indicate that they would be willing to pay extra for PHEVs.

David Greene: This is largely a function of the PHEV assumptions used in the NRC modeling. In some sensitivity analyses they did actually see much greater penetration of PHEVs.

Volker Krey: What would be the best manner to incorporate the early-stage infrastructure costs in IAMs?

David Greene: I leave it to the modelers to decide, but it makes sense to me to simply include an extra cost mark-up on vehicles in the early years of the transition. This will be relatively small compared to the overall cost of the car.

Hannah Daly, *University College London, United Kingdom*

Daly discussed how in public planning and policy, the "predict and provide" approach to infrastructure planning for roads and aviation has dominated in recent decades. Incidentally, this approach is also what is largely applied in scenario modeling. There are several approaches to model behavior, demand, and infrastructure: (1) scenario/what-if/off-model analysis, (2) logit-based approach, and (3) adding non-technology and fuel costs. The advantage of using energy systems models for climate policy analysis is that different carbon mitigation options can be ranked based on their relative attractiveness. Ideally, the modeling of transport in an energy system framework would break out systems optimization from maximization of individual utility.

Daly put forward the exploratory work on incorporating infrastructure decisions in energy systems models, which she carried out in collaboration with UC-Davis. Using the TIMES models for both Ireland and California, infrastructure investment was proxied through a travel time investment parameter (TTI). This allowed for costing out transport infrastructure. Daly proposed that such an approach could potentially be explored in ADVANCE. In addition, a next step could be to incorporate supply curves for representing car and bus lanes, railroads, and airports. Such modeling techniques allow one to rank transport infrastructure investments along with other carbon mitigation options.

Alexander Körner, *International Energy Agency , France*

Körner presented the main results of a recent IEA study on transport infrastructure. The report shows that around 2% of global GDP is spent on road and rail infrastructure. Global road additions continue to grow at a rapid pace, while rail capacity has remained stagnant or even decreased. In the IEA ETP 4DS scenario (4 °C warming in long term), paved road lane-km are likely to grow by nearly 25 million paved by 2050. This will necessitate cumulative $80 trillion by 2050. In the "avoid/shift" scenario of IEA ETP 2012, there are major savings in less road infrastructure (~$20 trillion cumulative). The 2DS scenario could save as much as $90 trillion cumulative relative to 4DS spending. This is due to reduced demand and changing transport technologies.

A key question that arises in these scenarios is what is the road construction capacity limit? China has added on average 350,000 km/yr of new road infrastructure. Also, what is the density limit for roads? The IEA took the Japanese situation as an upper limit to road space per square km.

Körner mentions that the IEA has a large road/rail infrastructure database, which contains data from IRF, UIC, ITDP, and EMBARQ. In particular, the database includes cost data for more than 1300 individual projects in 110 countries.

Körner concluded by stating that in the IEA scenarios road infrastructure account for almost 20% of all cumulative transport expenditures between 2010 and 2050. Given that these infrastructure costs can be a big piece of climate change mitigation scenarios, shouldn't IAM studies include them?

Discussion and questions from the audience

Alexander Körner, responding to a question on the relation between refuelling infrastructure and behavioural aspects: Apart from biofuels (whose real potential to serve as a *sustainable* transport fuel with significant market share is still not entirely clear and which might need to play a big role in aviation and shipping), two potentially zero carbon options exist – Battery electric vehicles and FCEVs. When comparing both options we find a complex interaction of vehicle and fuel characteristics, infrastructure requirements and consumer behaviour. From my point of view high levels of CO_2 reductions can be achieved based on a pretty different vision of sustainable individual motorized transport:

- BEVs and high share of car sharing, lower vehicle ownership, long distance travel by train, overall high system efficiency – requires big behavioural change and has big impacts on other industrial sectors.
- FCEVs and vehicles with comparable service as of today, lower system efficiency due to lower efficiency of hydrogen generation and T&D, big infrastructure investments – requires much less behavioural change, has maybe less impact on other industry sectors, is less efficient with regard to PE to service conversion.

Discussion Session: Where do we go from here?
Wrap-up of the meeting.
Chair: Keywan Riahi

Keywan Riahi summarized the main topics that were discussed during the day-long workshop. Regarding data, the general impression was that there is quite a lot out there, though it is sometimes difficult to find and is a bit fragmented in nature. He reiterated Detlef van Vuuren's earlier suggestion to form a working group on data, together with the data experts from the ITF/OECD and IEA. With respect to behavior, Riahi posed the question: given the multitude of behavioral aspects to be considered, which elements do we want to model endogenously and which would be better to include exogenously? Finally, the infrastructure session revealed that there are two main issues concerning the modeling of infrastructure: how can we represent existing and future transport infrastructure (roads, rail lines, ports, etc.), particularly its cost, in models; and how do we model new refueling infrastructure for sustainable transport technologies and the associated transition phase. Riahi then opened up the floor to all workshop participants and asked what they thought are the key areas for improvement in IAMs.

David Greene: It seems that there is a contradiction here between regulatory approaches to policy (e.g., fuel economy standards) and price approaches (e.g., carbon taxes; relying on elasticities). The models can be run looking at these two approaches. The price elasticity approach will probably yield smaller reductions in energy use and emissions. Greene suggested that modelers can enhance their representation of energy efficiency improvement in IAMs by relying on studies that analyze fuel economy at the vehicle level and how much it costs to achieve those improvements.

Felix Creutzig: It is important to include infrastructure investments in IAMs. Urbanization could probably also be represented in IAMs in some way, even if only simply. Published urbanization studies available for different regions may provide guidance on how to do this. The IEA's 2DS scenario could be used as an example. In Creutzig's view, if many of the effective solutions for mitigating transport emissions are local and IAMs have trouble representing these local-scale options, then this creates a problem.

Tom Longden: The difficulty with modeling regionality and local-scale results is also seen in other fields. For instance, climate models have recently been criticized for the divergent nature of results regarding local impacts. Different climate models show very different rainfall patterns, etc. IAMs are not alone in this sense.

Lew Fulton: At a simple level it should not be that hard to include road and rail infrastructure in IAMs. Then, once the infrastructure is represented (perhaps tied to the number of pass-km or tonne-km), it's a straightforward matter to add infrastructure costs to the cost equations and objective function. If this is included, modelers can run policy scenarios where, for example, they look at the effect of not building the new road/rail infrastructure. This would cause congestion to build up in certain regions, which would cause a feedback in the model.

Page Kyle (PNNL, USA): It could be a good idea to develop a harmonized data set on passenger and freight service demands dating back to for example the 1970s. Then we could do historical runs and run them up to the present to see how far the model is off. Of course, such validation exercises only make sense to do with certain models.

Keywan Riahi: Regarding the historical validation idea, some models will inevitably fail to reproduce past trends, even after the data has been calibrated. Yet, this may be okay: one could interpret how far off the models are from past trends as an indication of how much human behavior has pushed society away from the 'optimal' solution.

Cristiano Façanha (ICCT, USA): There could be a better integration between global IAMs and sector-specific national/local models. Most of the time national/local policies are based on the latter. So if you want to make IAMs maximally relevant for policy making, then they need to be able to be updated relatively quickly to incorporate the latest policies and information – information that sector-specific models typically have. This is the value of integrating the two types of models.

