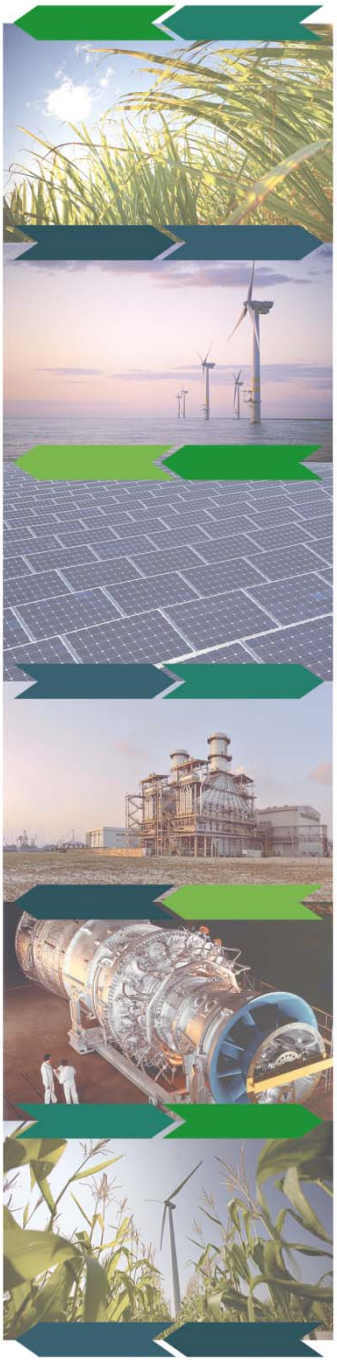
NAVIGATING THE ROADMAP FOR CLEAN, SECURE AND EFFICIENT ENERGY INNOVATION



D10.6.: Enhancing modelling capabilities

Findings from the modelling seminars and the model extensions undertaken

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www.set-nav.eu

Work Package Leader: DIW Berlin

Project Coordinator: Technische Universität Wien (TU Wien)

SET-Nav Strategic Energy Roadmap

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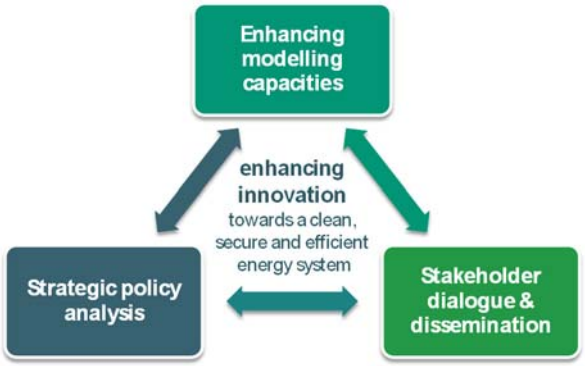
About the project

SET-Nav aims for supporting strategic decision making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically-advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU's energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with stakeholder community. This is our third pillar.



Who are we?

The project is coordinated by Technische Universität Wien (TU Wien) and implemented by a multinational consortium of European organi-sations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implement-tation of the project: policy research, energy technology, systems modelling, and simulation.

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Table of Contents

1 Introduction: The SET-Nav Modelling Forum

The SET-Nav project has aimed at pushing the state-of-the-art of energy-economic-engineering modelling. It has built on the existing capacities in a large European consortium of research institutions, higher education institutions, and actors from the private sector that have come together to develop consistent pathways of the European energy transition as defined by the SET Plan.

As a cornerstone of SET-Nav, the project consortium has used a variety of approaches to energy modelling, each with different foci and methods. Therefore, an integral part of the SET-Nav project, work package 10 (WP 10) was dedicated to the SET-Nav Modelling Forum. The Modelling Forum is devoted to a set of different objectives in line with the overall project focus and the ambitions of the European Commission, visualised by Figure 1.

The SET-Nav Modelling Forum was a series of five workshop organised by the lead institution of WP 10, DIW Berlin, with different local hosts from the project consortium (NTNU Trondheim, ETH Zurich, TU Vienna, Universidad Comillas Madrid). It created a platform for the exchange of modelling capacities within the project consortium but even more so to the broader research community. Thereby, it aimed at contributing to overcoming current modelling limitations and facilitating model extensions (inside and outside of SET-Nav) by studying best-practise examples. Importantly, the Modelling Forum was in line with the H2020 goal to achieve transparency and openness in applied modelling though its free-of-charge events which were broadly advertised to the community.

During the SET-Nav project course, we have succeeded in organizing a total of five workshops – one of them as part of the EMP-E conference in Brussels, September 2018. By welcoming approximately 200 participants, the Forum has by far outperformed the initial goals set by the consortium, and the participants' feedback to the organisers was very good. The Forum has also succeeded in the facilitation of modelling capabilities within the project consortium, and it contributed to the dissemination of the project methods, case studies and results.

The remainder of this document gives an overview of the events and publications realised as part of the SET-Nav Modelling Forum and an outline of the different workshops before moving to a special issue, organised as part of the Forum.

