INTERNATIONAL ENERGY AGENCY (IEA)

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

Topical Expert Meeting (TEM) #113 on

Net Zero Electricity System Studies

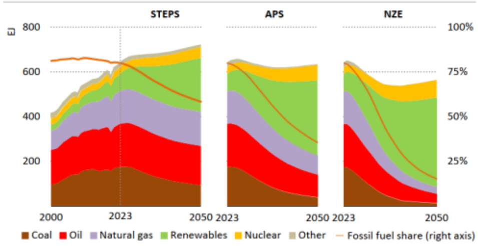
IEA Wind Task 11

April 8–9 2024

Sustainable Energy Authority of Ireland (SEAI), Camden Court Hotel

Dublin, Ireland

Figure 3.1 ▷ Global total energy supply by source and fossil fuel share by scenario, 2000-2050



Each fossil fuel peaks by 2030 in all scenarios and then declines over time as renewables and other low-emissions sources of energy increase strongly

Notes: EJ = exajoules; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Renewables includes modern bioenergy. Other includes the traditional use of biomass and non-renewable waste.

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Executive Summary of TEM#113

Introduction

The concept of Net zero has become central to discussions of climate change and energy transition. The term refers to achieving a balance between the greenhouse gases emitted into the atmosphere and those removed or offset. To achieve our net zero objectives, it is crucial to accelerate the required changes across all sectors of the economy, including electricity, industry, transportation, and building sectors.

One of the primary ways for countries to work to achieve climate change ambitions has been to set targets for achieving net zero emissions. While details vary, most net zero plans involve significant reductions in the use of fossil fuels and the adoption of variable renewable energy (VRE), for example, wind and solar. From a wind perspective, it is important that we encourage the use of well-defined wind cost, performance, and value assumptions and discuss related issues, needs and solutions. Topical Expert Meeting (TEM)#113 on Net Zero Electricity System Studies aims to facilitate information exchange and discussion among the experts working in net zzero system modelling and analysis.

Meeting overview

TEM#113 was hosted by SEAI in Dublin city center on 8–9 April 2024. At the meeting, experts from diverse disciplines presented their research, expert insights and experience on a range of subjects, including:

- Energy and power system modelling, including coupling;
- Power and transmission system planning and operation;
- Power system reliability, flexibility and stability;
- Resource adequacy;
- Long duration storage vectors (including hydrogen, e-fuels and heat);
- Meteorological and spatial influences upon generation and demand over various timescales;
- Economics;
- Open-source modelling tools;
- Transboundary imports of fuels and materials; and
- Technological and investment uncertainty and risk.

Following the expert presentations, two topical breakout sessions were held on

State of the Art and Knowledge gaps and research and development (R&D) topics.

For each of the above topics, four individual breakout groups focused on:

- The role of wind energy in the net zero electricity system;
- Power system modelling for net zero;
- Communication on net zero studies; and
- Energy system modelling for net zero.

Each group reported the primary outcomes of their discussions to the other groups. A final common session drew together priority recommendations for future action.

Main results of TEM#113

The main points from the breakout sessions of IEA Wind TEM#113 are summarized below (as the main results of the workshop).

The role of wind energy in the net zero electricity system

The role of wind in net zero studies depends on assumptions made about competing and enabling technologies and flexibility in the future system, as well as the development of these technologies. The value of wind energy should be considered more broadly; however, modelling and quantifying value remains a challenge. A focus on aspects of resilience is a new area for wind technology. Points discussed included:

- The benefits of wind technology, which include the provision of short-term balancing, supporting stability (grid support services) as well as long-term resource adequacy (to some extent). As a technology, it is modular and relatively fast to deploy.
- Its deployment limitations, which come into play at higher amounts of energy: saturation will take place in some areas, as site availability decreases and market value declines. Social acceptance and environmental impact also present challenges and supply bottlenecks may impact the availability of materials. Ultimately, power systems dominated by wind (and solar) need to evolve to manage very low inertia and the need for flexibility (especially in the long term).
- A net zero power system based on non-synchronous wind and solar generation has very different technical characteristics compared to existing power systems dominated by synchronous generation (based on fossil fuels, hydro and/or nuclear). This has major implications for the stability and operating rules of the power system.

Knowledge gaps identified included:

- The value of wind;
- The extent of externalities from wind in future scenarios when scaling up;
- Longer predictability periods; and
- Market design.

R&D topics identified and prioritised included:

1. The value of wind;
2. Scenario validation, including pathways and reality checking; and
3. Market design.

Energy system modelling for net zero

Specific improvements to current model tools are needed, including:

- Modelling process needs include multi-sector data, workflow management (including automatic pipelines all the way to charts), and scenario management;
- Best practices include integrating all elements into one model (the tradeoff here is computational time) or soft coupling of models (something that is hard to achieve);
- Sensitivity analyses should include uncertainties of input data. Best practices include data transparency and good documentation;
- Modelling time: time resolution is key. Best practice includes consideration of many years on (sub-) hourly basis;
- Modelling networks: include all key physics processes (for example, heat flows, power flowsetc.); and

- Improving computational speed: focus on parallelisation (running scenarios in parallel), data efficiency (removing components not used by the model), and code improvements.

Knowledge gaps include:
  - Reliable data (for example, on transmission system, industry assets);
  - Consolidation of tools—data input and output (standard structures would assist benchmarking);
  - Power system expertise is missing from energy system studies, with implications for the usefulness of the results obtained;
  - Push back against deployment of technologies (societal acceptance, environmental issues);
  - Negative emission asset needed to help the final 10% integration of variable renewables, but it is still unknown technology; and
  - Solver performance.

R&D topics:
  1. Modelling results for inputs for decision makers—modelling should be useful for setting policy.
  2. Decisions about what technologies to use —consider end user transitions (for example, industry and transport, amongst others).
  3. Uncertainties and how to make resilient choices. Data exchange, model interoperability.

Power system modelling for net zero

- Net zero studies typically do not check network power flow or stability considerations, and there is no (or limited) iteration or feedback from these analysis stages to policy and market planning.
- Modelling complexity of new technologies is unresolved, particularly dynamic models.
- Regional and (sub-)hourly time scale analysis are needed.
- The distribution grid is generally not modelled.
- All technologies are assumed to be always available and deployable (no outages or maintenance)

It is proposed to actively include experts at different stages to check modelling results, as an indirect way to validate model results. In power systems, timescales are key, ranging from microseconds to seconds and hours, and much longer. Questions should be asked regarding how they will respond for the relevant timescales.

Knowledge gaps:
  - 100% inverter-based resource (IBR) systems are still a relatively new research topic; it is not clear how best to model and analyse such systems and to predict what individual technology solutions can best offer in the future.
  - Electro-magnetic transient (EMT) modelling is still at a relatively early stage, with limited knowledge of (power electronic) control systems; it represents a very high computational burden for large systems. However, it is critical to ensure correct understanding of power systems with very high IBR (wind and solar) shares.
  - We lack screening processes to identify the scenarios of greatest interest and concern. Too many scenarios are difficult to process, though there is potential for AI techniques to lessen the burden.

- Distribution networks are ignored in most system studies due to a lack of data, while challenges to recognising temporal and spatial correlations between wind/PV/load at individual network nodes remain. Distribution system upgrade costs (associated with electrification of heat and transport sectors, as well as distributed generation) will be high, but it's not clear how best to include such aspects while not exploding the computational burden. Nodal prices for Ancillary Services (AS) are not considered, even if energy prices are locational. AS locations have not been considered in sufficient detail.
- Offshore, DC grids and offshore hubs, including their operation and protection, are emerging.
- Best practices are not available on how to best model, analyse, and operate net zero systems.

R&D topics:

1. Distribution level is to be included in system modelling tools.
2. Operation of 100% wind/PV system, including stability and EMT modelling.
3. Screening processes, how to decide what to represent, and with what level of detail, linking with system security considerations.