Tom Longden: It would be really interesting to explicitly incorporate certain transport policy targets in IAMs and then run a policy baseline, much like how the scenarios were designed in the AMPERE and LIMITS projects. This policies would include, for example, fuel economy standards around the world, high speed rail plans in China, biofuel targets in EU and US, etc..

Keywan Riahi wrapped up the final discussion session by repeating that it would be beneficial to form two working groups within ADVANCE to push the transport modeling agenda forward: one group focusing on data and another on behavior. These groups would bring together IAM modelers and experts in these two areas.

NETHERLANDS ENVIRONMENTAL ASSESSMENT AGENCY (PBL) AND
INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS (IIASA) WORKSHOP ON

ENHANCING THE STATE OF TRANSPORT MODELING IN IAMS

AN EXPERT MEETING CARRIED OUT WITHIN THE FRAMEWORK
OF THE EUROPEAN COMMISSION FP7 ADVANCE PROJECT
(WODAK ROOM, IIASA, LAXENBURG, AUSTRIA – 19 NOVEMBER 2013)

Biosketches of Speakers and Chairpersons

Keywan Riahi leads the Energy Program at the International Institute for Applied Systems Analysis (IIASA, Austria). In addition, he holds a part-time position as Visiting Professor in the field of energy systems analysis at the Graz University of Technology, Austria. Professor Riahi is a member of the Scientific Steering Committee of the Integrated Assessment Modeling Consortium (IAMC) and a number of other international and European scenario activities. His work within international modeling comparison projects, such as the Stanford-based Energy Modeling Forum (EMF), focuses on the spatial and temporal characteristics of technology diffusion and the path-dependent development of the energy system under alternative policy configurations.

David McCollum is a Research Scholar with IIASA's Energy Program, having joined the group in February 2011. He received his doctorate in transportation technology & policy from the University of California, Davis (USA), Institute of Transportation Studies in 2011. Dr. McCollum's main fields of scientific interest include techno-economic analysis of advanced energy and transport technologies and the development and application of energy-economic and integrated assessment models. Dr. McCollum is an author of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (Working Group III) and was previously a lead analyst on the Global Energy Assessment. He has co-organized policy workshops with the Global Environment Facility and United Nations in multiple countries.

Detlef van Vuuren is professor in Integrated Assessment of Global Environmental Change at the Faculty of Geosciences, Utrecht University and senior researcher at PBL Netherlands Environmental Assessment Agency. He is also member of the board of the Integrated Assessment Modelling Consortium (IAMC) and member of the Working Group on Coupled Models of the World Climate Research Programme (WCRP). Prof. van Vuuren serves on the editorial boards of the journals

Climatic Change and *Earth System Dynamics*. He played a coordinating role in the development of the Representative Concentration Pathways (RCPs), now used heavily in the IPCC's assessments. Prof. van Vuuren has participated as (Coordinating) Lead Author in various assessments such the Millennium Ecosystem Assessment, UNEP's Global Environmental Outlook, the International Assessment on Agricultural Science and Technology Development, and the OECD Environmental Outlook.

Bastien Girod works as senior researcher at Prof. Hoffman's Chair for Sustainability and Technology (SusTec) at the Department of Management, Technology, and Economics of ETH Zurich. His research centers on the socio-techno-economic changes required to reduce environmental impacts especially greenhouse gas emissions. Past research includes contributions in the field of long-term climate change scenarios, environmental assessment of household consumption, Life-Cycle-Assessment, rebound effects and global energy modelling in the field of transportation. At SusTec he currently investigates the framework conditions enabling firms in the power sector to invest towards low carbon technologies, in particular energy efficiency. Bastien developed the detailed transport sector module in the IMAGE/TIMER model and authored one of the few papers to date summarizing the results of a model inter-comparison focusing on transport.

Thomas Longden started at FEEM in April 2010 and is currently working as a modeller for the Sustainable Development Programme and within the ICARUS research group on alternative energy innovation. Whilst at the University of New South Wales (located in Sydney, Australia), Longden worked as a Lecturer of Environmental Economics and as a Research Officer at the Social Policy Research Centre. After leaving UNSW in 2009, he worked as an Economic Development Officer at the Vietnamese Institute of Fisheries Economics and Planning in Hanoi, Vietnam.

Oreane Edelenbosch is a junior researcher at the PBL Netherlands Environmental Assessment Agency. She is working for the ADVANCE project, where her main topic of scientific interest is the representation of energy demand in IAM models. Currently she is developing a service sector module, focusing on different end uses, into the IMAGE/TIMER framework. Edelenbosch completed her MSc in 2012, with a thesis on luminescent solar concentrators at the Experimental Physics department of the Imperial College London and a thesis on the interaction between Climate- and Air quality Policy at the University of Utrecht.

Lewis Fulton has worked internationally in the field of transport/energy/environment analysis and policy development for over 20 years. He is Co-Director of the NextSTEPS Program within the Institute of Transportation Studies at the University of California, Davis. There he helps lead a range of research activities around new vehicle technologies and advanced fuels, and how these can gain rapid acceptance in the market. From 2007-2012 he was a Senior Transport Specialist with the International Energy Agency, Paris, as well as Division Head for Energy Technology Policy during 2011-2012. He returned to the IEA in 2007 after working there originally from 1999-2005. During 2006-2007 he worked in Kenya with the UN Environment Program, developing and implementing GEF-funded sustainable transport projects around the world. During the 1990s he also worked at the US Department of Energy for 4 years, and taught at the Independent University of Bangladesh and the University of Maryland.

Jari Kauppila

Biosketch forthcoming

Charlie Wilson is a Research Scholar in IIASA's Transitions to New Technologies (TNT) Program, working with Arnulf Grübler on energy technology innovation and scaling dynamics, research that fed into the Global Energy Assessment. Dr. Wilson is currently a Lecturer in Energy & Climate Change in the Tyndall Centre at the University of East Anglia (UK). His research interests lie at the intersection of technology, policy, behavior and decision making. After completing his PhD at the University of British Columbia (Canada) on the social and behavioral determinants of energy use, Dr. Wilson has held teaching and/or research positions at the London School of Economics (UK), Chalmers University (Sweden), and IIASA. Prior to his academic career, Dr. Wilson worked for a number of years in the private sector on renewable energy finance and climate change policy.

Mark Jaccard has been a professor since 1986 in the School of Resource and Environmental Management at Vancouver's Simon Fraser University. His PhD is from the Energy Economics and Policy Institute at the University of Grenoble. He has published over 100 academic papers, most of these related to his principal research focus: the design and application of energy-economy models that assess the effectiveness of sustainable energy and climate policies. For this career research, he was named a Fellow of the Royal Society of Canada in 2009 and British Columbia's Academic of the Year in 2008. He has contributed to several major processes and assessments, including the Intergovernmental Panel on Climate Change (93-96 and 2010-2012), the China Council for International Cooperation on Environment and Development (1995-2001 and 2007-2009), Canada's National Roundtable on the Environment and the Economy (2006-2009), British Columbia's Climate Action Team (2007-2009), and the Global Energy Assessment (2008-2012). In 2006, his book, Sustainable Fossil Fuels, won the Donner Prize for top policy book in Canada

Jillian Anable is Senior Lecturer at the Centre for Transport Research at the University of Aberdeen. Dr Anable's work focuses on transport and climate change with particular emphasis on the application of behavioural and psychological theory to the understanding of travel choice. She is Co-Transport Topic Leader at UKERC carrying out, among other things, a scenario analysis of the travel sector to 2050 incorporating lifestyle and policy changes. Prof. Anable has advised the UK Government advisory body - the Commission for Integrated Transport - on climate change and has carried out work for the Department for Transport and the Scottish Government on carbon abatement, public attitudes to climate change and 'smarter choices'. Her PhD, completed in 2002, applied market segmentation and psychometrics to divide the population into different traveller types to identify the characteristics and motivations of those most likely to respond to both hard and soft transport policies.