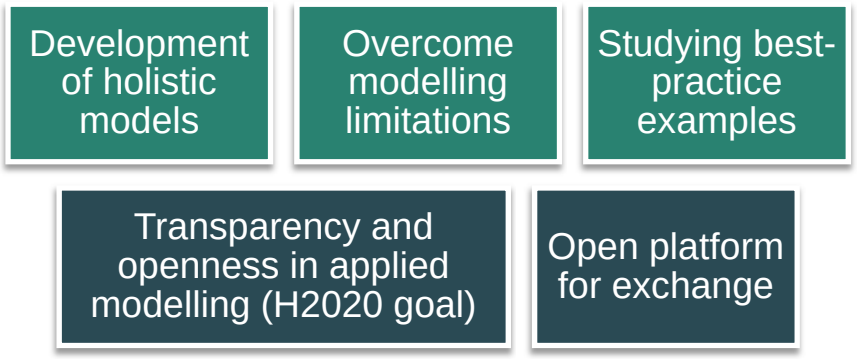

Figure 1: Illustration of the cornerstones of the SET-Nav Modelling Forum

2 Overview of activities

The following tables provide an overview of the events organised as part of the Modelling Forum (**Table 1**) as well as the publications released (**Table 2**).

Table 1: Overview of the workshops

No	Title	Venue	Date	Host	Approx. no. of participants	Models with methodological extensions enabled by the workshop
1	Top-Down Bottom-Up Hybrid Modeling	NTNU Trondheim	24 - 25 November 2016	NTNU Trondheim	30	NEMESIS, ASTRA
2	Modelling of Risk & Uncertainty in Energy Systems	ETH Zurich	29 March 2016	ETH Zurich	45	INMES-Security, GGM
3	Aggregating load profiles from the power sector models towards use in large-scale energy-system and integrated assessment models	TU Wien	7, September 2017	TU Wien	35	Enertile, Empire, RAMONA
4	Upcoming network challenges	Energy Modelling Platform for Europe (EMP-E), Brussels	25 – 26 September2018	Comillas Madrid	40	TEPES, EGMM, CCTSMOD
5	Two-stage decision making and modelling for energy markets	DIW Berlin	11 October 2018	DIW Berlin	50	Multimod, GGM

Table 2: Overview of the documents published in connection with the SET-Nav Modelling Forum

Title	Author	Type
Hybrid Modelling: Linking and Integrating Top-Down and Bottom-Up Models	Franziska Holz, Dawud Ansari (DIW Berlin), Ruud Egging, Per Ivar Helgesen (NTNU)	Issue Paper
Risk and Uncertainty Modelling in Energy Systems	Blazhe Gjorgiev, Giovanni Sansavini (ETH), Pedro Crespo Del Granado (NTNU)	Issue Paper
Aggregating load profiles	Dawud Ansari (DIW)	Issue Paper
Infrastructure prerequisites: Upcoming Network Challenges	Sara Lumbreras, Andrés Ramos, Luis Olmos (Comillas)	Issue Paper
Multilevel equilibrium problems with applications in energy	Dawud Ansari (DIW Berlin)	Issue Paper
Proceedings of the first Modelling Workshop	Dawud Ansari (DIW Berlin), Ruud Egging (NTNU)	Proceedings
Proceedings of the second Modelling Workshop	Dawud Ansari (DIW Berlin), Blazhe Gjorgiev (ETH)	Proceedings
Proceedings of the third Modelling Workshop	Dawud Ansari (DIW Berlin)	Proceedings
Proceedings of the fourth Modelling Workshop	Sara Lumbreras, Andrés Ramos, Luis Olmos (Comillas)	Proceedings
Proceedings of the fifth Modelling Workshop	Dawud Ansari, Franziska Holz (DIW)	Proceedings
A three-model linkage for energy-economics-environmental analysis: TIMES, REMES, and EXIOASE	Ruud Egging, Per Ivar Helgesen, Kirsten Svenja (NTNU), Geraldo Perez-Vales (SINETEF)	Discussion Paper
Engineering Resilience in Critical Infrastructures	Giovanni Sansavini (ETH)	Discussion Paper
Infrastructure prerequisites	Gianfranco Chicco, Andrea Mazza	Discussion paper
An Introductory Tutorial on Convex Formulations for Equilibrium and Bi-Level Problems	Ruud Egging (NTNU), Dawud Ansari (DIW)	Discussion Paper

3 Modelling Forum content & impressions

3.1 Workshop 1: Top-Down Bottom-Up Hybrid Modeling

Professor Christoph Böhringer from University of Oldenburg gave the opening session about **hybrid modelling in the integrated mixed complementarity** (MCP) framework. This framework generally allows for a large degree of flexibility, which can be necessary for combining models. However, complexity and dimensionality quickly restrict practical applications, such that a **decomposition method** should be used. The top-down, MCP problem is separated from the bottom-up framework, which is typically a quadratic programming problem. Then, an iteration algorithm is used that solves the top-down model and passes variables to the bottom-up model, which solves subsequently. Finally, the algorithm checks for convergence. This unified but decomposed approach allows both models to be specified and run in their own respective programming interface but to be solved in an iterative, computationally feasible way.

A practical implementation of this method was presented by Dr. Jan Abrell from ETH Zürich in his session on the **application of hybrid modelling**. Among other points, he raised the issue of robustness in generation decisions with respect to changes in costs and how this can be overcome with the usage of varying elasticities of substitutions along the branches of the nested utility function.