Electricity markets

There are several key factors to consider when it comes to the evolution of electricity markets to enable a net zero carbon future. These include:

- Stakeholder interactions and feedback should be evaluated.
- Better cost estimates for future projections should be provided.
- The various uncertainties regarding sets of scenarios should be considered; for instance, what is the likelihood or relevance per scenario?
- Social acceptance must be considered; for example, what is the right level of result? Results should be shaped to fit the audience.
- Electricity markets could consider including incentives for investments. European markets do not have locational signals for new investments.
- Sufficient financing and offtake. Open questions remain around Power Purchase Agreements (PPA) vs. contracts for difference (CFD) vs. merchant contract structures, Government vs private mixes.
- Industrial consumer collocation with H_2 generation should be considered.
- Risk sharing; how should this be done and how does it translate to a cost? Back up generation is needed, but it is unclear how to allocate the cost.

R&D topics:

- The cost of not building infrastructure, for example, transmission; evaluating the cost of social acceptance.
- Market design/auction design for long-term investments, risk sharing, how CFD affects markets.
- Spatial development implications of net zero, including human geography, industry, and environmental dimensions.

In all cases, the outputs of R&D should be useful to policy.

Summary of presentations

The information in this section provides an overview and selected highlights of each of the methodology snapshots provided during TEM#113.

All TEM#113 meeting material is available on the IEA Wind website. Access to download the material can be requested from the Task 11 Operating Agent.

Day 1, 8 April 2024

TEM#113 public session: Net zero Power System Studies

Abbas Rabiee, Laval University, Canada. A review of global net zero electricity and energy system studies

An overview of existing modelling approaches was presented. Consideration was given to different categories, including the electricity system, the energy system and the whole economy, as well as land use related to sinks and emissions. There is significant uncertainty surrounding the economic and operational viability of some potential net zero technologies, such as carbon capture storage (CCS). It becomes clear that supply chains for variable renewables play a key role, as does grid planning, stakeholder engagement and market reform.

Craig Hart, IEA, France. IEA global net zero assessments

A presentation of work carried out by IEA on the generation of net zero scenarios and analysis, both on a global scale as well as more detailed regional clean energy studies for Indonesia, China and India (based on public documents available on IEA web site). World Economic Outlook (WEO) team modelling for global scenarios show residual emissions for 2050 balanced by atmospheric removals. Tripling of renewable energy sources by 2030 and doubling of nuclear by 2050 are seen, with grid investments doubling.

Antje Orths, Energinet, Denmark. Net zero planning in Denmark and at a European level ENTSO-E

Energinet is considering both electricity and gas transmission infrastructure in their planning activities; they have also become the system operator for hydrogen infrastructure in Denmark. Potential hydrogen infrastructure needs have been a focus for initial studies, with the physical interaction between electricity and hydrogen and market implications also considered, as well as other relevant factors. The modelling process for both electricity and hydrogen considers production, infrastructures and consumption and is run with a higher granularity than traditional studies. Initial model runs for Denmark show that hydrogen infrastructure reduces the need for electricity infrastructure.
ENTSO-E scenarios show increasing uncertainty for more distant time horizons, with the scenarios complying with EU 2030 and 2050 goals. In 2024, ENTSO-E scenarios include future demand modelling with innovations on hydrogen, EV, offshore, expansion and heat. The key focus of innovation activities relates to sector integration, which perfectly reflects the ENTSO-E vision for a carbon neutral EU; the vision is based on energy system flexibility, operating future grids, energy infrastructure investments and market design.

Andrew Smith, UCC, Ireland. UCC net zero energy system modelling for Ireland

TIMES-Ireland Model (TIM) shows that projected demand in 2030 ranges from 30 TWh to 60 TWh. The deployment rates are very high for wind energy during this decade, especially for offshore. Constraints have been identified with PLEXOS. Offshore wind has a positive impact on the grid in terms of stability, due to a better duration curve and broader spatial deployment.

The more we delay decarbonisation, the more aggressive the reductions needed at a later stage. In general, TIM modelling can help to identify optimal pathways to decarbonisation across sectors, but models cannot answer certain questions. For example, who should pay for what? What policies should be implemented? How do we solve conflicts relating to land use and food, grid stability issues and infrastructure development? Wind energy production correlations studies require a broad enough spatial scale; negative correlations have been found in Ireland when considering distances larger than 2000km.

Eamonn Lannoye, EPRI, USA. Net Zero 2050: US economy-wide deep decarbonisation scenario analysis

The US study included primary energy, conversion, storage, delivery, and energy end use. CO_2 emissions reductions were considered by US sectors (power, transport, industry and buildings), and scenarios considering all options, higher fuel costs and limited options cases were generated, leading to significant changes in the role of renewables, nuclear or carbon capture.

Clean electricity, efficiency and electrification are key: net zero is a demand side story as much as a supply side story. As electricity dependence increases, power system reliability also becomes increasingly important. Grid modernisation and technology advancements are needed. Choosing the right low carbon technologies and amplifying their value will help us on the path to decarbonisation, as low carbon fuels will help to reduce gaps. Gas infrastructure will play a role. Customer adoption focus will be crucial. Implementing energy transition shows a need for significant changes, as well as methodology/model tool development.

Jonathan O'Sullivan, ESB, Ireland. Lessons from Ireland for Net Zero Energy System

Changes to Ireland's generation mix have been rapid in recent years, with an increased role for wind energy; looking forward, the role of wind will be much larger. ESB is focused on achieving net zero, but there are evolving challenges facing the market, connection, uncertainties, electromagnetism, reserves and adequacy. Seasonal storage becomes critical, even at a European scale. A system based on a high share of renewables requires stage 5 operation, while keeping the same amount of reserves; ramping capabilities are increased as adequacy should be guaranteed even without wind. What technologies can we plan, dispatch and schedule? Solid principles for investments are needed, with the right allocation of risks and a proper market design. The main risks are oversupply, constraints, and curtailment.

Juha Kiviluoma, VTT, Finland. Impact of sector coupling on the cost efficiency of net zero carbon energy systems

Electricity demand is expected to grow significantly, but how flexible can that demand be? An analysis of different storage options (from seconds to years) and their economic viability has been completed; it shows technologies, such as pumped hydro, fuel systems or large-scale thermal storage, having a broad competitive profile in different timescales, while battery potential is focused on shorter timescales. Analysis on managing seasonal and inter-annual variability of renewables in reference systems (drawing on a report by IEA and VTT) was also presented. Thermal plants are an important source of flexibility in high VRE systems. Hydro power plants drive inter-annual variation in the continental reference system. Inter-annual variation can be met with legacy thermal capacity. A work on electrofuels (EF) by VTT analysed multiple EF pathways, showing a threefold increase in electricity demand when EF are developed. Some regions (for example, equatorial) require EF imports, while in other areas hydro reservoirs reduce the need for other storage (for example, EF).

Hannele Holttinen, Recognis, Finland. Task 25 presentation. Design and operation of energy systems with large amount of renewable energy

High-level challenges include stability and short-term and long-term balancing from seconds to years. In the road towards 100% renewable energy solutions, the first challenge is balancing; stability issues come into play at a later stage. During the last stage on the journey to reach 100%, it is key to focus on adequacy. Modelling gaps today focus on reliability, flexibility and stability at the same time; there is also a clear need to consider sector coupling and weather dependency. Task 25 recommended practices for wind/solar integration studies contain many modelling and data recommendations that are also relevant to net zero studies. An updated RP16 Ed.3 will be submitted to the IEA Wind review process by summer 2024.

Fabian Neumann, TU Berlin, Germany. Co-Production of long-term decarbonisation plans

In this presentation, PyPSA (Python for Power System Analysis) Europe net zero modelling results were provided. The work considered both power and hydrogen networks, focusing on the benefits of the combined approach. The modelling approach considers demand (including heating and transport) as well as supply aiming at cross-sector optimisation. In Europe, 200 regions were considered; results point at the minor role of hydrogen as power backup, with that role mainly connected to transport (shipping and aviation) and chemicals. Hydrogen can also play a role as intermediate buffer between VRE and power to X. When considering the global market, cost reductions are possible if imports of different vectors are taking place (for example, fuels or materials). Europe could benefit from cost reductions up to 14% when considering steel, MeOH and H2 international imports. Socioeconomic factors must be considered in relation to international exchanges.

TEM#113 Q&A topics

- Security of supply will be achieved through a diversified supply, without overly relying on a single source. Reliability and resilience are key areas for improving system modelling and scenario building.

- Biodiversity requires a continuous focus on learning and information gathering , as well as data on the technology deployment impacts on biodiversity. This is currently a priority area of focus for research on IEA Wind collaboration (Task 34).