Robert Pietzcker is a PhD candidate at the Potsdam Institute for Climate Impact Research (PIK). In his thesis he uses hybrid energy-economy models to analyze two paramount building blocks of mitigation scenarios, namely the decarbonization of the transport sector and the integration of variable renewable energy into the power system on the example of Photovoltaics and Concentrating Solar Power (CSP). Further research interests include the representation of capital inertia in hybrid energy-economic models, the modeling of load management and storage, learning curves in energy models, and the effect of differing economic damage valuation on climate protection policies. Pietzcker joined the PIK Research Domain "Sustainable Solutions" as PhD student

after working as a short-term consultant with McKinsey & Company. Previously, he studied physics at University of Freiburg as well as McGill University in Montreal, Canada, before graduating with a Diploma from the University of Jena.

David Greene is an author of more than 200 publications on transportation and energy issues. His current work focuses on the potential to mitigate greenhouse gas emissions from transportation, technological and economic potential for fuel economy improvement, impacts of fuel economy policies, modeling energy transitions for transportation, developing scenarios for alternative fuel infrastructure build-out, and estimating the costs of oil dependence. He is an emeritus member of both the Energy and Alternative Fuels Committees of the Transportation Research Board and a lifetime National Associate of the National Academies. He received the Society of Automotive Engineers' Barry D. McNutt Award for Excellence in Automotive Policy Analysis, the Department of Energy's 2007 Hydrogen R&D Award and 2011 Vehicle Technologies R&D Award, and was recognized by the Intergovernmental Panel on Climate Change for contributions the IPCC's receipt of the 2007 Nobel Peace Prize.

Hannah Daly is a Research Associate in Energy Systems at the University College London Energy Institute. She joined the Energy Institute in October 2012 upon completing her PhD at University College Cork. Dr. Daly's research interests are in developing transport and energy models and using these tools to inform policy-making. Her PhD research involved creating a model of the Irish car stock, which was used to examine the impact of policy measures on meeting climate targets in the future. She has also worked on developing the representation of travel behaviour in energy systems models. Hannah graduated in 2009 with a BSc in Mathematical Sciences from University College Cork.

Alex Körner joined the IEA Energy Technology Policy Division in January 2011, where he is working as an energy analyst in the transport sector. The main focus of his work is to develop modelling tools and to assess strategies towards sustainable transport, including technological as well as behavioural aspects. Körner is the co-author of the IEA Technology Roadmap on Fuel Economy of Road Vehicles and one of the authors of the 2012 IEA Energy Technology Perspectives publication. He studied at Technische Universität Berlin and holds a Master's Degree in Power and Process Engineering. Before joining the IEA, he worked on integrated assessment modelling to investigate the transition of the global energy system at Potsdam Institute for Climate Impact Research (PIK).

NETHERLANDS ENVIRONMENTAL ASSESSMENT AGENCY (PBL) AND
INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS (IIASA) WORKSHOP ON

ENHANCING THE STATE OF TRANSPORT MODELING IN IAMS

AN EXPERT MEETING CARRIED OUT WITHIN THE FRAMEWORK
OF THE EUROPEAN COMMISSION FP7 ADVANCE PROJECT
(WODAK ROOM, IIASA, LAXENBURG, AUSTRIA – 19 NOVEMBER 2013)

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Expert Workshop of the ADVANCE project

UNCERTAINTY IN CLIMATE CHANGE MODELING AND POLICY

Milan, May 13-14, 2014
Fondazione Eni Enrico Mattei
Corso Magenta 63

Minutes

Objectives

Uncertainty is a key component of climate change, characterizing both the science and the human response of a changing climate. Understanding the problem of climate change and formulating a set of policy responses will thus need to account for the key uncertainties at play, and to provide risk management strategies which are robust to such risks.

In the most recent years, new research has emerged with the potential to improve the way we model uncertainty in climate change policy. Advances in decision theory, dynamic and stochastic programming, and in data availability allows for a richer accounting of uncertainty than previously possible. Yet, important challenges remain in the applicability of these new methods to large scale integrated assessment models (IAMs) which are routinely used for assessing climate change policies.

The aim of this expert workshop is to provide an opportunity for reviewing the latest developments in uncertainty and risk analysis in climate change, and their potential applications to IAMs. The agenda is organized around three main sessions, covering the theoretical, numerical and applications aspects. The final part aims at compiling a set of insights and recommendations for modeling climate change policies under uncertainty.

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 308329 (ADVANCE).

Tuesday, 13 May 2014

The workshop started at 11 with the opening remarks of Giuseppe **Sammarco**, FEEM Executive Director. He introduced the workshop welcoming the participants and presenting FEEM.

Objectives of the workshop and framing of climate change uncertainty in the ADVANCE project (Massimo Tavoni, FEEM)

Massimo Tavoni, FEEM, presented the objectives of the workshop and showed how climate change uncertainty is framed in the ADVANCE project.

Session I: Decision Making Under Uncertainty

Uncertainty and decision in climate change economics (Antony Millner, LSE)

Antony Millner**,** LSE, noted how models are needed to reduce the complexity of reality and make better decisions, even though in some cases big structural challenges arise. In particular, in climate change long time-scales and significant uncertainties induce different models to predict a wide range of results, especially in terms of impacts. The models also rely on economic structural assumptions not always thoroughly validated on the past, and not always accounting for unanticipated disruptive events (like the recent technological advance in the US). Millner then introduced the concept of decision making under deep uncertainty (or ambiguity), and mentioned the consequences of choosing alternative criteria to the most common expected utility framework. He also recalled the difference between ethical disagreement and empirical uncertainty, and how for the first one more effort could be spent for finding an aggregated consensus.

Abatement under ambiguity (Loic Berger, FEEM)

Loic **Berger**, FEEM, recalled how uncertainty is ubiquitous, with different sources and types. He introduced the concept of ambiguity, and the possibility of extending usual expected utility models of decision with explicit distinction between uncertainty and ambiguity aversion. This was then applied in a simple model of optimal abatement under the possibility of catastrophic event, first analytically and then numerically using real climate expert probability judgments. The extension to ambiguity aversion matters in the results: one should abate more today in order to decrease the ambiguous probability of suffering from a severe loss. These tools could help policy makers to aggregate and make more sense of the different results models provide.

Discussion

Roger Cooke questioned the need for ambiguity reasoning to support ambitious abatements. He also argued for greater clarity when using the concept of climate sensitivity. Erin Baker mentioned the possibility of learning in the uncertain decision process, even though modelling such a dynamics leads to computational difficulties. Elmar Kriegler emphasized the aspect of completeness of preferences.
A discussion was led about the normative appeal of ambiguity in climate change for modelling any policy recommendations. Millner and Berger argued that the behavioural foundations but also axiomatic foundations of non-expected utility theories are relevant and usable in this context. Cooke

and Kriegler among others expressed some concerns about the usability. There was however an agreement that this is an important and ongoing debate.

