# Final report on ETSAP WS series: Approaches to include human and social dimensions in TIMES energy system models: Practices, recommendations and further research needs.

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## Foreword

This report summarizes the outcome of three workshops about modelling of energy behaviour in TIMES energy system models. The workshop series has provided an overview of the approaches that are used in the ETSAP community, identified knowledge needs and gaps, and facilitated discussions and suggestions for best practices of modelling. The workshop series is partly financed by ETSAP but primarily builds on own financing of ETSAP partners through participation and ongoing and previous research projects.

The workshop series is relevant to the ETSAP Annex XV "Energy Systems and Sustainable Development Goals" since it relates directly to the objective "Research and Development" by contributing to pathways to net zero GHG emissions systems, where energy behaviour plays an important role. Furthermore, exchanging knowledge regarding energy behaviour relates to the objective on improved modelling of the consumption side of energy systems, demand side flexibility, integrating human behaviour and societal aspects into energy systems modelling.

In general, it has been a great interest among the ETSAP partners to meet and discuss this topic that is of common interests among energy system modellers. This is confirmed by a high participation rate, both in person and online. We experienced however some challenges with aligning discussion with members that attend in person and members that attend online in the hybrid meetings. A learning from this experience is that it can be a better solution to have pure digital and pure physical meetings. Nevertheless, this WS series has contributed to increase the knowledge among, enhance collaboration between and motivate researchers in the ETSAP community. The input from, and discussions with, all participants has been highly valuable and the outcome of the WS series is a result of the preparation to, and the common effort in all the three WSs. A specific outcome of the workshops has been a common scientific paper with numerous of the project participants, on the fairness and feasibility of low energy demand scenarios. The paper will be a part of the ETSAP book, published by Springer, that will be launched on the International Energy Workshop (IEW) in summer 2024.

## Background

Consumer-behaviour has significant impact on the transition to a low-carbon energy system (Dubois et al., 2019). Implementation of energy efficiency measures, flexible consumption and adoption of new technology can contribute to lower the need for new energy infrastructure, reduce GHG emissions, lowering the cost of the energy transition and minimize nature interventions. From a techno-economic modelling perspective, there is a gap between what models predict to be the cost-optimal action and what consumers will do. If allowing for behaviour change to reduce the energy demand a cost-minimizing model will always do the behaviour change if not associated with a cost. While it might be possible to estimate the price needed for people to make a behaviour change today to reduce the demand, it is difficult to predict how people value the same behaviour in the future.

Individuals do not necessarily make decisions that are techno-economically optimal from an energy system perspective. A reason for this is that the assumed techno-economic behaviour in the models is a poor representation of preferences and purchasing decisions (DeCarolis et al., 2017), and that these models struggle to analyse complex situations where interactions may lead to 'emergence' and new kinds of patterned behaviour (McDowall and Geels, 2017). This can be e.g., due to that individual do not make rational decisions, there is a mismatch between what is a rational solution for an individual and for the energy system, there is a lack of direct rewards for making decisions beneficial for energy transition, there is a lack of information on the benefits or drawbacks of energy related decisions, or individuals have other preferences. If the energy behaviour is not considered in energy system models, the solutions can be too optimistic and underestimate the developing needs of the energy system. For example, the implementation of energy efficiency measures, the adaption of new technologies, the demand for energy services, and the availability of end-use flexibility are typically limited by energy behaviour. On the other hand, changing values and norms may also motivate individuals and societies for more rapid transition to sustainable energy systems. The techno-economic models can serve as an illustration for what is possible, which again may impact the energy behaviour.

## Workshop series overview

The Workshop series was split in three Workshops over one day that was held in different locations with the following focus:

**WS1: Current modelling practices**

15th of September 2022

Organised by Institute for Technology (IFE), Kjeller, Norway

WS Responsible: Institute for Technology (IFE), Kjeller, Norway

Participants: 16 digital and 13 in person

**WS2: Main challenges**

29th of November 2023

Organised by Centre of Global Energy Policy (CGEP), New York, United States

WS Responsible: Luleå University of Technology (LTU), Sweden

Participants: 17 digital and 13 in person

**WS3: Best modelling practices**

21st of March 2023

Organised by Luleå Technical University (LTU), Sweden

WS Responsible: University College London (UCL), United Kingdom

Participants: 9 digital and 8 in person

The main findings of the WS are presented at the ETSAP summer WS in Colorado, United States, the 15th of June 2023. In the following, a summary of each of the three WSs are summarised in separate sections.