- Heat storage is currently the cheapest storage option that can also provide support services to the electricity grid. District heating is the most effective and efficient approach at large scale for heat storage.

- If the market does not support the right investments today, we will not be able to operate a future system with a very high renewable energy share. Overcapacity, curtailment and negative prices are the main threats to the green transition.

TEM#113 closed session

Jody Dillon, Energy Reform, Ireland. Spine H_2 Ireland. Review of open-source tools for energy system modelling

There is a clear need for open-source, validated modelling tools for the energy system. In this session, tools designed to study the role of H_2 in the Irish energy sector were presented. The focus should stay on the development of models for scenario building, keeping in mind different communities of users. A case study was presented for Ireland that modelled energy networks (electricity and H_2) and analysed flexibility and reliability scenarios. Results included analysis of different storage options for H_2 and options for investments in H_2 transportation.

Damian Flynn, UCD, Ireland. Operational and stability impacts of VREs in power systems

Existing synchronous powerplant have been providing crucial services on top of electricity generation; displacing them requires finding alternative solutions. The system of the future will require new and faster services as new problems emerge (for example, detection of faults and system restoration). New operational constraints that require new (or faster) solutions (for example, ramping and maximum rates of frequency changes) must be considered. Looking forward, a broader scope of events should be considered in the modelling work. Consideration of load and supply locations should be included in the models. Power system reliability and security must be maintained in all cases. There are no “magic” solutions— we need to look at problems collectively, not individually, to find optimal solutions. Moving to zero carbon system services is possible but requires the right incentives to be activated. Introducing new single points of failure such as smart grids communications must also be avoided (for example, we must avoid reliance on very fast comms).

Gianni Goretti, ESB, Ireland. Independent and reliable energy system with green hydrogen

In this session a Net Zero ESB scenario was presented, which included an annual load of 88 TWh, RES-based, no imports and storage based only on H_2. In this scenario, how big does the storage capacity need to be? Resilience comes at a cost; scenarios point at increasing from 17 GW to 22 GW offshore wind capacity for Ireland to ensure resilience). Planning should consider potentially difficult years and not just average conditions; for instance, the 2010 extreme low wind year is seen as depleting H_2 storage for almost 20 years of data.

Magnus Korpas. NTNU, Norway. Optimal mix and dispatch of resources in low carbon energy systems

This session focused on H_2 demand. H_2 flexibility can increase the value of solar and wind generation, but it requires extensive amounts of affordable and available underground storage for H_2. The Texas case study showed optimal capacity developments calculated as a function of CO_2 price. Flexible H_2 reduces price variations, supports system stability and can reduce CoE. Impact of batteries for optimal RES mix. Optimization should be considered for a long period (for example, 30 years). In terms of pricing in thermal systems with RES and energy storage, how does storage influence the prices? The value of stored energy is uncertain; demand side flexibility can play a significant role. When considering only RES and storage the equilibrium prices change, short-term prices may not represent long-term costs.

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Madeleine McPherson, University of Victoria, Canada. Interprovincial transmission in Canada

Studies show the benefit of interprovincial transmission expansion projects, which are related to the availability of large storage in some of the provinces. Two cases of province pairs were analysed and two scenarios with and without additional transmission were considered, showing clear benefits in adequacy by adding interprovincial transmission. However, procurement, local political issues and regulation are major obstacles limiting interprovincial exchanges. Incorporating models of transmission expansion planning (proven to work in other countries) may speed up and facilitate the process in Canada.

Matti Koivisto. DTU Wind, Denmark. Wind and solar system integration

Transmission lines are crucial: energy hubs must be integrated into planning. H_2 pipelines offer potential in highly coupled scenarios. Heat and H_2 storage are important sources of flexibility. Novel wind technologies can play a role (such as LowWind designs to stabilise energy production), potentially reducing transmission or storage costs. Hybrid power plants can play a significant role, potentially reducing grid connection and balancing costs.

Ana Estanqueiro. LNEG, Portugal. Methodologies for optimal hybridisation and complementary aggregation of VREs

Hybridisation can improve spatial planning of variable renewables, improving operation and increasing the value. Location for new VRE plants should be based on existing ones, aiming at maximising value. Overplanting with PV gives increased generation and reduced curtailment. For combined wind and PV, optimisation including forecasts gives enhanced operation results (with reduction of forecast errors). Improving the value of VREs can lead to increased profits of 10% and a decreased cost of imbalances in 60%.

Martin Densing. Paul Scherrer Institute, Switzerland. Low dimensional scenario generation method of solar and wind availability for representative days in energy modelling

In this session, the concept of capturing correlation of wind and solar per season was discussed. Simplifying Wind-PV correlation through a limited number of scenarios. Extreme events can also be considered and quantified statistically. Scenarios are built producing distributions of market prices. It’s difficult to select time; is there potential to slice average days that contain all needed information? Chronological models work better.

Philipp Beiter. The National Renewable Energy Laboratory (NREL), US. Expanded modelling scenarios to understand the role of offshore wind in decarbonising the US

Modelling limitations are relevant for deep decarbonisation scenarios. How sensitive is offshore wind to modelling factors? NREL’s Regional Energy Deployment System (ReEDS) model includes high resolution modelling and uncertainties. Clean energy policies expand opportunities for offshore wind. Offshore wind to reach 133 GW to comply with decarbonisation. Growing electrification moves peak demand to winter, which matches offshore wind. Lower costs and fewer technological alternatives favour offshore wind. Transmission alters the competitive landscape for offshore wind. The projected role of offshore wind is expected to be modest (1 to 4% total generation for the US) in the overall picture, but modelling assumptions have a considerable impact on results.

Breakout session notes

Day 2, 9 April 2024

Breakout session 1. State of the art

Group 1: Wind energy's role in the net zero electricity system

The value of wind energy should be considered more broadly, with modelling and quantifying value remaining a challenge. A focus on resilience is a new area for wind technology, with the potential for novel solutions both at wind turbine and wind farm levels. Ancillary services should evolve, expanding the range of services that wind technology can provide. Improving predictability remains an important area for further research. Flexibility needs to be improved both from system and wind technology perspectives. Further industrialisation of wind technology and large-scale electrification (considered the optimal solution when combined with wind energy) will be very relevant looking forward. Co-location of wind with other forms of generation, storage and consumers is crucial. Optimisation of both the operation of VRE plus demand response can lead to significant benefits for the system. Market design will be crucial to enable the investments needed, while system design will also have to evolve to account for all benefits and issues related to renewables. LCA methodologies will require broader consensus, data and ongoing updates.

Group 2: Power system modelling for net zero

Studies do not always properly link policy, plant performance, unit commitment, network power flow and system stability (power flow and/or stability analysis stages are often not implemented). This group examined a proposal that would see experts check modelling results at different stages, as an indirect way to validate model results. Timescales are key to power systems; when new technologies are considered (milliseconds to seconds, hours, days and longer), questions should be asked regarding how they will respond for the relevant timescales. Regional representation of power systems is important (for example, the ability to capture system protection, local flexibility, grid-forming capability, etc.). Today, models generally assume that all technologies are available, reliable and deployable, which is not realistic.

Group 3: Communication on net zero studies

This group looked at a proposal to invite key stakeholders to ask for regular feedback on the studies, with consideration to regional workshops also. Expert consultation informing studies was mentioned as good practice. Known issues on communicating system studies include timings for engagement with stakeholders, and the potential of too much influence wielded by single users. A consultation group case (organised by the Government) was mentioned as a good example, one that resulted in better engagement. Technology characterisation studies can benefit from regular reporting due to technological evolution. Instead of one-off validations, ongoing validations are proposed. How to deal with uncertainty? Scenarios require quantification of the level of uncertainty. Timelines for availability of technologies are needed, together with supply chain development. In terms of social acceptance, what constitutes the right level of resources? Instead of exploring certain questions in high detail, focusing on what the audience wants to know is recommended. Broad market focus, inclusion of carbon tax, focus on power system only vs. economy and society remain key challenges in the modelling.