13.00 - 14.00 Lunch

Session II: Incorporating uncertainty in IAMs

Integrated Comparison of Uncertainties in Climate Change Mitigation (Haewon McJeon, PNNL)

Haewon McJeon, PNNL, described the GCAM Integrated Assessment Model framework, and how its components are subject to uncertainty. He reviewed some Monte Carlo studies performed in the past, emphasizing a recent work where 161 thousand combinations of technology assumptions were implemented and the corresponding results visualized in galaxy-like plot. An overview of his other most significant works dealing with uncertainty followed: exploring combinations of technologies that are most vulnerable to exceed threshold stabilization costs, assessing probabilities of technology success, calculating optimal act-then-learn strategies, trading off technological and climatic uncertainties via stabilization targets, and designing robust energy efficiency policies for buildings.

FEEM: Selection of robust climate policies under current knowledge of uncertainties (Laurent Drouet, FEEM)

Laurent Drouet, FEEM, reminded how uncertainty permeates climate change modelling, and how this can be taken into account in climate decision making. Using the model outcomes produced for the AR5, Drouet explored a large space of possible future emissions/mitigation cost scenarios. He also assessed a probabilistic relation between cumulative emissions and induced changes in temperature, and between temperature and economic impacts. He finally combined all this information with several decision criteria, showing how different choices lead to different optimal carbon budgets, testing also for the importance of time preference, risk aversion and ambiguity aversion. Surprisingly, only one type of decision criterion would lead to policies consistent with 2°C.

Discussion

A discussion followed. Elmar Kriegler (PIK) asked some insights about the expected utility function and the selected carbon budgets showed by Drouet. The importance of the type of sampling used in Monte Carlo exercises was also mentioned as a convenient way to cut the order of magnitude of runs required. The availability of comprehensive databases of scenario and model runs as from the recent IPCC AR5 report and others was seen as a great potential to derive robust decisions under uncertainty.

R&D Decision Making Frameworks (Erin Baker - U. Mass**)**

Erin Baker, U. Mass, posed the question of R&D funds allocation across competing clean energy technologies, given that the the outcome of R&D is uncertain. Her approach consisted in integrating expert judgments on future prospects for technology with economic models of interactions between technologies, climate, and economy. She presented probabilistic estimates of future costs and efficiencies for a set of technologies, as elicited from experts in the TEaM project. Using importance sampling to better capture the costs of interest, and adopting a two-stage decision framework, it was

possible to calculate optimal R&D portfolio investments for different stabilization targets and teams of experts. Results vary across both of these dimensions.

Global sensitivity analysis and climate change (Emanuele Borgonovo - Bocconi Univ.)

Emanuele Borgonovo, Bocconi Univ., emphasized the need to introduce robust sensitivity practices in Integrated Assessment Modelling. He overviewed several sensitivity methods, focusing on the probabilistic ones, and mentioning pros, cons, caveats and potential remedies. He then explained different settings of a sensitivity analysis, including prioritization of uncertainty drivers, understanding of model first order response to change in inputs, and monotonicity of that response. He eventually recalled the results of a factor analysis done for the DICE model, and mentioned other ongoing works.

Discussion

Several modelers expressed great interest in the methods outlined by Borgonovo to apply to model runs. A discussion about the feasibility of implement the substantial number of model runs to be performed in the context of climate-energy models followed. Regarding the expert elicitation study of Baker, the need of expert estimates in particular on yet to be implemented on a large scale technologies was reiterated. A concern was raised with regard to the elicitation so far only referring to two countries and the validity of the data for global applications. Cooke maintained that additional information such as subjective confidence given by experts could be used to improve the precision of the estimates.

Wednesday, 14 May 2014

Session III: Managing risks and vulnerabilities

Instrument effectiveness and uncertainty: a review of empirical and model findings (Antony Patt - ETH)

Antony Patt, ETH, first talked about various uncertainty sources and their type and extent, as they emerge along the dimensions of climate policy choices and scale of action. He then moved to consider how investments are sensitive to changes in the likelihood of profitability or loss, bringing evidence from the literature in the energy sector. In particular, he showed how investors in low carbon technologies could be influenced by the uncertain future market and regulatory conditions, and how different climate policy instruments may have a an effect on altering such uncertainties. He then challenged the idea that a carbon price is what is needed to stimulate low-carbon investments, or that it is the most efficient way of doing it, as a lot of imprecision and perceived risk affect the decision making of investors.

Messaging Uncertainty in Climate Change (Roger Cooke – RFF)

Roger Cooke, RFF, observed that despite the guidance notes for IPCC lead authors for treating numeric assessment of uncertainties consistent, climate change scientists still sometimes convey misleading messages when quantifying uncertainty. This may favour deniers and alarmists, to the detriment of science-based communication. Cooke then touched briefly on how people, and in particular experts, can violate basic rules of probability and logic. This is crucial, especially when considering estimates from expert judgments, where a good balance of information and statistical accuracy should be sought. He eventually mentioned the issue of aggregating expert elicitation responses with a proper weighting scheme. His suggestion is to assign weights that reflect the accuracy and variability of experts evaluated with a preliminary set of training questions.

Discussion

The role of regulatory uncertainty for investment and costs as outlined by Patt was discussed as an important potential barrier to the implementation of technology intensive low carbon transitions. The methods of measuring e.g., differences in capital costs across countries was discussed and referred to future work by Patt. Cooke's points were well taken in particular the need to elicit data and expert estimates for instance for renewable technologies. In particular, improvements in the design and interpretations of expert elicitations were discussed and agreed to be important for the numerical model implementations and the use of different decision criteria under uncertainty. Millner argued that including for considering ambiguity this improved elicitation data is very relevant. Cooke maintained his opinion on the expected value as the normative criterion that should be considered for policies.

Presentation from main modeling groups on their experience in incorporating uncertainty into IAMs (Celine Guivarch – CIRED, Volker Krey – IIASA, Elmar Kriegler – PIK, Gauthier De Maere – FEEM, Ilkka Keppo – UCL)

Celine Guivarch, CIRED, presented two approaches her team followed to include uncertainty in a IAM. First, they performed a sensitivity analysis with many runs of a deterministic model (ex ante uncertainty on model parameters) exploring a large space of socio-economic assumptions, according

to the SSP framework. Second, they considered a built-in uncertainty/stochasticity within a model run, in particular on damages and social preferences, experiencing potentially higher optimal abatement levels.

Volker Krey, IIASA, explained how with his colleagues he set up an optimization problem minimizing not only expected costs, but also a risk measure of those costs. Using a reduced-version of the MESSAGE model, and considering only economic uncertainties, the resulting hedging strategy visibly reduced the 99th percentile of costs. Then, Krey showed how they used Latin Hypercube Sampling to efficiently evaluate the implications of assuming particular investment cost distributions for a set of key energy technologies.

Elmar Kriegler, PIK, first focused on major conceptual problems of using cost-effectiveness analysis for climate targets framed as constraints on the probability of crossing a certain threshold. He then presented a cost-benefit approach where two different welfare and policy outcome evaluation methods are compared. Eventually, he presented a study on the joint effect of uncertainty and heterogeneity of climate damages on climate policies, considering how this could be compensated with a proper insurance for various society risk and inequality aversion assumptions.