## Main findings:

This section is dedicated to give a short overview of the main fundings of the three WSs.

A first conclusion is that energy behaviour has a large influence on the energy system transition but is not straight forward to incorporate in energy system models, such as TIMES models. It is thus a complex topic that requires a reflected modelling approach to be able to generate relevant and credible analysis.

To accommodate this, TIMES modellers are recommended to:

- be transparent about assumptions related to energy behaviour.
- be clear on the purpose of analysis; explorative vs. normative.
- collaborate and align assumptions and methodology with social scientists and other experts.

Throughout the WSs the following further research needs were identified:

- how can energy behaviour be represented in a long-term perspective in energy system models? For example, what are the realistic, long-term constraints to reflect energy behaviour?
- how should optimization models conceptualise and incorporate energy behaviour? Constraining optimisation models to incorporate energy behaviour can lead to TIMES models that are normative simulation models in the short-term and explorative optimization models in the long-term.
- what structural factors are most influential on energy behaviour, and how should this be best included in TIMES models?
- under what conditions is linking with other models worth the effort to introduce energy behaviour heterogeneity?

## Workshop 1: Current modelling practices

The Workshop had 28 participants from ten different institutes/ universities located in 9 different countries as shown in Table 1. The names that are marked with a star, *, were the presenting on behalf of their modelling team.

Table 1: List of participants in Workshop 1.

| **Institute/ University** | **Country** | **Name** | Digital | Physical |
|---|---|---|---|---|
| Luleå University of Technology (LTU) | Sweden | Anna Krook Riekkola* | | x |
| Luleå University of Technology (LTU) | Sweden | Parvathy Sobha | | x |
| University College Cork (UCC) | Ireland | Olexandr Balyk | x | |
| University College Cork (UCC) | Ireland | Ankita Gaur* | | x |
| University College Cork (UCC) | Ireland | Connor McGookin | x | |
| University College Cork (UCC) | Ireland | Andrew Smith | x | |
| University College Cork (UCC) | Ireland | Vahid Aryanpur | x | |
| University College London (UCL) | UK | Rachel Freeman* | x | |
| University College London (UCL) | UK | Mark Barratt | x | |
| VTT Technical Research Centre | Finland | Tiina Koljonen* | x | |
| VTT Technical Research Centre | Finland | Antti Lehtila | x | |
| Centre of Global Energy Policy (CGEP) | USA | James Glynn* | x | |
| Centre of Global Energy Policy (CGEP) | USA | Taiba Jafari | x | |
| VITO-EnergyVille | Belgium | Pieter Valkering * | | x |
| VITO-EnergyVille | Belgium | Andrea Moglianesi | | x |
| VITO-EnergyVille | Belgium | Marco Sanchez | x | |
| VITO-EnergyVille | Belgium | Negar Namazifard | x | |
| Chalmers University of Technology | Sweden | Erik Ahlgren* | | x |
| Chalmers University of Technology | Sweden | Kushagra Gupta | x | |
| Ricerca sul Sistema Energetico (RSE) | Italy | Maria Gaeta | x | |
| Ricerca sul Sistema Energetico (RSE) | Italy | Fabio Lanati | x | |
| Paul Scherrer Institute (PSI) | Switzerland | Lidia Stermieri | x | |
| Institute for Energy Technology (IFE) | Norway | Kristina Haaskjold | | x |
| Institute for Energy Technology (IFE) | Norway | Pernille Seljom* | | x |
| Institute for Energy Technology (IFE) | Norway | Eva Rosenberg | | x |
| Institute for Energy Technology (IFE) | Norway | Stine Fleicher Myhre | | x |
| Institute for Energy Technology (IFE) | Norway | Miguel Chang | | x |
| Institute for Energy Technology (IFE) | Norway | Lars Even Egner* | | x |
| Institute for Energy Technology (IFE) | Norway | Mari Lyseid Authen | | x |
| **Total** | | | **16** | **13** |

## Definition of energy behaviour

To have a common basis for the discussions, the participants discussed the definition of energy behaviour that is to be used in this project.