Group 4: Energy system modelling for net zero

This group looked at the process of modelling and data. Having automatic pipelines from data to results would be desirable. The development of many scenarios would benefit from management tools that would keep information organised. Best practices include integrating as many parameters in one model as possible, instead of coupling different models. Sensitivity analysis and the ability to address uncertainties in input data is desirable, capturing alternative pathways or analysing many scenarios to identify commonalities. Data transparency is key. Modelling time is an issue that calls for flexible model resolution. More than one year and (sub-)hourly time steps are desirable. The selection of the right representative modelling periods should also consider investment-relevant periods. However, too many details can make running models unfeasible. Consistency in the level of detail is important. Correctly including physics in the energy system models is key. Improved computational speed can be achieved through decomposition. Parallelisation can be achieved easily by running scenarios in parallel. Data efficiency can be achieved by checking that no unnecessary data is included, by simplifying the model code, and by reducing the number of variables.

Breakout session 2. Knowledge gaps and R&D topics

Group 1: The role of wind energy in the net zero electricity system

- The benefits of wind technology include the provision of short- and long-term adequacy to some extent. Wind energy generation is also predictable to some extent; wind technology supports stability to a degree, is quick to deploy and modular.
- Deployment limitations. There is saturation in some areas due to factors like site availability, market value, etc.
- Wind technology limitations: inertia, materials bottlenecks, limited knowledge of acceptance and environmental impact, limits on flexibility, lack of well-established LCA methods.
- The role of wind in net zero studies depends on the assumptions/development of competing and enabling technologies and flexibility in the future system.
- Knowledge gaps:
    - The value of wind;
    - Low externalities of wind in future scenarios when scaling up;
    - Longer predictability periods; and
    - Market design.
- R&D topics:
    4. The value of wind;
    5. Scenario validation including pathways, reality checking; and
    6. Market design.

Group 4: Energy system modelling for net zero

- Modelling process needs include multi-sector data, workflow management (including automatic pipelines all the way to charts), and scenario management.
- Best practice includes integrating all elements into one model (the tradeoff here is computational time) or soft coupling of models (something that is hard to achieve).
- Sensitivity analyses should include uncertainties of input data. Best practice includes data transparency and good documentation.
- Modelling time: time resolution is key. Best practice includes consideration of many years on (sub-) hourly basis.
- Modelling networks: include all key physics processes (for example, heat flows, power flows, etc.)
- Improving computational speed: focus on parallelisation (running scenarios in parallel), data efficiency (removing components not used by the model), and code improvements.

- Knowledge gaps:
    - Reliable data (for example, on transmission system, industry assets).
    - Consolidation of tools—data input and output (standard structures would assist benchmarking).
    - Power system expertise is missing from energy system studies.
    - Push back against deployment of technologies (societal acceptance, environmental issues).
    - Negative emission asset needed to help the final 10% integration of VRE, but it is still unknown technology.
    - Solver performance.

- R&D topics:
    4. Inputs for decision makers: modelling should be useful for setting policy.
    5. Decisions about what technologies to use—consider end user transitions (for example, industry, transport, etc.).
    6. Uncertainties and how to make resilient choices. Data exchanging, model interoperability.

Group 2: Power system modelling for net Zero

- Net zero studies typically do not check network power flow or stability considerations, and there is no (or limited) iteration or feedback from these to policy and market planning.
- Modelling complexity of new technologies is unresolved, particularly dynamic models. Regional and (sub-)hourly time scale analysis is needed. The distribution grid is generally not modelled. All technologies are assumed to be always available and deployable (no outages or maintenance).
- Knowledge gaps:
    - 100% IBR systems are still a new research topic; it is not clear how to best model and analyse such systems and predict what individual technology solutions can offer in the future.
    - EMT modelling is still at a relatively early stage, with limited knowledge of (power electronic) control systems; it represents a very high computational burden for large systems.
    - We lack screening processes to identify the scenarios of greatest interest and concern. Too many scenarios are difficult to process, though there is potential for AI techniques to lessen the burden.

    - Distribution networks are ignored in most system studies due to a lack of data, while challenges to recognising temporal and spatial correlations between wind/PV/load at individual network nodes remain. Distribution system upgrade costs (associated with electrification of heat and transport sectors, as well as distributed generation) will be high, but it's not clear how best to include such aspects while not exploding the computational burden. Nodal prices for AS are not considered, even if energy prices are locational. AS locations have not been considered in sufficient detail.
    - Offshore, DC grids and offshore hubs, including their operation and protection, are emerging.
    - Best practices are not available on how to best model, analyse, and operate net zero systems.
    -
- R&D topics:
    4. Distribution level is to be included in system modelling tools.
    5. Operation of 100% wind/PV system, including stability and EMT modelling.
    6. Screening processes, how to decide what to represent, and with what level of detail, linking with system security considerations.

Group 3: Electricity markets

- Stakeholder interactions and feedback should be evaluated.
- Better cost estimates for future projections should be provided.
- Various uncertainties regarding sets of scenarios should be considered; for instance, what is the likelihood or relevance per scenario?
- Regarding social acceptance, what is the right level of results? Results should be shaped to fit the audience.
- Electricity markets. Pricing could include incentives for investments. European markets do not have locational signals for new investments.
- Sufficient financing and offtake. PPAs vs. CFDs vs. merchant contract structures, Government vs private mixes are open questions.
- Industrial consumer collocation with H_2 generation should be considered.
- Risk sharing: how should this be done and how does it translate to a cost? Back up generation is needed, but it is unclear how to allocate the cost.

- R&D topics:
    - The cost of not building infrastructure, for example, transmission.; evaluating the cost of social acceptance.
    - Market design/auction design for long-term investments, risk sharing, how CFD affects markets.
    - Spatial development implications of net zero, including human geography, industry, and environmental dimensions.

In all cases, the outputs of R&D should be useful to policy.

Conclusions and next steps

As countries around the world work to reduce greenhouse gas emissions, setting targets for achieving net zero has become a core part of this transition. In terms of wind energy, it is crucial that we encourage the use of well-defined wind cost, performance, and value assumptions and discuss the issues, needs and solutions. The role of wind will be impacted by net zero study outputs for policy decisions. There is a risk that the wind share in systems will be limited if net zero modelling is not correctly executed, resulting in adverse policy outcomes.

The role of wind in net zero studies depends on the assumptions and development of competing and enabling technologies and flexibility in the future system. The value of wind energy should be considered more broadly; however, modelling and quantifying value remains a challenge. A focus on resilience is a new area for wind technology.

Improvement to current model tools is needed. Net zero studies typically do not check network power flow or stability considerations, and there is no (or limited) iteration and feedback from these to policy and market planning. Research topics to cover these were identified and presented in the Main Results section of this document.

Discussion on the topics that should be considered for a continuation of Task 25:

- What impacts the role of wind in net zero studies?
    - Modelling assumptions significantly impact the amount of wind needed.
    - Especially the role of competing and enabling technologies and flexibility in the future system.
    - Model improvements are needed to capture the detail, especially regarding power system stability and resource adequacy.
- Zero emission power system analysis should be on one focus area, including Task 25 expertise in power system analysis and methodologies. However, power systems are not enough; sector coupling must be included.
- Evidence-based knowledge on wind integration will still be important to include in the new Task.
- Inter Technology Collaboration Programs are desirable in order to enable a proper system approach:
    - Who to collaborate with? For modelling, we need to find very specific experts within the various TCPs. Desired inputs need to be specific to facilitate cross-TCP collaboration.
    - IEA Paris: idea of annual workshops for all TCP Tasks, established before the Covid pandemic, could be set in motion again.
    - The possibility of forming a joint Task has been explored but Photovoltaic Power System Program (PVPS) has issues in providing funding for participants without a focus on PV. Task 11 OA can help in continuing discussions through PVPS TCP Chair.

Next steps

- Organize a webinar with other TCPs to evaluate interest in collaboration.
- Take relevant points to Task 25 for next Task proposal.