Gauthier De Maere, FEEM, summarized the major topics related to uncertainty on which FEEM has been working on. He then mentioned stochastic programming and approximate dynamic programming as two of the main computational methods successfully applied to IAMs for exploring problems with uncertainty, like assessment of optimal R&D portfolios and option values of innovative mitigation technologies. He concluded encouraging the opportunity to spot and leverage on synergies across different methods.

Ilkka Keppo, UCL, explained some of the research activities related to uncertainty undertaken at UCL. He first spoke about the implementation of stochastic programming in TIMES models, with an application to multi-stage stochastic decision making on R&D investments. He then presented an energy system model designed to run in a Monte Carlo mode, used for recent assessments on the likelihoods of meeting targets with predetermined emission price trajectories. Eventually, a work on exploring the space of near optimal decarbonization pathways with different techniques was shown.

Discussion: how to integrate uncertainty in climate change modeling and policy (*Chair:* Valentina Bosetti – FEEM)

The main points emerged in the workshop were summarized and are reported bellowed.

- Quantifying uncertainty (e.g. assessment of subjective probabilities through expert elicitation, aggregation of multiple model results, estimation of confidence intervals) is crucial to address for climate decision making.
- New frontiers of research are underway, and include alternative decision criteria beyond the traditional expected utility framework, more comprehensive description of preferences (e.g. including ambiguity aversion or inequality aversion), combination of stochastic programming techniques with large IAMs, and global sensitivity analysis.
- Three crucial roles were identified for uncertainty: to increase credibility, reliability and transparency of integrated assessment models (e.g. global sensitivity), to better choose robust and flexible policies (e.g. criteria), to understand major socio-economic drivers and their relative roles in shaping future climate decision making.

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INNOVATION IN RELATION TO BUILDING ENERGY DEMAND IN IAMS

AN EXPERT WORKSHOP CARRIED OUT WITHIN THE FRAMEWORK
OF THE EUROPEAN COMMISSION FP7 ADVANCE PROJECT

LEEUWNBERGH, SERVAASBOLWERK 1a, 3512 NK, UTRECHT, THE NETHERLANDS
20-21 JANUARY 2015

AGENDA

TUE. 20 JANUARY 2015

12:45	**Opening remarks** *Welcome from host,* Pieter Boot, PBL *Objectives of the meeting,* John Weyant, Stanford University *Setting the stage, comparison of models,* Detlef van Vuuren, PBL
13:30-13:45	**Coffee Break**
13:45-15:45	**Session 1: Technological options in buildings, and implications for modelling / potential game changing innovations for energy demand** *Chair: John Weyant, Stanford University*
	Cathy Zoi, Stanford University ***Diana Vorsatz***, Central European University ***Robert Harmsen***, University of Utrecht - Barriers to innovation in building ***Vassilis Diaoglou***, IMAGE - Model talk Group discussion
15:45-16:05	**Coffee Break**
16:05-18:00	**Session 2: Behavioral options in buildings, and implications for modelling** *Chair: Keywan Riahi, IIASA*
	Carrie Armel, Stanford University (tbc) ***Robert Lowe***, UCL ***Joe Hagerman,*** US.DOE (tbc) Group discussion
18:00	Departure to Janskerkhof NH hotel

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 308329 (ADVANCE)

WED. 21 JANUARY 2015

09:00-11:00	**Session 3: Demand management options to support VRE grid integration** *Chair: Gunnar Luderer, PIK*
	Marissa Hummon, NREL ***Michael Hogan,*** The Regulatory Assistance Project ***Wilfried van Sark*****,** Utrecht University ***Hans Christian Gils*****,** DLR **-** Implications for IAM models Group discussion
10:45-11:30	**Coffee Break**
11:30-12:15	**Discussion Session: Where do we go from here?** Wrap-up of the meeting. What follow-up activities can we imagine? Which areas are the most feasible? Which are of the highest priority (for policy, for the IAM community, for other research communities, etc.)? *Chair: Detlef van Vuuren, PBL*
12:15	*Lunch at Leeuwenbergh*

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INNOVATION IN RELATION TO BUILDING ENERGY DEMAND IN IAMS

AN EXPERT WORKSHOP CARRIED OUT WITHIN THE FRAMEWORK
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LEEUWENBERGH, SERVAASBOLWERK 1a, 3512 NK, UTRECHT, THE NETHERLANDS
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REPORT

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Background

IAMs tend to focus on energy supply rather than on energy demand. Still, energy demand is a main driver of emissions and, related to this, energy efficiency can form a major part of mitigation strategies. The ADVANCE expert workshop dug deeper into this topic with a focus on energy efficiency in buildings. It brought together external experts and stakeholders to discuss technological and behavioural options to increase energy efficiency in buildings as well as demand management options to support grid integration of VRE.

Catherine Radford Zoi – Stanford University

Cathy Zoi is a Consulting Professor at Stanford and directs the Energy Transformation Collaborative (ETC). She has spent 30 years in the energy and environmental sectors at the nexus between technology and policy. Cathy served in the Obama Administration as Assistant Secretary and acting Under Secretary at the Department of Energy, overseeing more than $30 billion in energy investments. In the private sector, Cathy has been an energy investor (Silver Lake and Bayard Capital), a board member (Ice Energy, SES, Pacific Solar), and a management consultant (ICF and Next Energy) with bases in the US and Australia. She was the founding CEO of both the Alliance for Climate Protection (established by Al Gore) and the NSW Sustainable Energy Development Authority -- a $50m fund to commercialize technologies to reduce greenhouse gas emissions. In the early 1990s, Cathy was Chief of Staff for the Office on Environmental Policy in the Clinton White House and she pioneered the Energy Star program while at the US EPA. Cathy has a BS in Geology from Duke and an MS in Engineering from Dartmouth.

Getting Innovation in Buildings to Take Hold: Good Technology is Necessary, but Not Sufficient

The potential for improved energy efficiency in buildings was huge 30 years ago – and it remains so. Last week, for example, California Governor Jerry Brown announced a new goal of doubling the energy efficiency of existing buildings across the state. The good news is that building technologies continue to improve: LED lighting, smart windows, evaporative air conditioning, and advanced controls could dramatically reduce energy consumption and associated greenhouse gas emissions, while delivering improved comfort and building functionality. Recent analyses by the New Climate Economy project and others found potential energy savings >50% are achievable. History demonstrates that the rate at which such technical innovation is deployed will be dependent on both commercial and policy drivers. To address timing imperatives of climate change, a combination of policy instruments and business model innovations will be required to seize this future potential: building codes and equipment standards, technology targets, tax incentives and penalties, finance and leasing packages, marketing and education, and of course -- leadership.

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Diana Ürge-Vorsatz – Central European University

Diana Ürge-Vorsatz is a Professor and Director of the Center for Climate Change and Sustainable Energy Policy (3CSEP) at the Central European University (CEU) in Budapest. She has conducted her Ph.D. studies at the University of California (Berkeley and Los Angeles), and has been a Fulbright Scholar. She has worked on and directed several international research projects for organisations including the European Commission, the European Parliament, the Global Environment Facility, United Nation's Environment Programme, the World Energy Council and the World Bank. She has been regularly advising the Hungarian government on environmental, climate change and energy issues.