In a hands-on session following Dr. Abrells presentation, the workshop participants explored and applied a classroom version of Jan Abrell's model for simulating the effect of different climate policies on the energy mix.

Figure 2: Impressions from Workshop 1 at NTNU during the keynote lecture of Prof. Dr. Christoph Böhringer

Strengthening the ties between the consortia funded through the Horizon2020-LCE21-call, the SET-Nav modellers were happy to welcome Professor Ulrich Fahl from University of Stuttgart as a representative of the **REEEM project**. In his session, he presented several hybrid models: **NEWAGE** (which integrates hybrid features into a computable general equilibrium model), **TIAM-MACRO** and **TIAM-LOPEX** (energy systems

models with macroeconomic extensions and an oil market extension respectively) as well as linkages of **TIMES-PanEU with E2M2 and NEWAGE** for analysing the European energy sector.

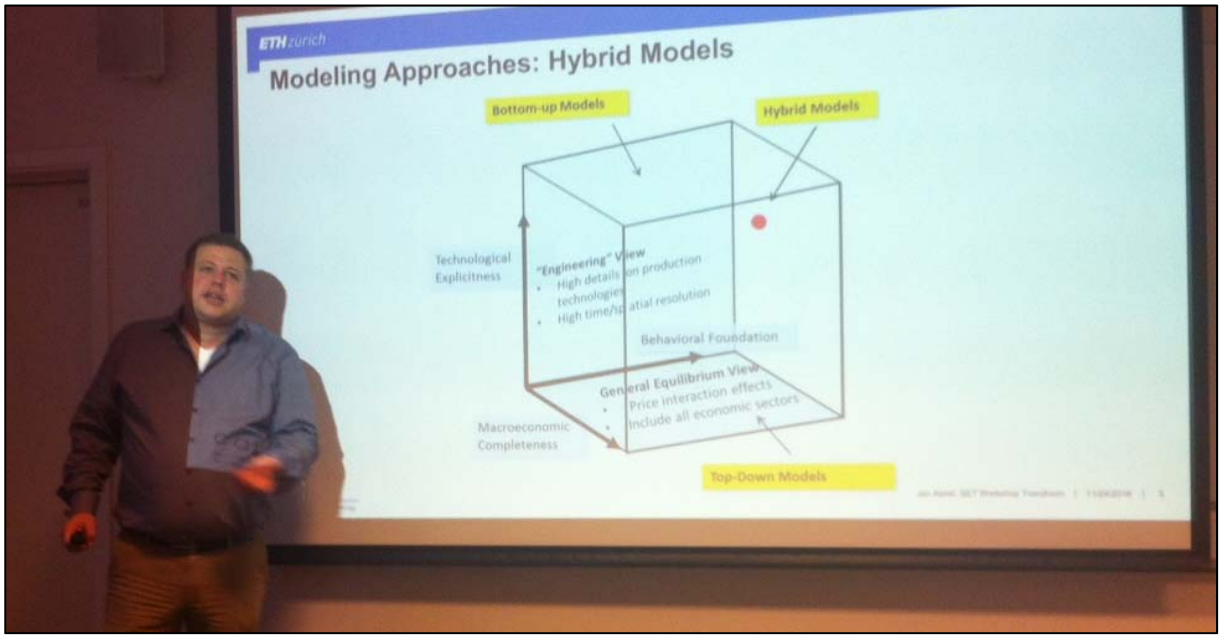

Figure 3: Dr. Jan Abrell presenting at the NTNU Workshop

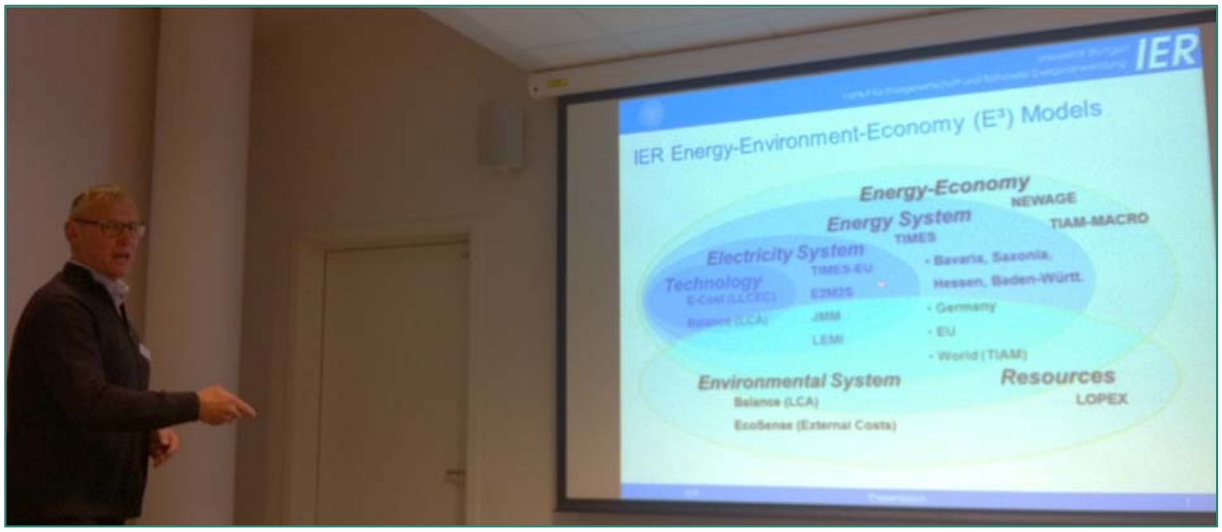

Figure 4: Presentation by Prof. Dr. Ulrich Fahl at the NTNU Workshop

Another input session, given by Per Ivar Helgesen and Dr. Gerardo Perez-Valdes from NTNU, dealt with applied issues in the **hard-linking of TIMES-Norway and REMES** as a regionalized energy system model and a regionalized computable general equilibrium model for Norway, respectively. Besides explaining the system of linkage, the session emphasised the different practical obstacles faced in model linking that arise from differences in granularity, i.e., a different (dis-) aggregation patterns regarding time, geographical regions, and demand or other sectors. To overcome this issue, appropriate mappings have to be specified for implementation of hard-linked model interface (topic of Workshop 3, see below).

Philipp Härtel from Fraunhofer IWES presented some results of the North Sea Offshore Network (NSON-DE) project. In particular, he described a novel approach of **regional decomposition with a subsequent unit decomposition** to solve an – otherwise infeasible – convex linearly-constrained non-smooth problem of European transmission expansion planning. Although yielding initial success, up-scaling and determining appropriate termination criteria, in addition to practical implementation challenges, still leave ample scope for future research.

3.1.1 Panel discussion - Future research directions in hybrid modelling

Following the presentations, a concluding session sought to summarize lessons learned and identify future developments and issues in hybrid modelling. Dr. Franziska Holz from DIW Berlin was joined on the panel by Dr. Jan Abrell, Professor Ulrich Fahl, and Per Ivar Helgesen. The following subsections briefly reflect some discussed items and suggestions by category.

3.1.1.1 Drivers of model development

- Research questions (should) drive the developments. These originate from policy analysis and decision support.
- Where can hybrid modelling be located, compared to integrated assessment modelling? Emphasis was given to the fields climate, emissions, footprints, maritime ecosystems.
- Is it more important to include a further decomposition of the household or a differentiation? This raises the point of distributional impacts and their reflectance in computable equilibrium models: To which extent can the absence of distributional impacts in models lead to solutions that are then found to be not implementable for political reasons and, hence, not applicable?