APPENDIX ONE – TEM#113 Introductory Note

INTRODUCTORY NOTE

IEA WIND TASK 11 TOPICAL EXPERT MEETING #113

ON

NET ZERO ELECTRICITY SYSTEM STUDIES

Abbas Rabiee – Université Laval
John McCann, Arash Alavi – SEAI
Hannele Holttinen, Damian Flynn – IEA Wind Task 25, Recognis/UCD
Philipp Beiter, Tyler Stehly – IEA Wind Task 53, NREL

A. VALUE FOR IEA WIND TCP

BACKGROUND

Net zero has gained great importance in discussions surrounding climate change and energy transition. The concept refers to achieving a balance between the greenhouse gases emitted into the atmosphere and those removed or offset. In May 2021, the IEA released a landmark report entitled "Net Zero by 2050, a Roadmap for the Global Energy Sector[1]" which outlines a pathway to achieve global net zero emissions by 2050. The report highlights the importance of rapid and widespread changes across all sectors of the economy, including electricity, industry, transportation, and buildings.

Setting targets for achieving net zero emissions has become one of the primary ways for countries to plan towards their climate change ambitions. Whilst details vary, most net zero plans involve significant reductions in the use of fossil fuels and adopting variable renewable energy (e.g., wind and solar). From a wind perspective, it is important that we encourage the use of well-defined wind cost, performance, and value assumptions and discuss the issues, needs and solutions. In 2023, 32 countries – including all 27 EU Member States – have enacted net zero targets into law, with 2050 as the target date. In addition to the countries with net zero targets encoded in law, more than 120 countries across the world have net zero targets in proposed legislation, in published policy documents, or under discussion, with target dates ranging from 2030 to 2070, though 2050 is by far the most common. Detailed analyses for how net zero targets are achieved, however, are not publicly available for the majority of cases.

[1] Net Zero by 2050 – Analysis - IEA

Net zero electricity system studies and policies are crucial for:

- **Decarbonizing the Power Sector:** The electricity sector is one of the largest sources of greenhouse gas emissions worldwide, primarily from the burning of fossil fuels, such as coal and natural gas. Achieving a net zero emissions electricity system is essential for effectively reducing carbon dioxide and other greenhouse gas emissions.
- **Energy Transition:** Moving towards a net zero electricity system requires a significant increase in the deployment of renewable energy sources and other non-carbon sources. Studying and developing policies that facilitate the integration of these clean energy sources, each with their own characteristics and implications for system operation, into the electricity grid are essential for achieving decarbonization targets.
- **Energy System Integration:** As countries aim to decarbonize their economies, the electrification of various sectors, such as transportation and heating, becomes critical. Net zero electricity system studies and policies enable the integration of electric vehicles, heat pumps, electrified heat storage, and other electrified innovative technologies, ensuring efficient and sustainable energy use across sectors.
- **Technological Innovation:** The transition to a net zero electricity system necessitates the development and deployment of innovative technologies, such as advanced energy storage, grid-forming converters, smart grids, and demand response systems. Studies and policies provide a framework for fostering research and development, encouraging private investment, and driving technological advancements.
- **System Resilience and Flexibility:** A net zero electricity system requires a resilient and flexible grid that can accommodate variable renewable energy sources, while managing the complexities of energy supply and demand balancing. Studies and policies can address the challenges of grid integration, network development, system stability, storage, and demand-side management, ensuring a reliable and stable power system.
- **Quantifying Economic Impacts and Opportunities:** The shift to a net zero electricity system presents economic opportunities, such as job creation, investment in clean energy infrastructure, and the growth of innovative industries. Studies and policies can identify such opportunities and provide guidance to policymakers, businesses, and investors to leverage the economic potential of a sustainable energy transition. Research collaboration through expert elicitation, techno-economic cost models, and assessment of innovations are critical enablers to support this significantly higher level of zero emissions energy deployment and grid services.
- **Building Societal Support:** Achieving net zero within power systems will require new infrastructure, technologies and behaviors. Net zero system studies should (must) involve the public, in creating a common vision for the future electricity system, to avert potential future implementation challenges due to an absence of consensus.

MOTIVATION

To guide countries in developing robust and credible net zero electricity roadmaps, consenting best practices to help inform them would be useful. The outcomes of international net zero electricity system studies vary and are not easy to compare. Wind energy was the original variable renewable resource to be incorporated at scale in electricity systems, but even today it is not necessarily straightforward to include in power and energy system studies in an appropriate way. In order to ensure that the challenges, and opportunities, of wind energy are best captured in the studies, IEA Wind TCP involvement is justified. From IEA Wind TCP point of view the main question is how we can ensure the best possible assumptions and modelling approaches for representing wind in net zero studies. The sector would benefit from developing a report detailing current and foreseeable challenges faced by policymakers, network operators, market regulators, and relevant sectors (e.g., industry, transportation, etc.) as well as some findings from the first wave of net zero studies performed so far. Some general outcomes that may arise from a review of international net zero electricity system studies could include:

- **Building Socio-Political Support:** The leading international net zero studies have been commissioned through a variety of circumstances. The impact, and the manner of commissioning and executing studies, in terms of how well the study outcomes are embraced by society should be understood.
- **Methodological Approaches:** The modelling assumptions, analytical methods and sequence of execution for system studies should be reviewed and compared to arrive at conclusions on best practices. Particular characteristics of both renewable energy resources and demand need to be considered in detail e.g. technical progress in the grid compatibility of advanced wind turbine technology.
- **Technological Pathways:** Identification of common wind energy technological pathways and solutions that are consistently explored across studies, such as technology costs, siting constraints, availability of technologies (e.g., floating offshore wind), and coupling with energy storage and hydrogen. Further wind energy's interaction with the extent of electrification of other sectors of the economy, the availability of carbon capture and storage, and demand-side management. System stability and network expansion implications should also be taken into account.
- **System Optimization and Planning:** Understanding the importance of system-level optimization and planning to achieve a net zero electricity system. This could involve modelling assumptions, suitable representation of other energy vectors, and assessments of generation, transmission, and distribution capacities, considering factors such as renewable resource availability, load profiles, energy market dynamics, and system stability. In particular the analytical methods that should be used to appropriately represent wind power in models across multiple timescales.
- **System Flexibility:** Recognition of the importance of system flexibility and the need for advanced grid infrastructure, energy storage, and demand response technologies to accommodate variable renewable energy sources and ensure a reliable and resilient net zero electricity system.
- **Policy and Regulatory Considerations:** Representation of current and potential future policy and regulatory frameworks that can support the transition to a net zero electricity system. This could include analysis of policies promoting zero emissions energy, carbon pricing mechanisms, procurement regimes, public support for necessary infrastructure and the broader regulatory environments.
- **Economic and Social Implications:** Consideration of the economic and social implications of transitioning to a net zero electricity system. This could include evaluating the costs and benefits associated with different pathways, job creation potential, supply chain and infrastructure investment needs, impacts on energy affordability, and equitable distribution of benefits.

ADDED VALUE OF COLLABORATION

The design of a robust pathway for net zero electricity system is a global task, which needs deep knowledge and expertise sharing across different stakeholders. The IEA as well as the TCPs are unique in their global reach and ability to convene relevant government actors and policymakers. Hence, collaboration within IEA framework adds significant value to net zero electricity system studies by facilitating knowledge sharing, harmonizing standards, promoting collaborative research, providing policy guidance, and enabling capacity building. By working together, participants can leverage collective expertise, resources, and experiences to accelerate the deployment of wind power and support the successful transition to sustainable and carbon-neutral electricity systems worldwide.

The topic area is relevant for all renewable energy TCPs (Wind, PVPS, Hydro, Bioenergy) as well as the energy system modelers (ETSAP), and potentially also Hydrogen. Several Wind TCP Tasks could collaborate together to identify best practice methods/standards for wind energy input into net zero studies.

By highlighting the potential cross-disciplinary applications and collaborative opportunities, we can ensure that the research transcends its immediate context, fostering a comprehensive understanding of net zero strategies that resonates with diverse TCPs and contributes to a collective and impactful approach to addressing the challenges of transitioning to net zero.

ALIGNMENT WITH IEA WIND STRATEGY

Wind energy is a critical component of the future net zero electricity system. Its abundance, carbon-free nature, and renewable characteristics make it an attractive solution for combating climate change, reducing emissions, enhancing energy security, and fostering a sustainable and resilient energy system for future generations. This topic has good alignment with the IEA Wind TCP strategy under Strategic Objectives 1, “Maximize the value of wind energy in energy systems and markets”. Moreover, it is aligned with IEA’s mission, “Energy security”. In terms of IEA Wind TCP research priority areas, it may primarily come under Priority Area 3, “The Plant and Grid”, but will also deliver upon Priority Area 6, “Collaborative Communication”. A TEM that brings experts on net zero electricity system studies together will foster the exchange of best practice, as well as steer collaborative research, the other aim of IEA Wind TCP.