Dr. Ürge-Vorsatz has authored over 70 publications, and has been serving on several advisory and governing bodies of organisations including UK Energy Research Centre, REEEP (the Renewable Energy and Energy Efficiency Partnership), the, the Hungarian Energy Efficiency Cofinancing Program (HEECP), the European Council for an Energy Efficient Economy (ECEEE), and the Collaborative Appliance Labelling and Standards Programme (CLASP), among others. She has been a Coordinating Lead Author for the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) for the chapter "Climate Change Mitigation in Buildings", serves on the United Nation's Special Expert Group on Climate Change, and is member of the United Nations Foundation's expert group on energy efficiency advising the German G8+5 process. She has been acknowledged to share the Nobel Peace Prize of 2007 that was awarded to the IPCC.

Challenges to modeling the new frontiers in building energy demand reduction: holistic solutions, integrated options and behavior

The presentation fist provided a systematic comparison of building sector emission and energy demand models produced using IAMs and engineering-economic models. The talk, based on the analysis in and for the Fifth Assessment Report of the IPCC, provided a list of hypotheses that may explain the differences found. The talk highlighted the importance of treating direct and indirect emissions combined when conducting sectoral analyses. Then, the presentation focused on potential game-changing innovations for building energy demand. Within this it reviewed the potentials for upcoming breakthroughs in a few fields of building energy demand. Then, it highlighted the importance of systemic, holistic and integrated solutions and showed examples from the literature that emphasize that the larger reduction opportunities in most end-use sectors for the future are much more likely in such solutions rather than in further perfecting individual technologies where much progress had been made in the past decades. The paper concluded with another angle that may importantly inform building energy modeling: the phenomenon of stabilizing per capita residential energy use.

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Robert Harmsen – Utrecht University

Robert Harmsen (PhD) is Assistant Professor Energy & Resources at the Copernicus Institute of Sustainable Development (Utrecht University). Robert is an expert in energy efficiency and renewable energy policy analysis. His main fields of interest are policy interactions and the built environment. After finishing his PhD in 2000, he worked for COGEN (Dutch CHP association), the Netherlands Energy Research Centre (ECN) and Ecofys Netherlands. As consultant for the European Commission he was involved in the implementation of the CHP Directive and task manager for the development of harmonised reference efficiency values to calculate the primary energy for CHP and district heating. He has led a potential study for renewable heat and cooling in the Dutch built environment and other sectors for the Dutch Ministry of Economic Affairs and initiated a potential study on air/water heat pumps for existing buildings for a consortium of manufacturers. He was involved in a project for the European Climate Foundation (ECF's) to analyse the policy gap for Europe's 2020 energy savings target and to explore design options for binding energy savings targets which may be of particular interest for the non-ETS sectors such as transport and built environment. He was involved in a study for the European Investment Bank in which he analysed the Energy Efficiency Investment Potential up to 2020 for the built environment and other sectors. In 2013 he coordinated a project for the Dutch Ministry of Internal Affairs to study the innovation barriers in the Dutch construction sector. In 2014 he got a grant from the Rexel Foundation to study the role of installers and SME contractors in the renovation market. Currently, he works for the European Commission to provide technical support to the Energy Efficiency Directive regarding cogeneration and district heating. He is also coordinating a TKI STEM project (Dutch top sector research program) that analyses the barriers towards implementation of 300 thousand heat pumps in existing residential buildings in the Netherlands between 2015 and 2020.

Barriers to innovation in new and existing buildings: Dutch experiences

In this presentation insights were presented from three projects recently carried out by Utrecht University on innovation barriers in new and existing buildings. All three studies aim to combine the Technology Innovation System (TIS) approach with complex systems thinking. The first study is on the innovation barriers in the Dutch construction sector. As this study has been subject to an international comparison with Austria and Finland, differences and similarities between the countries are addressed. The second study is about the (changing) role of installation companies in the (energy) renovation of existing buildings. The third study takes a technology perspective and analyses the position of heat pumps in the transitioning of existing buildings into more energy efficient buildings. Insights from these three studies were linked to the field of IAM. All studies show that different scenarios exist to achieve the same (i.e. very efficient buildings), that some scenarios are preferred by stakeholders with vested interests, and that the required effort in terms of type of policy interference to become successful is very different for each of the scenarios.

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Vassilis Daioglou – Utrecht University

Vassilis Daioglou holds degrees in *Mechanical Engineering* (M.Eng, University of Southampton, 2007) and *Sustainable Development – Energy and Resources* (M.Sc, Utrecht University, 2010). At the Netherlands Environmental Assessment Agency (PBL) he helped develop and implement a global residential energy model which investigated the effects of income inequality and technology development on projections of energy access and indoor air pollution. He is currently PhD candidate at Utrecht University and PBL and his research focuses on assessing the long term possibilities of using bioenergy for carbon dioxide emission mitigation. His interests lie in the relations between energy-economy-environment and how models which assess these interactions can be developed and used effectively.

The Perspective of IAM models: Buildings in IMAGE-TIMER

Energy demand for buildings has been included in the IMAGE model by investigating the residential and service sectors separately. The presentation outlined the method adopted in order to model the energy demand of the residential and service sectors. The level of disaggregation, demand functions and key drivers were explained. Following, a number of important issues and difficulties were highlighted and knowledge gaps were identified.

The useful energy demand of specific energy function (cooking, lighting, space cooling/heating and appliances) has been related to economic indicators. Technologies and fuels which can deliver these services compete based on relative costs, while changes in efficiency may be exogenously set or a reaction to energy prices. The model is calibrated to historic data for these sectors. Key knowledge gaps include uncertainty on the drivers of energy choices, the possibilities of game-changing technologies and the elasticity of demand.

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Carrie Armel – Stanford University

Dr. Carrie Armel is a research associate at Stanford's Precourt Energy Efficiency Center (PEEC) where she investigates the diverse ways in which an understanding of human behavior can lead to improvements in energy efficiency. For example, the application of behavioral principles can produce significant energy reductions through interventions implemented at the policy, technology, built environment, media/marketing, and organizational/community levels. Dr. Armel co-chairs the Behavior, Energy, and Climate Change Conference; oversees Precourt Institute's Behavior and Energy Bibliographic Database and Website; and teaches courses on behavior and energy at Stanford.

In addition to these initiatives, Dr. Armel develops specific energy efficiency interventions that apply behavioral and design principles, and develops measures to evaluate the efficacy of such interventions. Her most recent project involves a collaboration between academic and non-academic organizations to design and evaluate a technology that takes advantage of smart meters to provide feedback to residents on home electricity use.

Dr. Armel completed a Ph.D. in Cognitive Neuroscience from the University of California at San Diego, and postdoctoral work in Neuro-Economics at Stanford. In these programs she employed behavioral, psychophysiological, and neuroscientific methods to investigate how affect and motivation influence behavior. She most recently completed postdoctoral work at Stanford's School of Medicine, translating intervention techniques used in health promotion work into the domain of energy efficiency.