This is what the group discussed and agreed upon:

**Energy behaviour** is the set of **actions** of individual actors and organisations that, collectively, influence the consumption and production of all forms of energy.

**Actions** are taken by actors across society, including those in households, commercial organisations, finance industry, the energy industry, the public sector, etc.

**Actions** can be direct (e.g. turning on a thermostat) or indirect (e.g. granting planning permission for new energy infrastructure to be built)

**Energy behaviours** can be viewed at the individual level (e.g. with behavioural economics) and at the collective level (e.g. social practice theory, consumer theory).

**Energy behaviours** in the real world are driven by a combination of many different factors, including cost of purchase, cost of running (energy), equipment control, sense of safety, ownership model, trust in technology, social norms, convenience, and others.

## Energy behaviour in TIMES energy system models

Prior to the WS, all participants provided a short-written reply of the following questions/ survey. The participants were also asked to address these in the presentation of the workshop.

How does your TIMES model(s) consider the following behavioural aspects related to:

- Acceptance of investments in energy supply and infrastructure?
- Adaption/ investments of demand technologies and energy efficiency?
- Use/ operation of demand technologies?

The questions were inspired by (Huckebrink and Bertsch, 2021), that is a review paper on addressing behavioural aspects in energy system models.

It is a common understanding among the participating modelling teams that energy behaviour is highly uncertain in the long-term. Consequently, assumptions related to various outcomes of energy behaviour is often considered as a part of different scenarios/ storylines/ futures that is used in long-term analysis. For example, from the survey VTT states that "The behavioural aspects have mainly been considered by creating different storylines, which reflect people's norms, values, social and cultural changes, etc." and RSE writes "Behaviour assumptions are in most cases included to our TIMES_RSE model, as a part of the scenario description, and highly depends on the analysis that is conducted". This implies that the assumptions made related to energy behaviour often depends on the context of energy system analysis and needs to be continuously updated with time and scope of the analysis.

The parameters that have been adjusted to consider energy behaviours differs between the TIMES modelling teams. A summary of used modelling assumptions that are adjusted to consider energy behaviour is shown in Table 2.

Several modelling teams include assumptions related to **acceptance** of energy supply and infrastructure, such as wind power expansion and Carbon Capture and Storage (CCS). UCL models acceptance of different technologies using a range of dynamic constraints that represent how fast technologies can be adopted, which are derived from several different phenomena including behaviours, innovation, R&D, etc. For bioenergy, acceptance reflects different trends in expected levels of land use conversions to energy crop production.

The **adoption** of end use technologies that depends on energy behaviour involves building applied PV, stationary batteries, and energy efficiency measures, such as building mass upgrades. Related to **use** of end-use technologies, it is primarily different assumptions of flexible end-use demand, like flexible EV charging that is used to reflect energy behaviour. Technology preference is included in UCL transport scenarios by setting market shares for smart vehicles; these shares could be interpreted as individual preference on the consumer side just as easily as they could be related instead to policy mandates.

Among the modelling teams, assumptions related to energy behaviour is often included as a part of the energy service **demand projections**, that is a model input. For example, the residential energy service demand depends on number of people living in a building, area of new buildings and type of new buildings, apartments or single-family houses and preferred comfort level. Another example is the personal transport demand, that depends on driving lengths and the rate of modal shifts to more public transport, walking and cycling. UCL use demand projections in projects looking at lower energy demand futures, such as using sector-based models to assess quantified changes in sectoral demand drivers that are then adopted in the UK TIMES model.

The end-use technologies that are used to meet the energy service demand is also assumed to depend on energy behaviour. Using **hurdle rates**, that is technology specific discount rate, is commonly used to reflect the return of an investment from an end-use perspective. The hurdle rate for end-use technologies is often set higher than the global discount rate of the energy system model as it is assumed that end-users require a higher return on the investment to invest in a technology. A consequence of using a higher hurdle rate is that technologies with a low investment cost and high operational costs are favoured over technologies with high investment cost and low operational costs. UCL uses hurdle rates across all sectors and across different technology levels, not just for energy demand end use.

There are also other assumptions that reflect specific preferences on end-use technologies in some teams. This is either modelled by e.g., availability factors or market shares.