IEA Wind Task 25 “Design and Operation of Energy Systems with Large amounts of Variable Generation” has moved from power system studies to include also energy system coupling – critical for net zero studies. Task 25 is in its final year and will start discussions for a proposal of a new Task for 2025-28. Some net zero studies have already been discussed in Task 25 meetings as country presentations, and the topic has been identified as a potential future area of focus for the Task.

IEA Wind Task 53 “Wind Energy Economics” has ongoing work where researchers evaluate cost and value primarily in the context of anticipated deep decarbonization developments and emerging wind energy applications. The task focuses on methods development and data collection of new wind applications, plant configurations and operations, and associated uncertainties that may complement net zero studies.

B. MEETING FORMAT AND GOALS

OBJECTIVES

This TEM will bring together international experts on net zero electricity studies to initiate a discussion on the key considerations for a guiding framework on net zero electricity roadmap studies. Discussion will centre on those elements of net zero electricity systems that are fundamental across jurisdictions in order that the end result benefits the broadest number of jurisdictions.

While the objective of the meeting will be to publish proceedings for dissemination to policy makers and those executing net zero studies, the discussions will directly inform a continuation Task on grid integration (Task 25), potentially in collaboration with other IEA TCP Tasks. The ultimate objective is the identification and synthesis of current global challenges for net zero electricity pathways, lessons learned, and best practices, in order to provide a resource usable across agencies, jurisdictions, and technologies.

SPECIFIC OUTCOMES

A review of international net zero electricity system studies would typically involve an assessment of various studies conducted by different organizations and researchers worldwide, while noting the underlying characteristics and peculiarities of individual systems and individual studies. The objective is to analyse and synthesize the findings and methodologies used in these studies, to better understand their common outcomes and key considerations for achieving a net zero electricity system. A journal article is already under preparation that will be informed by the outcomes of the meeting.

The meeting aims to identify current and foreseeable future challenges and outline observed best practices, potentially in categories aligned with specific aspects of net zero electricity system design. Net zero electricity system design requires expertise well beyond that of the electricity (power) system itself, such that a multi-disciplinary approach must be adopted to ensure robust and comprehensive analysis and decision making. The meeting proceedings should present a draft net zero studies best practices document, outline a plan for dissemination, and specify potential follow up activities such as further, more in-depth work on key aspects of the synthesis and regular updates to the document, as well as a plan for future supports and coordination.

The meeting discussions will provide a basis for scoping the continuation Task for IEA Wind TCP Task 25.

INTENDED PARTICIPATION

This TEM will bring together international experts on net zero electricity studies and in particular those from IEA TCPs, to initiate a discussion on the key considerations for a guiding framework net zero electricity roadmap studies. In addition, potentially also experts on specific energy technologies present in the net zero studies and also experts on communicating the outcomes of complex studies to a wide audience and building societal support. These intended participants bring diverse perspectives, expertise, and experiences to international net zero electricity system studies. Their collaboration and knowledge sharing are critical for developing comprehensive strategies, policies, and frameworks that can enable the successful transition to a sustainable and carbon-neutral electricity system.

Institutions where experts are currently working on the topic include:

- University of Victoria, Natural Resources Canada, Canada Energy Regulator (Canada)
- DTU, Energinet (DK)
- VTT (FI)
- EdF, RTE (FR)
- Fraunhofer, FfE, Deutsche Windguard (Germany)
- UCD, UCC, Sustainable Energy Authority of Ireland (IE)
- TNO (NL)
- Sintef, NTNU, Norwegian Water Resources and Energy Directorate (NO)
- LNEG (PT)
- Imperial College London, OFGEM (UK)
- NREL, LBNL, Princeton University (USA)
- University of Queensland, University of Melbourne (Australia)
- Renewable Integration and Secure Electricity (RISE) Unit of the IEA

TENTATIVE PROGRAM

The TEM is proposed to be in Dublin, hosted by SEAI, on 8-9 April, 2024.

The meeting will be co-located with Task 25 and Task 53 meetings (on 10-11 April).

The meeting will start with presentations from participants on their experience of net zero studies internationally. The presentations would highlight challenges encountered to set up a net zero electricity system pathway, including knowledge gaps, technological development needs, or procedural difficulties, as well as positive experiences. These presentations would be followed by breakout sessions for specific discussion topics/questions, such as:

- Future net zero power system modelling – how to take into account wind energy, and other technologies, energy sector coupling with power system, system stability and network congestion (expansion)
- Key risks associated with the main components of net zero energy system (e.g., variable renewable generation, hydrogen, energy storage, interconnectors, demand flexibility, system balancing, grid-forming converters, etc.). Increased societal reliance placed on “electricity”, due to electrification of heat, transportation, and other sectors
- Impact of current policies on key energy-related assets (e.g., phase-out of coal reserves and power stations, nuclear power plants, underground gas storage, underground carbon storage, large land area for VREs, interconnectors, network expansion, etc.)
- Future climate forecasts and their incorporation into net zero electricity system studies.

APPENDIX TWO – Meeting agenda

IEA Wind TEM# *113* on *NET ZERO ELECTRICITY SYSTEM STUDIES*

8-9th April 2024, Dublin, Ireland

Final Agenda

Day 1: Monday, 8th April, 2024

Time	Topic	Presenter
9:00 AM	Check-in and Badging	
9:30 AM	Welcome and meeting overview	John Mc Cann, *SEAI*
9:45 AM	**Public Session – Net Zero Power System Studies**	
9:45 AM	IEA Wind TCP and Tasks 11, 25 & 53	Ignacio Marti, *IEA Wind* Hannele Holttinen, *IEA Wind* Philipp Beiter, *IEA Wind*
10:00 AM	**Presentation 1:** *A Review of Global Net Zero Electricity and Energy System Studies*	Abbas Rabiee, *Laval University, Canada*
10:15 AM	**Presentation 2:** *IEA Global Net Zero Assessments*	Craig Hart, *IEA Paris*
10:30 AM	**Presentation 3:** *Net Zero Planning in Denmark / ENTSO-E*	Antje Orths, *Energinet, Denmark*
10:45 AM	**Presentation 4:** *UCC Net Zero Energy System Modelling for Ireland*	Andrew Smith, *UCC, Ireland*
11:00 AM	**Q&A**	
11:15 AM	Break	
11:30 AM	**Presentation 5:** *Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis*	Eamonn Lannoye, *EPRI, USA*
11:45 AM	**Presentation 6**: *Lessons from Ireland for Net Zero Energy System*	Jonathan O'Sullivan, *ESB, Ireland*
12:00 PM	**Presentation 7:** *Impact of Sector Coupling on the Cost Efficiency of Net Zero Carbon Energy Systems*	Juha Kiviluoma, *VTT, Finland*
12:15 PM	**Presentation 8:** *Studying large shares of wind and solar in the energy system - IEA Wind Task 25 Recommended Practices*	Hannele Holttinen*, IEA Wind*
12:30 PM	**Presentation 9:** *Co-Production of Long-Term Decarbonisation Plans*	Fabian Neumann*, TU Berlin, Germany*
12:45 PM	**Q&A**	
1.00 PM	Lunch break	

2:00 PM	**TEM 113 Closed Session**	
2:00 PM	Participant Introductions	All
2:15 PM	**Presentation 10:** *Spine H2 IRL - A case study in developing and applying state of the art open-source tools to model the transition to net-zero*	Jody Dillon, *Energy Reform, Ireland*
2:30 PM	**Presentation 11:** *Operational and stability impacts of high shares of variable renewables in power systems*	Damian Flynn, *UCD, Ireland*
2:45 PM	**Presentation 12:** *Independent & Resilient Energy System with Green Hydrogen: System Requirements for Net-zero Ireland*	Gianni Goretti, *ESB, Ireland*
3:00 PM	**Presentation 13:** *Optimal mix and dispatch of resources in low-carbon energy systems - results energy system modelling studies*	Magnus Korpas, *NTNU, Norway*
3:15 PM	**Q&A**	
3:30 PM	Short break	
3:45 PM	**Presentation 14:** *Interprovincial transmission in Canada*	Madeleine McPherson, *University of Victoria, Canada*
3:55 PM	**Presentation 15:** *Wind and solar system integration*	Matti Koivisto, *DTU Wind, Denmark*
4:05 PM	**Presentation 16:** *Methodologies for optimal hybridization and complementary aggregation of vRES.*	Ana Estanqueiro, *LNEG, Portugal*
4:15 PM	**Presentation 17:** *Low-dimensional scenario generation method of solar and wind availability for representative days in energy modeling*	Martin Densing, *Paul Scherrer Institute, ETH Zurich, Switzerland*
4:25 PM	**Presentation 18:** *Expanded modelling scenarios to understand the role of offshore wind in decarbonizing the United States*	Philipp Beiter, *NREL, USA*
4:40 PM	Summary presentation & discussion	Ignacio Marti, All
5:00 PM	Day close	