Behavior change programs

This talk provided a survey of Stanford's ARPA-E Sensor and Energy Behavior Initiative as an illustration of the diversity of behavior change programs. The goal of this initiative is to develop a comprehensive human-centered solution that leverages the widespread diffusion of energy sensors to significantly reduce and shift energy use. The initiative has several parts: (1) a software platform that enables behavioral programs to be implemented at scale; (2) behavioral interventions to reduce and shift energy use; (3) data modeling that incorporates behavior into prescriptive engineering and economic analyses; and (4) an extensible energy communication network to enable future innovation. The behavioral interventions include technology (behavioral analytics, human-centered computational infrastructure), media (interaction design, social networking, games and feedback interfaces), policy (behavioral economic incentive programs) and community (schools, NGO's, utility and social organizations).

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Robert Lowe – University College London

Robert Lowe is a physicist with a broad interest in the field of buildings, energy and sustainability. Until 2006 he was at Leeds Metropolitan University, where he directed numerous studies relating to climate change and the energy performance of housing, culminating in the Stamford Brook Project. In February 2006 he joined UCL as Professor of Energy and Building Science. Since 2004 he has been a member of the FMNectar Consortium supporting DCLG in the development of UK building performance standards. He is currently the Deputy Director of the UCL Energy Institute and Director of the UCL-Loughborough Doctoral Training Centre in Energy Demand Reduction in Buildings.

Behavioural options in buildings – a socio-technical perspective

A socio-technical system is one in which the human and the material are closely coupled, giving rise to the potential for complex whole system behaviour. This presentation reviewed two case studies that demonstrate such behaviour, and offer some tentative conclusions. First that predictive modelling needs to be informed by an expanding body of high quality and data-rich case studies on a wide variety of buildings. Such data, generated and interpreted from a socio-technical perspective, may help modellers to identify contingent combinations of variables likely to be involved in the deployment of relatively novel packages of technologies at scale. Secondly, that the complexity in such systems is not restricted to end users, but also involves people working in the supply chains that deliver packages of technologies to end users.

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Robin Roy - Natural Resources Defense Council

Robin is Director of Building Energy and Clean Energy Strategy at the Natural Resources Defense Council (NRDC), and Founder and Director of Next Energy. He has worked for three decades to help meet society's need for secure, economic, and environmentally sound energy. His work often focuses on the nexus between the practicalities of effective public policy, the capabilities business, and the opportunity created by technological and institutional innovation. As a member of NRDC's energy and climate senior management team, Robin identifies and pursues new directions for federal energy policy for buildings including federal efficiency standards and codes, as well as strategies for clean energy development. While focusing on federal opportunities, he contributes to strategic opportunities for advancement of building energy and clean energy policies at the state, regional and international level.

He is also co-founder and director of Next Energy, a Sydney-based adviser to government, industry and environmental organizations on energy policy and strategy, often delivering on that advice with operational and project management services. Robin was formerly Project Director & Fellow at the United States Congress Office of Technology Assessment, where he advised the Congress on energy efficiency initiatives in the federal government and housing sectors, competition in the electricity market, vulnerability of electricity systems to terrorism and natural disaster, and nuclear industry issues.

Prior to that, he was with the Pacific Gas and Electric Company, focusing on demand management and strategic planning. Robin received a PhD - Civil Engineering, MS - Engineering-Economic Systems and BS - Electrical Engineering from Stanford University.

Grid-interactive consumer appliances for an increasingly decarbonized, economic electricity system: The case of water heaters, and beyond

Utility control of electric water heaters has long been used for energy storage, shifting demand to low-cost, low demand times. With increasing uptake of low-emissions, variable output generation such as wind and photovoltaics, the benefits of such customer-side energy storage will likely continue to grow. Further, fast two-way communications and control systems that allow use of consumer equipment for ancillary grid services are rapidly emerging, offering further economic and environmental benefits. In some cases such as water heaters, there can be a significant trade-off between energy efficiency and grid interactivity. Economic and environmental analysis is nascent, and much more work is needed to support good policy-making.

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Marissa Hummon & Doug Arent - National Renewable Energy Laboratory

Dr. Marissa Hummon is a senior scientist in the Energy Forecasting and Modeling Group at the National Renewable Energy Laboratory (NREL). Since joining NREL in 2010, her areas of expertise include: Integration of demand-side resources in grid simulation and optimization models, Parallel computation of power system models, and Quantitative/statistical analysis and modeling. Before joining NREL, she was a Research Associate with Harvard University, Analyst with Ecos Consulting, and Consultant and VP Operations with Apogee Strategies. Marissa has a PhD in applied physics from Harvard University and a BA in physics from Colorado College.

Dr. Doug Arent is Executive Director of the Joint Institute for Strategic Energy Analysis at the National Renewable Energy Laboratory (NREL). In addition to his NREL responsibilities, Arent is Sr. Visiting Fellow at the Center for Strategic and International Studies, serves on the American Academy of Arts and Sciences Steering Committee on Social Science and the Alternative Energy Future, is a member of the National Research Council Committee to Advise to U.S. Global Change Research Program (USGCRP), and is a Member of the Keystone Energy Board. Arent was recently invited to serve on the World Economic Forum Future of Electricity Working Group, and is a member of the International Advisory Board for the journal Energy Policy.
Arent was a Coordinating Lead Author for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). He has been a member of Policy Subcommittee of the National Petroleum Council Study on Prudent Development of North America Natural Gas and Oil Resources, served from
2008 to 2010 on the National Academy of Sciences Panel on Limiting the Magnitude of Future Climate Change, and also served on the Executive Council of the U.S. Association of Energy Economists. His research interests are centered in energy and sustainability, where he has been active for more than 30 years. He has published extensively on topics of clean energy, renewable energy, power systems, natural gas, and the intersection of science and public policy. Arent has a Ph.D. from Princeton University, an MBA from Regis University, and a bachelor's of science from Harvey Mudd College in California.

Modeling Demand Response for Integration Studies

Modeling flexible demand for integration studies requires new techniques. Demand can provide capacity, energy, and reserves for the system. This talk demonstrated the NREL approach to developing a data set and modeling techniques to measure the value of demand response. NREL applies this model of flexible demand to the western interconnect in the United States, in concert with solar and wind annual power production ranging from 30 to 55% of annual generation. The talk concluded with a look toward integrating flexible demand in integrated assessment models.

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Michael Hogan - The Regulatory Assistance Project

Mr. Hogan is a Senior Advisor to the Regulatory Assistance Project on matters relating to power industry decarbonization in Europe and the US, in particular matters of wholesale market design, the role of demand response, and integration of intermittent renewable generation. Previously he was based in The Hague directing the European Climate Foundation's power sector programs; in that role he initiated and led ECF's influential "Roadmap 2050" power sector decarbonization project. He began his career in 1980 with GE's Power Systems business marketing large fossil and nuclear power systems in the US, the Middle East and Latin America. Beginning in 1988, he helped build the J. Makowski Co. in Boston into a leading U.S. private power developer. After selling the company in 1994, he and other JMC executives founded private power developer InterGen. He spent the next seven years in London leading the growth of InterGen's regional business unit, successfully developing, financing, building and operating over 8,000MW of greenfield power plants across the U.K., the Netherlands, India, Egypt and Turkey. He returned to the U.S. to lead the restructuring of InterGen's 3,700MW North American business in 2001 and 2002, after which he joined Centrica's North American affiliate Direct Energy, based in Toronto, as head of its upstream gas and power unit, where he oversaw a mid-sized Western Canadian gas exploration and production business and built up a 1,300MW power plant portfolio in Texas over the course of three years. He earned an MBA from Harvard and an ScM from MIT in Urban Studies and Planning, and a BA in Philosophy and a BS in Aerospace Engineering from the University of Notre Dame.