- Instead of focussing on climate policy, other issues should be included. Among them, most importantly, the emerging idea of NEXUS issues, i.e. interdependencies between different dimensions such as energy, food and land use, and water. In that way, hybrid modelling could become an important tool in assisting the UN Sustainable Development Goals (SDG). A functioning and reliable energy system, in general, is a prerequisite for human well-being and economic development, but it is not an objective in itself, in a narrow sense. Therefore, it has to be seen in the context of broader societal questions.
- Often, researchers face only low incentives to develop novel models, due to the lack of funding, missing long-term resources, and because development time often amounts to multiple years.
- Integrated assessment models, as a potential rivalling concept to the hybrid models dealt with in this workshop, typically assume GDP and/or population data. Hence, there is no feedback between the energy systems and the economy. The framework might broadly profit from including ideas of bottom-up modelling.

3.1.1.2 Improving hybrid modelling

- Hybrid models need more detail and a better representation OF WHAT?. However, often, the solution time is used to solve for all the details. Hence, detailed models should only be used when needed.
- When aggregating a model to perform the integration, one needs to be careful to not lose the strengths of the different original models.
- A future issue might be multi-sector bottom-up models.
- The time horizon in modelling has been named an important issue BY WHOM?. As SET-Nav project's workshop 3 will cover, mappings in temporal resolution are non-trivial. However, they are central for the model's outcome. As always, when determining a model's resolution, the right

balance between computational or data effort and the degree of detail needs to be found. This does not necessarily invoke an hourly resolution, especially for policy support.

3.1.1.3 Expanding modelling scope and size

- Linking dynamic recursive computational equilibrium modelling with bottom-up modelling was named as a potential way forward. Problematically, dynamic recursion implies myopic foresight, with is inconsistent with perfect foresight from bottom-up modelling.
- Sector coupling has been named an important buzz word in the field. Current energy system models could benefit from a better sector coupling, and top-down models often lack a heating sector.
- The question was raised, if it is possible to link more than two models. The panel has found that it is possible, as long as the direction of causality is clear, such as performed by an IIASA model that combines three bottom-up models or the SET-Nav three layers of models. However, it may prove difficult if models have fairly different strengths.
- Solving larger models requires decomposition. In general, such decompositions need tuning, fine-adjusting, and a lot of testing. Alternatively, some aspects can be integrated by functional linkages, such as flexible and self-adjusting boundary conditions and functional forms. For instance, supply or demand curves that mimic the stronger model in these regards can be implemented.

3.1.1.4 Communication

- When input data with higher detail is required, it might be necessary to lobby with statistics bureaus for a future collection of data with the necessary degree of detail.
- Cross-disciplinary communication towards the broader public is necessary to create awareness and teach the contributions, strengths and weaknesses of models. Problematically, public dissemination does typically not involve scientific reward. Large numbers of graduating master students in "energy system modelling" is certainly a step in the right direction, but still more interdisciplinary study programs that work cross-disciplinary and cross-regional are necessary.
- Initiatives pushing for data sources and models to be published under open-source/open-access licenses are an interesting development that might influence future modelling.