Table 2: Overview of used TIMES modelling assumptions related to energy behaviour.

| | UCC | Chalmers | UCL | GCEP | VTT | VITO | PSI | IFE | LTU |
|---|---|---|---|---|---|---|---|---|---|
| **Acceptance** | | | | | | | | | |
| Wind power | x | | x | | x | x | x | x | |
| CCS | | | x | | x | x | x | x | |
| Nuclear | | | | | x | x | | | |
| Power grid | | | | | | | x | x | |
| Bio energy | | | x | | x | x | | | |
| **Adoption** | | | | | | | | | |
| Building PV | x | | | | | x | x | x | |
| Stationary batteries | | | | | | x | x | x | |
| Energy efficiency | x | x | | | | x | x | x | x |
| Heating Technologies | x | x | | | | x | x | | |
| **Use** | | | | | | | | | |
| Flexible EVs | | | | | | x | x | x | x |
| | | | | | | | | | |
| | | | | | | | | | |
| **Demand projections** | | | | | | | | | |
| Residential | x | x | x | | x | x | x | x | x |
| Commercial | x | x | x | | x | x | x | x | x |
| Transport | x | x | x | | x | x | x | x | x |
| Industry | x | | x | | x | x | x | x | |
| **Hurdle rates** | | | | | | | | | |
| Residential | | | x | | | | x | x | |
| Commercial | | | x | | | | x | x | |
| Transport | x | | x | | | | x | x | |
| Industry | | | x | | | | x | x | |
| **Technology preferences** | | | | | | | | | |
| Residential | | | | | | | x | | |
| Commercial | | | | | | | x | | |
| Transport | | | x | | | | x | | x |
| Industry | x | | | | | | x | | x |

## Methods for incorporating energy behaviour in TIMES models and scenario analysis.

There are several methods that are used to derive the parameters that represent energy behaviour in TIMES models among the ETSAP members.

**Monte Carlo Analysis** have been done with the ETSAP-TIAM model to explore what parameters that has an impact on the model results and conclusion of analysis. Using a probabilistic distribution of uncertain input parameters enables a focus on the energy behaviour parameters that has a significant impact on the results.

**Stakeholder workshops and dialogue with expert and policy makers** are a common tool to derive input related to energy behaviour in future scenarios. Also, some teams build on large public opinion surveys that reflect for example the willingness and/or ability to invest and take into use new technologies.

Several teams use a **linkage with Agent Based Models (ABM)** to provide assumptions representing the dynamics of energy behaviour among agents in TIMES energy system models. In the ABM model of PSI, the agents select technologies that are used to meet the heat and transport demand, as well as investments of PV. VITO uses ABM to investigate the uptake of PV and batteries in households. IFE is currently developing an ABM model to be bi-directional linked to TIMES in relation to the energy behaviour of building mass upgrade, building applied PV and flexibility of options in residential buildings.

While agent-based models are used to describe disaggregated parts of a system, system dynamics models represent the aggregated system in the form of stocks and flows. There are attempts to **use system dynamics models to represent energy behaviour in TIMES models** in several modelling teams, for example Chalmers, VITO and UCL, but a demonstration and documentation of this is missing. General feedback from these teams is that it is not necessarily straight forward to implement a linkage between a system dynamics model and TIMES energy system models.

Another possible approach is to use a **Discrete Choice Experiment (DCE)**, that is a quantitative technique for eliciting individual preferences. VITO is currently experimenting on how to use insights from DCE to provide TIMES input on e.g., the adoption of smart EV chargers and the provision of EV charging flexibility. In the current model, EV charging flexibility is an optimization option ‘free of charge’ once the smart charging capacity is invested in. Individual consumers will likely require a monetary incentive (via dynamic tariffs or flexibility contracts with aggregators) to provide that flexibility. This remuneration can be considered as a system cost that can be approximated (despite the high uncertainty) with DCE and can be used to run sensitivity cases.

## Suggestions for way forward

The participants agreed on that it was useful to receive some questions/ survey prior to the workshop, both for preparation reasons and because it enables a thread of the presentations and discussions. For the next Workshop, it was therefore decided to give some kind of “homework” to the participants. Also, it was discussed that it could be beneficial to narrow down the topic of the next workshop.