Demand Management Options to Support VRE Grid Integration

Demand management in buildings has the potential to reduce dramatically the cost of integrating intermittent renewable energy sources into the energy system. This potential breaks down into two broad categories:

1) *Energy efficiency reduces the quantity of production capacity needed to meet the demand for energy services; given that most renewables are highly capital intensive the economic benefits of energy efficiency are more front-loaded (and thus greater on a present value basis) where large new investments in renewables are planned.*

2) *Demand response, in the form of shifting consumption of electricity and other energy inputs from periods of scarcity to periods of surplus, is among the most technically feasible and economically efficient means available to mitigate the intermittency of renewable energy production.*

The focus of the presentation was on the latter category of benefits. Much of the discussion around demand response has tended to focus on active management of consumption by building owners/lessees in response to various forms of dynamic pricing signals, with advanced metering systems being a key enabler. In reality this is unlikely to be the case for a number of reasons, including:

1) *Savings on bills from even the most assiduous attention to price signals are unlikely to be enough to drive the sustained commitment in time and resources required of the average building owner, and they would struggle to evaluate the expected return any needed investments.*

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2) *As the share of renewables grows on the system the timing and pattern of periods of scarcity and surplus will become less predictable, rendering mechanisms such as time of use and critical peak pricing less effective and increasing risk for consumers exposed to real-time retail pricing.*

3) *The most valuable services DR can provide are of more immediate value to system operators than to consumers, few of whom are in a position to exploit them in any case; consumer benefits will come in the form of lower overall costs to manage a system with high shares of renewables, something individual building owners have little or no ability to evaluate.*

As a result, demand management in buildings is only likely to come anywhere close to its full potential, and to deliver tangible and material benefits to building owners, via energy services aggregators acting as intermediaries between building owners and retail and wholesale market operators. In this model building owners strike a commercial deal with service providers, be they evolved offerings from traditional suppliers or services offered by new third-party market entrants, in which the full range of benefits to be derived from building energy management (from simple arbitraging of real-time prices to the sale of ramping and balancing services to grid operators) are monetized in some sort of fee-for-services arrangement that dramatically eases the burden on the building owner and makes the benefits readily apparent. These deals can include needed investment in kit such as thermal energy storage equipment. Possible candidates for new entrants to provide these services include Internet and telecom service providers, electric vehicle manufactures and thermal appliance retailers. One other implication is that the "smartness" of meters is likely to play a more limited role in facilitating all of this than is often assumed. While interval metering will continue to be a key enabling function – and ToU and CPP rate options can serve as useful intermediate measures – the actuation of the most valuable end-use management functions is more likely to occur via the Internet.

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Wilfried van Sark – Utrecht University

Wilfried van Sark is associate professor at the Copernicus Institute of Utrecht University. He has over 30 years experience in the field of photovoltaics, ranging from thin film silicon and III-V solar cell experimental and modeling development and testing to solar cell processing development, out- and indoor performance of solar cells, policy and cost development. His current activities focus on employing spectrum conversion (down/up conversion) using nanocrystals to increase solar cell conversion efficiency for next-generation photovoltaic energy converters as well as performance analysis of PV systems in the field, in particular linked to the development of smart grid systems in the built environment.

Demand side management: we need electric mobility!

With increasing penetration of variable renewables in the residential sector such as photovoltaic solar energy, matching of demand and supply is a challenge. The University of Utrecht studied demand side management options in a neighborhood setting and found only limited beneficial effects on shifting demand. Local storage, especially using batteries of electric vehicles in conjunction with bidirectional charging/discharging is shown to improve the balance of demand and supply: self-consumption can be >80% with proper energy management algorithms and adequate solar forecasting.

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Hans Christian Gils – Deutsches Zentrum für Luft- und Raumfahrt (DLR)

Hans Christian Gils studied physics with emphasis on astronomy, particle physics and security policy at the Universities of Konstanz, Padua and Hamburg. In 2010, he joined the department of Systems Analysis and Technology Assessment of the German Aerospace Center (DLR) as a doctoral candidate. His main fields of scientific interest are the modeling of energy systems and the integration of high temporal and spatial resolution data into energy system models. Specific research foci are the role of load management and enhanced sector coupling in future energy supply systems with high renewable energy share.

Model-based Assessment of Potential Future Demand Response Utilization in Germany – Selected Results and Implications for Integrated Assessment Models

Demand Response (DR) measures have been identified as one of the options available for meeting the increasing power system flexibility needs arising from the fluctuating power generation of variable renewable energies (VRE). To what extent DR can contribute to a higher VRE integration has however not yet been thoroughly investigated.

The presentation briefly introduced the implementation of electric load shifting into the cross-sectoral energy system model REMix. The deterministic linear optimization model REMix is designed for the preparation and assessment of energy supply scenarios based on a system representation in high spatial and temporal resolution. In the following, selected results of a case study for Germany were presented. It is focused on a scenario assessment of the competition and interaction of DR with alternative balancing options in integrated European energy supply systems predominantly relying on renewable energy sources. Indicators regarding the DR impact on VRE integration were discussed, including back-up capacity demand, VRE curtailment and annual load shift. The presentation concluded with a derivation of implications of the REMix results for integrated assessment models and an outlook on future research.

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Discussion points and conclusions

The expert workshop “Innovation in relation to building energy demand in IAMs” looked into the key issues of future residential energy demand and more specifically into: mitigation potential; impact of behavior; relationship between integration of VRE and residential energy demand. By means of expert knowledge on these topics, participants could draw conclusions on how to represent these issues in integrated assessment models.

IAMs, which are used to advise policy makers on overall mitigation strategies in the next decades, need to be as much as possible consistent with the information provided by detailed case studies. However, the interpretation and use of detailed information from case studies for integrated systems and, eventually, implementation in global long-term models remains one of the greatest challenges. Also, further discussion is needed to clarify to what degree energy demand may be covered by endogenous or exogenous assumptions in the models. In any case, to better represent energy demand functions in the models there is a great need for additional data, especially on regions beyond the OECD.

Experts during this workshop have indicated that demonstrated by EE models and bottom-up studies, there is a very high potential for energy savings and clearly IAM models still have major problems with representing these energy saving opportunities. Again, the level of detail, but also the availability of data, appears to be a major obstacle. The need to cooperate for collecting information and data on building stocks’ age structure, efficiency of buildings, end-use energy consumption was supported by several participants.

The buildings sector offers great potential to shift energy demand in time and thus results being very suited for VRE integration. Several presentations showed potential for using residential energy (e.g. water heaters, air conditioning, heat pumps, and vehicle batteries) allowing higher intermittent use (much more attractive than central storage). These options seem to be too specific for IAMs, but a possibility would be to create a more generic option to peak shift or battery (depending on location, climate/culture etc.). Hereby it is important to research the trade-offs between load demand management and energy efficiency improvements in more detail.

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ADVANCE workshop "Innovation in relation to building energy demand in IAMs"

January 20 – 21, 2015

Utrecht, the Netherlands

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