3.2 Workshop 2 Modelling of Risk & Uncertainty in Energy Systems

Professor Terje Aven from University of Stavanger started the workshop day by presenting some of the recent advances on the foundations of risk assessment related to the conceptualisation, analysis and characterisation of risk. Key topics included: What is risk? How to best describe risk? How to treat uncertainties? How to reflect knowledge in risk assessments? How to assess uncertainties related to knowledge? How to understand and deal with model uncertainty? How to take into account potential surprises (black swans)? The presentation also addressed some management and decision-making issues related to the use of risk assessment.

The assessment of the risk, vulnerability and resilience of complex systems and infrastructures for energy production and transportation is based on models that are affected by uncertainty, due to: (i) the intrinsically random nature of several of the phenomena occurring during system operation (aleatory uncertainty); (ii) the incomplete knowledge about some of the features of the systems (epistemic uncertainty). The accurate characterization, quantification and propagation of this uncertainty is obviously fundamental for taking robust decisions in safety-critical applications. In the current

risk/vulnerability/resilience assessment practices, both aleatory and epistemic uncertainties are described by probability distributions. However, in some cases the imprecise knowledge, incomplete information and scarce data impair the probabilistic representation of epistemic uncertainty.

Professor Nicola Pedroni, from Université Paris-Saclay/CentraleSupélec in his presentation addressed the issue by way of a simplified case study consisting of two interdependent infrastructures (electric power system and gas network) and a supervisory control and data acquisition (SCADA) system connected to the gas network. In the presented examples, a multi-state probabilistic model captures the randomness in the behaviour of the systems components, while the epistemic uncertainty in some of the model parameters is instead described by intervals.

Electric power and gas infrastructures are and operate as interdependent systems. Gas fired plants are currently used to balance the volatility or renewable generation and load especially when the storage infrastructure is still poor. Professor Giovanni Sansavini from ETH Zurich presented risk-based security assessment of the interdependent power and gas carriers with high penetration of renewable generation.

Decisions involving energy systems are complex. Quantitative models help decision makers in understanding the risks involved with various risk management strategies. Professor Emanuele Borgonovo from Bocconi University, in his presentation addressed the decision analysis perspective of the problem discussing the link between decision and risk analysis and the role of sensitivity analysis as a key tool to enrich the information delivered by quantitative decision support models.

Figure 5: Impressions from the Zurich Workshop

Professor Chris Dent in his talk gave an overview of current capacity planning issues in the GB power system, and related academic and industry research projects. The overall philosophy of the presented work was to provide more rigorous arguments about the meaning of the mathematical modeling and what is not telling us about the real systems under study. Examples were presented from generation capacity planning (issues such as limited data, decision making under uncertainty, choice of risk metrics), and broader issues of methodology relating to uncertainty quantification in complex computer models. A discussion on efforts to model cascading blackout risk was also presented.

The last session of the workshop focused on the stochastic programing in modeling of energy systems. Dr. Martin Densing from Paul Scherrer Institute (PSI) presented an oligopolistic capacity-expansion and market-clearing model for Switzerland and the surrounding countries. The model uses a closed-loop formulation, and features transmission constraints between the players and decision-making under uncertainty. Selected numerical results under different degrees of market power were shown.

Managing the power system transition from a supply side based mainly on fossil fuel thermal generating technologies to one with significant shares of intermittent renewable generation requires the ability to handle short-term uncertainty and short-term dynamics in the planning process. Dr. Christian Skar from NTNU presented a stochastic programming investment model for the European power system applying a multi-horizon formulation. Investments in generation capacities for different technologies, interconnector capacities for cross-border exchange and storage capacities are made subject to uncertainty about load and intermittent generation profiles. Short-term operational decisions are considered not to affect future investment and operational decisions, which allows for a significant reduction of the scenario tree used to model the decision process. Thereby long-term dynamics, short-term dynamics and short-term uncertainty can be simultaneously be considered in a large-scale power system investment model without the curse of dimensionality issues.

Figure 6: Impressions from the Zurich Workshop

Han Xuejiao from ETH Zurich presented a method to derive optimal day-ahead trading strategies for an aggregator of a decentralized energy resources' mix, who participates in a multi-market environment, including a day-ahead, an intraday and a balancing market. The optimization problem is solved using multi-stage stochastic programming, which is subject to different levels of uncertainties. A case study based on the data from the Swiss electricity market is used to demonstrate the effectiveness of the proposed model.

3.2.1 Panel talk

The following bullet points outline the message of each panellist's take away message:

- Risk is a complex understanding and should not be reduced to expectation values, because many important aspects of risk are not included. Dealing with risk makes a proper interpretation crucial.
- Modellers tend to be very confident but underestimate the role of their assumptions.
- *All models are wrong, but some are useful* (George E. P. Box). Since models do not represent the real world in detail, researchers need to be careful about their statements, and models should only be used for the questions they have been designed for.
- Some modellers tend to see robustness checks and sensitivity analysis as dangers. However, a good model should be able to give robust advice. Otherwise, stakeholders will hardly trust conclusions derived from that model.
- Prediction needs a quantification of uncertainty. Otherwise, the predictions degree of certainty stays unclear, and trusting the prediction will not be possible, what renders it useless.
- Stochastic models should be compared with their deterministic counterparts. Only if the modeller has a good understanding of the effect of stochastics in his model, stakeholder advice will be possible.
- We need to distinguish clearly between modelling for insights and predictions. In this regards, many popular models need to be questioned critically.
- More transparency in modelling is necessary. Black-box-type research may lead to mistrust.