## Workshop 2: Main challenges

The Workshop had 30 participants from nine different institutes/ universities located in eight different countries as shown in Table 1. The names that are marked with a star, *, were the presenting to initiate discussions among the participants.

Table 3: List of participants Workshop 2.

| **Institute/ University** | **Country** | **Name** | Digital | Physical |
|---|---|---|---|---|
| Luleå University of Technology (LTU) | Sweden | Anna Krook Riekkola* | | x |
| University College Cork (UCC) | Ireland | Olexandr Balyk | | x |
| University College Cork (UCC) | Ireland | Hannah Daly | | x |
| University College Cork (UCC) | Ireland | Ankita Gaur | x | |
| University College Cork (UCC) | Ireland | Andrew Smith | x | |
| University College Cork (UCC) | Ireland | Vahid Aryanpur | x | |
| University College Cork (UCC) | Ireland | Brian O Gallachoir | x | |
| University College Cork (UCC) | Ireland | Francis Li | x | |
| University College London (UCL) | UK | Rachel Freeman* | x | |
| VTT Technical Research Centre | Finland | Tiina Koljonen | x | |
| VTT Technical Research Centre | Finland | Antti Lehtila | x | |
| Centre of Global Energy Policy (CGEP) | US | James Glynn | | x |
| Centre of Global Energy Policy (CGEP) | US | Kathryn Longobardi | x | |
| Centre of Global Energy Policy (CGEP) | US | Lewis Wu | x | |
| Centre of Global Energy Policy (CGEP) | US | Zhiyuan Fan | x | |
| Centre of Global Energy Policy (CGEP) | US | Emeka Ouchu | x | |
| Centre of Global Energy Policy (CGEP) | US | Taiba Jafari | X | |
| Centre of Global Energy Policy (CGEP) | US | Chris Bataille* | x | |
| Centre of Global Energy Policy (CGEP) | US | Nicolo Daina | | x |
| VITO-EnergyVille | Belgium | Pieter Valkering | x | |
| Chalmers University of Technology | Sweden | Kushagra Gupta | x | |
| University of Stuttgart (IER) | Germany | Markus Blesl | | x |
| University of Stuttgart (IER) | Germany | Drin Marmullaku | | x |
| University of Stuttgart (IER) | Germany | Felix Lippkau | | x |
| Danish Energy Agency (DEA) | Denmark | Simon Andersen | | x |
| University of Geneva (UNIGE) | Switzerland | Roman Kanala | x | |
| Institute for Energy Technology (IFE) | Norway | Pernille Seljom | | x |
| Institute for Energy Technology (IFE) | Norway | Kristina Haaskjold | | x |
| Institute for Energy Technology (IFE) | Norway | Eva Rosenberg | | x |
| Institute for Energy Technology (IFE) | Norway | Kari Espegren | | x |
| **Total** | | | **17** | **13** |

This WS was designed to facilitate discussions among the participants and to together agree on main challenges related to including human dimensions in energy system models.

The following ten key issues were identified in the WS related to challenges of including human dimension in energy system models.

1. **The importance of modelling behaviours**: how much does it matter for the usability of model outputs, their believability and validity; how accurate does modelling of behaviours need to be?
2. **Model paradigm:** Optimisation model paradigm provides a normative analysis (answering the question "what is our best course of action, considering the goals and resource constraints"), while simulation model paradigm provides a descriptive analysis (answering the question ""what will happen if sector A do X, Y and"). Nevertheless, optimisation models can be constrained to instead explore what-if scenarios, and by introducing a large set of scenarios to the simulation model if can support the identification of optimal pathways. How does the model paradigm relate to the ability to model energy behaviours? When is model linking a good solution (e.g. multi paradigm view), and when is it worth the effort?
3. **Structural factors influencing behaviours**: societal capacity for energy transition; democracy, social hurdle rates; how collective behaviours might change from interventions and whether this should be included in modelling.
4. **Actor agency**: Behaviours when modelled can focus on what actors do, but changing behaviour is not always and necessarily a choice for individuals; can and should this be included in modelling to represent heterogeneity in actor agency.
5. How do **direct and indirect behaviours** differ in terms of how they change and how their actions play out in the energy transition. An indirect action such as banning cars in city is a behaviour from a lawmaker – what are the drivers and barriers to indirect actions and should policy makers be represented in TIMES.
6. **Long and short-term behavioural changes**: at what rate will behaviours change, how long does it take for interventions to work in the real world and how to model that. Behaviours in energy demand can improve (lower demand) and then get worse (increased demand) later, often linked to economy. How to represent the unreliability of behavioural change in energy service demand.
7. **Realistic constraints for models**: constraints with cost-optimal solutions, constraints that represent realism about behaviours in the short term, how to set the constraints quantitatively from qualitative data.
8. **Purchasing behaviour influence on demand**: How much purchasing behaviours affect energy services demand (e.g. autonomous vehicles may increase or decrease travel)
9. **Uncertainty in services demand**: What is the future demand for energy and goods. Forecasting demand for the service sector is very challenging but will affect energy demand. How are behaviours impactful on services demand.