Day 2: Tuesday, 9th April, 2024

Time	Topic	Presenter
9:00 AM	**TEM 113 Breakout Sessions**	
9:00 AM	Introduction to objectives of session	All
9:10 AM	Short break and division in breakout sessions	
9:15 AM	**Breakout Session 1: *State of the art*** *Discussion of state of the current art in small groups. Groups divided by sub-topic and will elaborate on or challenge the state of the art findings from the questionnaire, initial talks.* *Potential Sub-Groups:* • *Wind Energy's role in the net zero electricity system* • *Identification of modelling assumptions, generation portfolio and scenarios studied* • *Future resource adequacy vs. electricity customer expectations* • *Net zero electricity system vs. net zero energy system studies* • *Network Expansion / Infrastructure / Operational Planning Studies* • *Communicating net zero study outcomes to diverse audiences* • *Economic factors in net zero systems / Costs to ratepayers / taxpayers, market evolution*	Small groups
10:30 AM	Results presentation & discussion	All
11:00 AM	Break	
11:15 AM	**Breakout session 2: *Knowledge gaps and disagreement*** *Building on the questionnaire and breakout session 1, and using the same groups, discussion focuses on where is there knowledge gaps, disagreement, unknowns or need for more data?* *Potential Sub-Groups:* • *Wind Energy's role in the net zero electricity system (*Deliberate repeat of Q1 in Session1)* • *Is net zero enough, do we need net negative?* • *Computational methods* *Model limitations: time resolution, power system stability, network resolution* • *Technology specific considerations* *Demand profiles for new electric loads (temperature dependency)* • *System Expansion Planning vs. Operational Planning* • *Collaborative open source tools / What do we need?*	Small groups

	Gap between current practice & state of the art in studies • *IEA Wind RP16 – Is it adequate for net zero studies? Why don't all modellers use it? Could it be an online guide / toolkit?* • *Improving resilience for future higher societal reliance on electricity* • *Data for infrastructure: network data for studies (transmission, distribution, gas and other networks). Interactions with neighbouring systems, e.g. export induced emissions, wheeling congestion (studied system boundaries)* • *Consistent meteorological input data for all resources - Future impact of climate change*	
12:30 PM	Results presentation & discussion	All
1:00 PM	Lunch break	
2:00 PM	**Breakout Session #3: *Research needs identification*** *Where do we need research? How should we prioritise research?* ***Topics and priorities to be developed from break out discussion***	Small groups
2:45 PM	Results presentation & discussion	All
3:00 PM	**Full group open discussion: *Research needs identification*** *Where do we need research? How should we prioritise research?* ***Topics and priorities to be developed from break out discussion***	All
4:00 PM	Break	
4:15 PM	Interactive poll or Additional Discussion	
4:30 PM	**Collect main points & identify follow-up responsibilities**	All
4:45 PM	Wrap up	
5:00 PM	Event close	

APPENDIX THREE – Survey Results

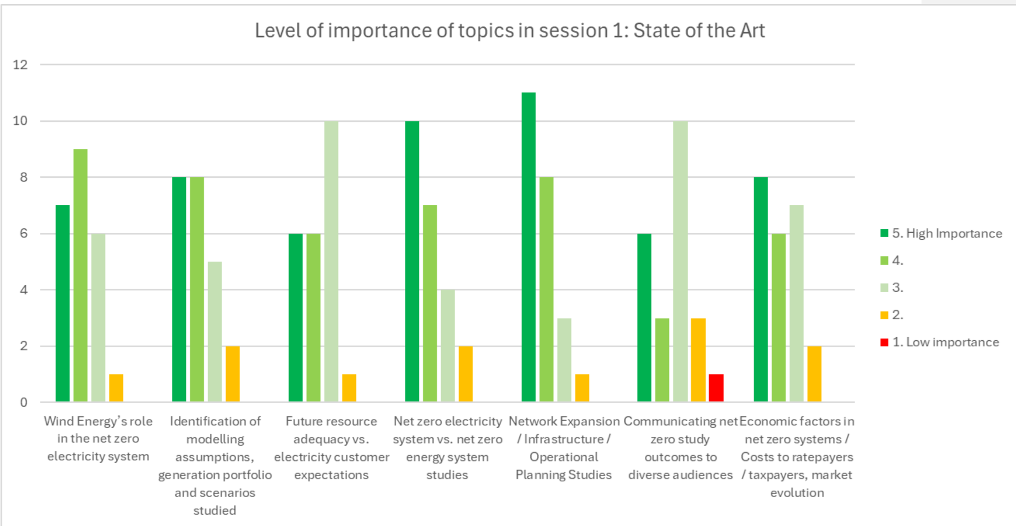
Preliminary Survey to 45 participants. Total participant response number: 23

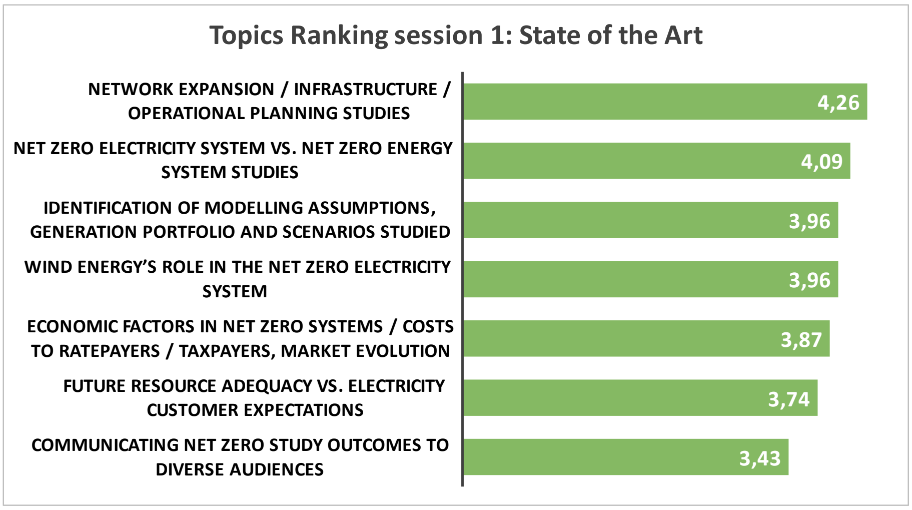
Objective:

Due to time limitations during the TEM and in order to maximize its effectiveness by encouraging focused debate on specific key issues, the participants were invited to:

1. Rank the importance of the proposed discussion topics
2. Choose the sub groups they would like to join for the breakout sessions