Figure 7: Impressions from the Zurich Workshop

3.3 Workshop 3 Aggregating load profiles

Figure 8: Impressions from the Vienna Workshop

8:45 - 9:00	***REGISTRATION***
9:00 – 9:30	Welcome by Marijke Welisch, TU Wien
	Overview of the SET-Nav modelling workshop series by Dawud Ansari, DIW
	Overview of load aggregation in the SET-Nav project, Michael Hartner, TU Wien
9:30 - 10:15	**Introduction: Review on aggregated electricity demand modelling (hourly) for use in long term power system analysis**, Karen Byskov Lindberg, NVE
10:15 – 11:00	**A novel method for incorporating power exchange limitations into energy system models and the impact of spatial aggregation**, Karl-Kiên Cao, DLR
11:00 - 11:30	***COFFEE BREAK***
11:30 - 12:15	**A parsimonious model for the complex German electricity system – what lessons to be learnt**, Philip Beran, University Duisburg Essen
12:15 - 13:00	**A simple approach to time series reduction - application in the model dynELMOD**, Clemens Gerbaulet, DIW
13:00 - 14:00	***LUNCH BREAK***
14:00 - 14:45	**Methodology for long term hourly electric load modelling taking into account building refurbishment, electric heating and climatic stochastics**, Karen Byskov Lindberg, NVE
14:45 - 15:30	**People's activities and residential electricity demand: A time use approach**, Jacopo Torriti, University of Reading
15:30- 15:45	***COFFEE BREAK***
15:45 - 16:30	**synPRO tool and other activities**, Bernhard Wille-Haussmann, Fraunhofer ISE
16:30 -17:00	Discussion time
17:00	**END OF WORKSHOP**

Figure 9: Impressions from the Vienna Workshop

3.4 Workshop 4 Upcoming network challenges

Figure 10: Impressions from the EMP-E 2018 Conference

This section provides an overview of the presentations and discussions in the EMP-E Session "Upcoming network challenges" that was organised as the 4th workshop of the SET-Nav Modelling Forum. The session brought together modellers from a broad variety of sectors and approaches. It showed that there is not one right method to analyse networks but that the methods are developing in strong relation to the network characteristics (e.g. telecom networks vs. electricity networks). The workshop aimed at starting an exchange between modellers from different sectors in view of potential exchanges of modelling approaches.

3.4.1 Presentation 1: DiNeMo: the distribution network models platform

Giuseppe Prettico holds a Ph.D. in Photonics (ICFO, Barcelona) and a Master in Energy Efficiency and Energy Markets (UPC, Barcelona). He received his Degree in Automation and Systems Engineering and his

M.Sc. in Science for Engineering from La Sapienza University (Rome). He joined the "Smart Electricity Systems and InteropeGiuserability" group at the European Commission, Directorate of Energy, Transport and Climate (JRC) in December 2013, as a Smart Grids Modeller. His research interests include Distribution System and Smart Grids Analysis, Electricity Markets (Retail and Wholesale), Electric Vehicles Integration and Interoperability, Agent-Based and Complex Network Modelling.

DiNeMo is the new platform the JRC C3 Unit is building to provide electricity stakeholders with on-request representative distribution grid models. The models are built based on the reference network models methodology developed by IIT-Comillas. The data and indicators used come from real data provided from European DSOs. Several roles for its users have been conceived, as researcher, validator, collaborator, etc. The platform will also be the virtual place where collaborations between diverse users will rise with the aim of building the smart cities of tomorrow. The feedback collected in the test of the beta version will be used to tailor the platform on the needs of its users

3.4.2 Presentation 2: Heuristic optimization of power and energy systems: underlying principles, myths and discussion of practical cases

Gianfranco Chicco is a Full Professor of Electrical Energy Systems at Politecnico di Torino, Italy. Fellow of the IEEE (Power and Energy Society). Chairman of the IEEE PES Innovative Smart Grid Technologies (ISGT) Europe 2017, held in Torino (Italy) on 26-29 September 2017. Research interests: include Power System Analysis, Distribution System Analysis and Optimization, Electrical Load Management, Energy Efficiency and Environmental Impact of Multi-Energy Systems, Data Analytics, Artificial Intelligence Applications to Power and Energy Systems, Renewable Energy Sources and Distributed Generation, and Power Quality.

The proliferation of publications on heuristic optimization methods has been striking in recent years. They have been applied to solve the main problems in the power and energy domain. The underlying principles of heuristic optimization were covered, together with some myths and reality about heuristic optimization. Finally, the do's and the don'ts in the use of heuristic methods were presented with a discussion of practical cases

3.4.3 Presentation 3: Modelling telecommunications systems together with power distribution networks

Javier Matanza holds a degree on Telecommunication engineering from Polytechnic University of Valencia (Spain) and a PhD from Comillas Pontifical University (Madrid). He is currently a Research Professional at the Institute for Research in Technology (IIT) and an Assistant Professor at ICAI School of Engineering. His current interests are in powerline communication technologies, in communication network simulations and signal processing for telecommunications.