10. **Actor priorities and alignment with climate change**: People are often more interested in energy security rather than climate change; local environments matter to people (e.g. BANANA, NIMBY); business want to make money; how to include these observed factors in models.

The identified issues address both challenges related to modelling methodology and on how to communicate modelling results.

## Modelling of energy behaviour

There were several aspects related to modelling of energy behaviour that was discussed in the WS. A first topic for clarification was that considering energy behaviour in energy system models can be very different things, from changing input parameters, modifying the Reference Energy System (RES), and by changing the methodology. Second, when including behaviour in the models, energy system models tend to go from optimization to simulation. This can lead to that models are driven by constraints rather than optimization to reflect feasible pathways. This can contribute to non-transparent and messy models, and a challenge related to communication of results. Furthermore, since the energy behaviour is uncertain in the long-term, it is important to also run the models without too much of today's reality. It is an option to incorporate behaviour for the first periods and thereafter assume economic rational choices.

## Communication of modelling results

Throughout the WS, the communication of modelling results was put on the agenda. The participants agree that it is important to explain limitations of your model, without reducing confidence. It is a need to highlight model strengths and not only the weaknesses. Although there is a lot of uncertainty in the assumptions and methodology related to addressing energy behaviour, it can be dangerous to communicate this as a weakness of the models. A strength of the TIMES modelling framework is particularly that we can quantify the effect of different energy behaviour.

Another challenge that was addressed, included how ETSAP members can communicate in a political-neutral manner. This can for example be challenging when we analyse demonstrate that current policy is insufficient to reach targets. For example, to quantify that behavioural change related to energy efficiency improvements is required to meet ambitious climate targets. It was questioned if the modelling community is keeping up with the current need from policy makers. Analysis based on energy system models are designed to inform our thinking and can be communicate in such a way that it can also inform the thinking of policy makers.

## Workshop 3: Best modelling practices

The workshop had 18 participants from 10 different institutes/universities located in 11 different countries as shown in Table 4. The names that are marked with a star, *, were the presenting to initiate discussions among the participants.

Table 4: List of participants Workshop 3.

| Institute/ University | Country | Name | Digital | Physical |
|---|---|---|---|---|
| Luleå University of Technology (LTU) | Sweden | Anna Krook Riekkola | | x |
| Luleå University of Technology (LTU) | Sweden | Jonas Forsberg | | x |
| Luleå University of Technology (LTU) | Sweden | Carina Lundmark | | x |
| Luleå University of Technology (LTU) | Sweden | Parvathy Sobha | | x |
| University College Cork (UCC) | Ireland | Ankita Gaur | x | |
| University College London (UCL) | UK | Rachel Freeman* | | x |
| University College London (UCL) | UK | Steve Pye* | x | |
| VTT Technical Research Centre | Finland | Tiina Koljonen | x | |
| VTT Technical Research Centre | Finland | Antti Lehtila | x | |
| Centre of Global Energy Policy (CGEP) | US | James Glynn | | x |
| VITO-EnergyVille | Belgium | Pieter Valkering | | x |
| Chalmers University of Technology | Sweden | Kushagra Gupta | x | |
| University of Geneva (UNIGE) | Switzerland | Roman Kanala | x | |
| Institute for Energy Technology (IFE) | Norway | Pernille Seljom | | x |
| Institute for Energy Technology (IFE) | Norway | Kristina Haaskjold | | x |
| Institute for Energy Technology (IFE) | Norway | Eva Rosenberg | x | |
| Ricerca sul Sistema Energetico (RSE) | Italy | Nsangwe B. Corine | x | |
| Paul Scherrer Institute (PSI) | Switzerland | Lidia Stermieri | x | |
| **Total** | | | **9** | **9** |

The participants voted for the four most important topics of the ten issues that were raised in WS2. The topics that were prioritised to focus on was:

1. **Realistic constraints for models**: constraints with cost-optimal solutions, constraints that represent realism about behaviours in the short term, how to set the constraints quantitatively from qualitative data.