ICT (Information and Communication Technologies) are increasingly important in Power Systems, and the need to incorporate them is growing with the upscaling of distributed generation or demand response. This presentation included an overview of the different approaches when modeling Telecommunications and Power Systems, emphasizing the most suitable Power-Line Communication technologies to Demand Response protocols. The co-simulation of Cyber-Physical systems was described, together with common interfaces and recent efforts. The presentation concluded with the most pressing challenges for the integration of ICTs in the distribution and transmission networks.

3.5 Workshop 5 Two-stage decision making and modelling for energy markets

The last workshop in the SET-Nav Modeling Forum brought together modelers and practicioners interested in game-theoretic modelling of energy markets, namely equilibrium modeling. This workshop was organized by the workpackage leader, DIW Berlin. It was organized one day before the BELEC Conference (Berlin Electricity Economics Conference, an annual event) which was beneficial for both presenter and audience presence.

The workshop day started with a keynote lecture by Prof. Sauleh Siddiqui from Johns Hopkins University in Baltimore (USA). He introduced the audience to the basic concepts of equilibrium modelling as well as to the advanced approaches of stating and solving multi-level equilibrium problems. Special emphasis needs to be given to a group of mathematical problems that are summarised under the umbrella term multilevel equilibrium problems. These problems represent multiple interdependent optimisation problems that are constrained by other optimisation problems. In a general context of decision-making, such a problem represents sequential decisions by actors who anticipate each other's actions and behave strategically. Hence, multilevel equilibrium problems can often be connected to issues of (dynamic) game theory, which aims to predict the outcome of strategic interactions. This talk outlined main characteristics of mixed complementarity problems (MCPs), mathematical problems under equilibrium constraints (MPECs), and equilibrium problems under equilibrium constraints (EPECs).

Figure 11: Prof. Sauleh Siddiqui during his keynote lecture at the Berlin Workshop

After the keynote lecture, the two following sessions focused on applications for different energy sectors. The first session saw three presentations of multi-level equilibrium modelling of electricity market features. First, Paul Neetzow (Humboldt University Berlin) focussed on the interaction of prosumage with the distribution and transmission grid and investigated how efficient regulation can be used to overcome countervailing objectives of different entities. The researchers evaluated different incentive schemes and regulations introduced by the distribution system operator (DSO) with respect to their efficiency and distributional effects. These policies allow the DSO to influence storage dispatch and hence decrease required grid expansion. However, the resulting storage operation and distribution grid capacities are not cost efficient from a systems perspective and lead to non-optimal deployment of transmission lines and use of dispatchable generation.

Second in this session, Dr. Alexander Zerrahn (DIW Berlin) proposed a three-stage model to describe how network investment can reduce market power exertion: a benevolent planner decides on network upgrades for existing lines anticipating the gaming opportunities by strategic generators. These firms, in turn, anticipate their impact on market-clearing prices and grid congestion. In this respect, we provide the first model endogenizing the trade-off between the costs of grid investment and benefits from reduced market power potential in short-run market clearing. In a numerical example using a three-node network, the researchers illustrated three distinct effects: firstly, by reducing market power exertion, network expansion can yield welfare gains beyond pure efficiency increases. Anticipating gaming possibilities when planning network expansion can push welfare close to a first-best competitive benchmark. Secondly, network upgrades entail a relative shift of rents from producers to consumers when congestion rents were excessive. Thirdly, investment may yield suboptimal or even disequilibrium outcomes when strategic behaviour of certain market participants is neglected in network planning.

Third in the session on applications for electricity market analysis, Tim Schittekatte presented a game-theoretic model with self-interest pursuing consumers to assess how to design a least-cost distribution tariff under two constraints that regulators typically face. The first constraint is related to difficulties regarding the implementation of cost-reflective tariffs. In practice, so-called cost-reflective tariffs are only a proxy for the actual cost driver(s) in distribution grids. The second constraint has to do with fairness. There is a fear that active consumers investing in distributed energy resources (DER) might benefit at the expense of passive consumers. We find that both constraints have a significant impact on the least-cost network tariff design, and the results depend on the state of the grid. If most of the grid investments still have to be made, passive and active consumers can both benefit from cost-reflective tariffs, while this is not the case for passive consumers if the costs are mostly sunk.

Figure 12: The work package team at the Berlin Workshop

In the second session, applications for fossil energy markets were presented. Prof. Dr. Olivier Massol (ifp School) discussed that Mathematical problems under equilibrium constraints (MPECs) are a special form of optimisation problems constrained by optimisation problems (OPcOP). An important field of application is a public authority that sets a policy in anticipation of a market equilibrium. This talk elaborated the idea, that an optimal policy should not depend on the point in time at which the

optimisation problem is solved. Otherwise, the policy may be regarded as time inconsistent and cannot be optimal in a dynamic framework. Therefore, this talk advocated for the use of feedback approaches, which nest multiple MPECs for different time periods in each other in order to achieve time consistent optimal policies.

In the second talk, Dr. Ibrahim Abada (Engie, Center of Expertise in Economic Modeling and Studies) started from the premise that for many resource-based economies, regulating exports is crucial. Nevertheless, we observe different countries deploying different export policies. The researchers explained this difference via strategic interactions by giving two competing countries the possibility to design their export markets and select the level of competition they exert. In a first step, the researchers tested standard models and find that they fail to explain the multitude of observed behaviours: under the closed loop Nash equilibrium paradigm, the equilibrium is reached when countries completely open their export market. The Stackelberg game on the other hand concentrates the market in a plausible way but is not symmetric since it appoints a leader and follower. In a second step, the researchers let countries choose between being strategic or passive in their interaction and demonstrate that the competitive outcome that they find in the closed loop Nash game rarely occurs. Only this last setup complies with the commonly observed situations.

In the third talk, Aurora del Valle Díez (Comillas Pontifical University) presented the GASMOPEC model, which is a multi-objective bi-level optimisation model for representing the investment decision process in the European natural gas market. The upper level is the investment decision process in pipelines and regasification units, while the lower level problem is a downstream equilibrium for the natural gas market. The model recognises that for the decision towards to so-called projects of common interests, several criteria need to be taken into account. For this example, the researchers identified investment costs, supply security, market integration, and competition as the different main objectives, which is why these criteria are inserted into the multi-objective modelling framework. The case study shows that Western Europe is well interconnected, that the investment in two new European regasification terminals will enhance consumer utility, and that the pipeline capacity with incumbent major gas suppliers should increase.

Contrasting the non-cooperative equilibrium modelling approach, Prof. Dr. Franz Hubert (Humboldt University Berlin) introduced the audience to cooperative game theory with a focus on bargaining power in energy networks. This talk presented an alternative methodology for analysing bargaining games in network markets, which are markets where transactions occur by means of network infrastructure (e.g., gas, electric energy, water, etc.). The overall economic surplus obtained in the market is distributed among all network agents the on the basis of their bargaining power, which in turn depends on a variety of factors: position of each agent (e.g., a country) in the network, reliability in the cooperation scheme (e.g., geo-political stability), existence of market distortions and availability of outside options (e.g., alternative energy sources). The method the researchers proposed, which is illustrated here through an application to a fictitious network structure, is based on a two-stage process: first, a network optimization model is used to generate payoff values under different coalitions and network structures; second, cooperative game solutions are identified. Any change in the network structure entails both a variation in the overall welfare level and in the distribution of surplus among agents, as it affects their relative bargaining power. Therefore, expected costs and benefits, at the aggregate as well as at the individual level, can be compared to assess the economic viability of any investment in network infrastructure. A number of model variants and extensions are also considered: changing demand, exogenous instability factors, market distortions, externalities and outside options.

In the final talk, Prof. Ruud Egging (NTNU) challenged the audience by presenting a method to model non-cooperative games without using equilibrium modelling. This talk elaborated on the issue that (bilevel) equilibrium problems suffer from a strong curse of dimensionality, which is why the computation of solutions to large-scale problems may not be feasible. Therefore, Prof. Egging advocated for the reformulation of (bilevel) equilibrium problems as convex non-linear optimisation problems, which can be solved much quicker due to more developed computational solvers and the omission of non-convex complementarity terms present in equilibrium models. The method was shown to lead changes in the order of magnitude regarding computation time for selected problems, but future research will still need to establish generalisations.

To close the workshop day but also the SET-Nav Modeling Forum, a panel discussion with some lead modellers and model users was organized. Under the title "Which road for applied modelling?" Dr. Franziska Holz (DIW Berlin) discussed with Prof. Ruud Egging (NTNU), Prof. Olivier Massol (ifp School), Prof. Sauleh Siddiqui (Johns Hopkins University) and Dr. Marijke Welisch (TU Wien) whether complex modelling methods are necessary or potentially too complex for policy communication. The panellists agreed that complex and advanced modelling methods need to be used, but that the communication to policy makers is crucial. Dr. Marijke Welisch, who has been coordinating the SET-Nav project and has therefore been in close contact with model result users reminded the panellists that practitioners are (currently) more interested in transparency on the data assumptions. The panel closed by calling for more interaction between modellers from different approaches and a continuation of activities of the type of the SET-Nav Modeling Forum.

Figure 13: Impression from the panel discussion at the Berlin Workshop

4 Special Issue

As part of the workshop series (in particular, the Vienna workshop), the SET-Nav project organised a special issue in the renown scientific journal Utilities Policy. Its title is "The challenges of temporal and spatial aggregation: Modelling and policy implications". The topic deals with challenges that arise from the aggregation of information from detailed power sector models for the further use in large-scale energy

system or integrated assessment models. The issue accounts for the increased complexity modern electricity grids face due to the integration of stochastic renewable generation and necessary demand side management.

The publication process is ongoing, and, at the moment, two articles are already online in Volume 57 of Utilities Policy journal.

J.M. Weinand, R. McKenna, W. Fichtner (2019). "Developing a municipality typology for modelling decentralised energy systems" Utilities Policy, Volume 57, Pages 75-96, ISSN 0957-1787

A. Forouli, H. Doukas, A. Nikas, J. Sampedro, D. J. Van de Ven (2019). "Identifying optimal technological portfolios for European power generation towards climate change mitigation: A robust portfolio analysis approach". Utilities Policy, Volume 57, Pages 33-42, ISSN 0957-1787