2. **Model paradigm**: Optimisation models are normative and simulation models are descriptive; constraining optimisation models can lead to model producing (theoretically) feasible pathways. How does the model paradigm relate to the ability to model energy behaviours. When is model linking a good solution (e.g. multi paradigm view), and when is it worth the effort?

3. **Structural factors influencing behaviours**: societal capacity for energy transition; democracy, social hurdle rates; how collective behaviours might change from interventions and whether this should be included in modelling.

4. **Long and short-term behavioural changes**: at what rate will behaviours change, how long does it take for interventions to work in the real world and how to model that. Behaviours in energy demand can improve (lower demand) and then get worse (increased demand) later, often linked to economy.

A conclusion from the discussions is that behaviour will change, and that it is thus a need to be transparent on the assumptions. This includes the behaviour of policy makers that is coloured by people's opinion. The energy behaviours of policy makers can for example influence the license processes of renewables. Further, there are many things that are input parameters in the models that are directly and indirectly related to behaviour. Also, there is a certain behaviour of the energy system modeler itself, that can influence the used model assumptions. There can be a distance between what is in peoples head and what is reality.

From a modelling perspective several methods for incorporating energy behaviour in TIMES models were discussed.

- One way to consider behaviour is to use **socially accepted potentials** instead of technical potentials as input to the model.
- Another option is **soft-linking TIMES models with other sectoral models** that include more behavioural assumptions. Such an approach can involve assumptions related to rebound effects.
- Rebound effects can be included by adding a **negative price elasticity**. When the price for energy services is low, the energy service demand can increase.
- **Linking TIMES models with Agent Based Models (ABMs)** is an option to include an adoption strategy of technologies that includes also non-economic component.
- The behaviour constraints depend on whether the analysis is **policy related or research-based** Modelers need to rethink on what is political feasible, what are the market constraints, what is acceptable, what is practical and so on for very model run.
- There is a need for new research from **social scientists to form assumptions** related to behavioural constraints in energy system models. However, so far, it has been limited on how social science can contribute with regards of long-term behavioural changes.

It was also a discussion on if it is possible to both have cost optimal and realistic models. Energy system model is designed to explore least cost pathways, and there is in most cases a difference in what people can do versus what people do.

## Proposed further work

It is needed a more systematic assessment of the uncertainty of the demand side in energy system models with respect to energy behaviour. This work can build on this WS series and be a further collaboration between several ETSAP members. One relevant topic is the feasibility of Low Energy Demand scenarios that presupposes large societal change.

## References


DeCarolis, J., Daly, H., Dodds, P., Keppo, I., Li, F., McDowall, W., Pye, S., Strachan, N., Trutnevyte, E., Usher, W., Winning, M., Yeh, S., Zeyringer, M., 2017. Formalizing best practice for energy system optimization modelling. Applied Energy 194, 184-198.

Dubois, G., Sovacool, B., Aall, C., Nilsson, M., Barbier, C., Herrmann, A., Bruyère, S., Andersson, C., Skold, B., Nadaud, F., Dorner, F., Moberg, K.R., Ceron, J.P., Fischer, H., Amelung, D., Baltruszewicz, M., Fischer, J., Benevise, F., Louis, V.R., Sauerborn, R., 2019. It starts at home? Climate policies targeting household consumption and behavioral decisions are key to low-carbon futures. Energy Research & Social Science 52, 144-158.

Huckebrink, D., Bertsch, V., 2021. Integrating Behavioural Aspects in Energy System Modelling—A Review. Energies 14, 4579.

McDowall, W., Geels, F.W., 2017. Ten challenges for computer models in transitions research: Commentary on Holtz et al. Environmental Innovation and Societal Transitions 22, 41-49.


## Pictures from meetings and social events