Survey's results session 1: State of the Art





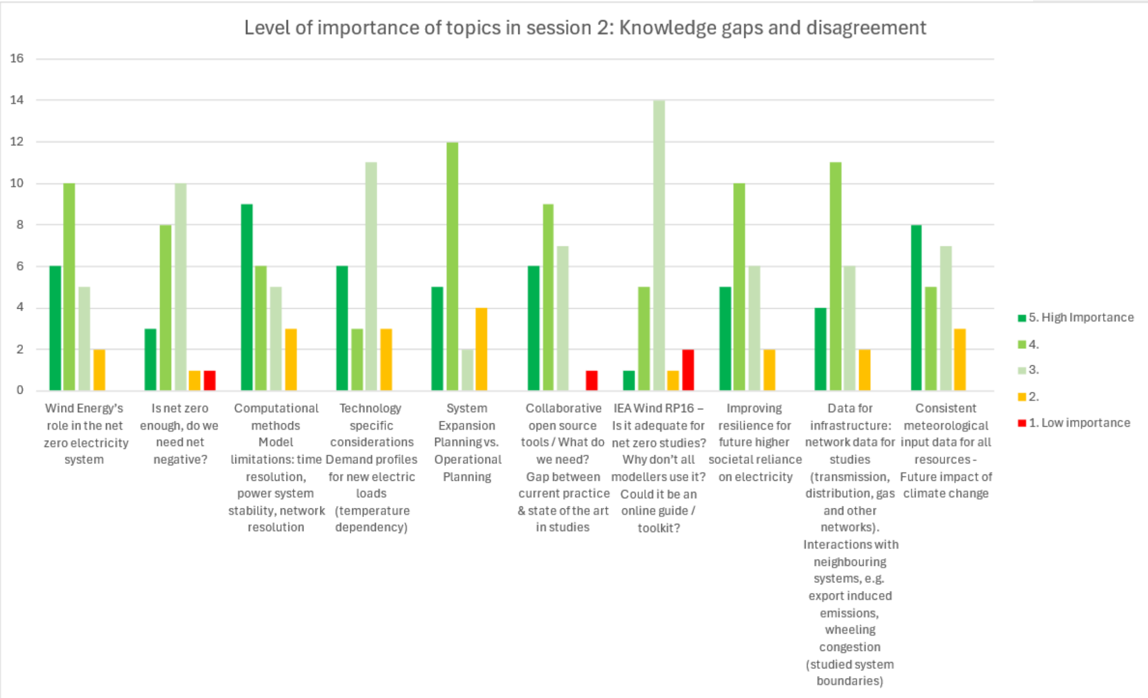
4 proposals for additional topics:

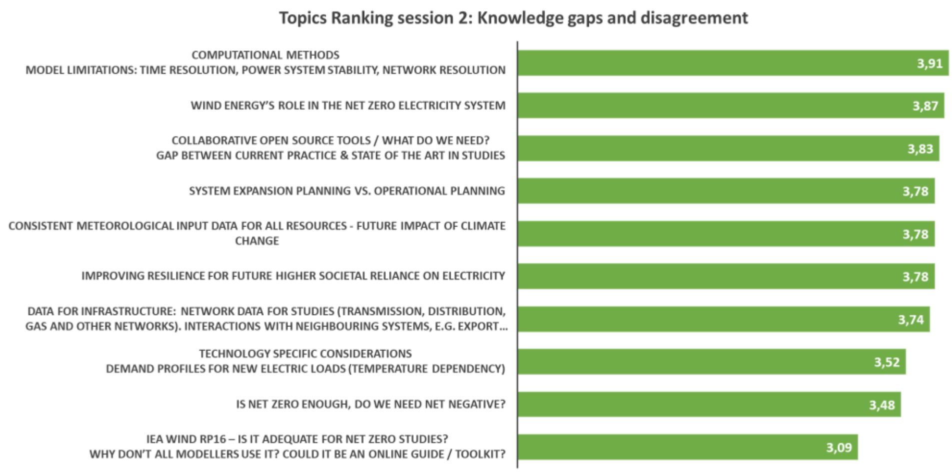
- Including coupled sectors in electricity system net zero models e.g. heat
  Data transfer between models/workflow management through software modules
- Industry transition pathway planning
- The role of consumers in the operation of near Zero Energy Electric Power Systems: Demand Side Management/Response
- Electricity market integration and subsidization of wind energy

Interest of participants for sub groups in session 1:

Topic	Nb of interested participants
Net zero electricity system vs. net zero energy system studies	15
Identification of modelling assumptions, generation portfolio and scenarios studied	12
Wind Energy's role in the net zero electricity system	11
Economic factors in net zero systems / Costs to ratepayers / taxpayers, market evolution	9
Network Expansion / Infrastructure / Operational Planning Studies	8
Communicating net zero study outcomes to diverse audiences	6
Future resource adequacy vs. electricity customer expectations	5

Survey's results session 2: Knowledge gaps and disagreement





2 proposals for additional topics:

- Integrated models vs. combined separate models
- * Modelling assumptions about energy storage and demand flexibility in net-zero studies? E.g. how much does the results depend on tech/cost improvements e.g. in the hydrogen sector
  * Role of central planning vs. markets in investments and power system operation

Interest of participants for sub groups in session 2

Topic	Nb of interested participants
Computational methods / Model limitations: time resolution, power system stability, network resolution	12
Wind Energy's role in the net zero electricity system	12
Improving resilience for future higher societal reliance on electricity	10
System Expansion Planning vs. Operational Planning	9
Data for infrastructure: network data for studies (transmission, distribution, gas and other networks). Interactions with neighbouring systems, e.g. export induced emissions, wheeling congestion (studied system boundaries)	8
Is net zero enough, do we need net negative?	8
Technology specific considerations / Demand profiles for new electric loads (temperature dependency)	7
Collaborative open source tools / What do we need? Gap between current practice&state of the art in studies	7
Consistent meteorological input data for all resources - Future impact of climate change	5
IEA Wind RP16 – Is it adequate for net zero studies? Why don't all modellers use it? Could it be an online guide / toolkit?	4

APPENDIX FOUR - Meeting Participants

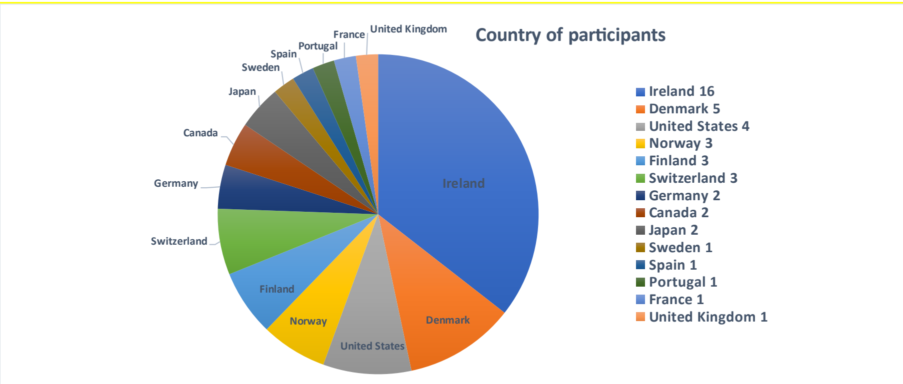
Participants TEM#113 on Net Zero Electricity System Studies

April 8th-9th 2024

First Name	Last Name	Country	Company / Organisation
Mikael	Amelin	Sweden	KTH Royal Institute of Technology
Philipp	Beiter	United States	National Renewable Energy Laboratory
Julien	Cabrol	Norway	Norwegian Water Resources and Energy Directorate
Meadhbh	Connolly	Ireland	ESB Electricity Supply Board
Lucy	Cradden	Ireland	Commission for Regulation of Utilities
Kieran	Craven	Ireland	Environmental Protection Agency
Nicolaos	Cutululis	Denmark	Technical University of Denmark
Pádraig	Daly	Ireland	Sustainable Energy Authority of Ireland
Martin	Densing	Switzerland	Paul Scherrer Institute
Joseph	Dillon	Ireland	Energy Reform
Ana	Estanqueiro	Portugal	National Laboratory of Energy and Geology
Damian	Flynn	Ireland	University College Dublin
Bethany	Frew	United States	National Renewable Energy Laboratory
Meabh	Gallagher	Ireland	Environmental Protection Agency
Emilio	Gómez Lázaro	Spain	Universidad de Castilla-La Mancha
Gianni	Goretti	Ireland	ESB Generation and Trading
Craig	Hart	France	IEA
Niina	Helistö	Finland	VTT Technical Research Centre of Finland
Hannele	Holttinen	Finland	Recognis / Task 25
Malte	Jansen	United Kingdom	University of Sussex
Juha	Kiviluoma	Finland	VTT Technical Research Centre of Finland
Matti	Koivisto	Denmark	Technical University of Denmark
Magnus	Korpås	Norway	Norwegian University of Science and Technology
Eamonn	Lannoye	Ireland	EPRI Europe
Debra	Lew	United States	Energy Systems Integration Group
Forest	Mak	Ireland	Sustainable Energy Authority of Ireland
Ignacio	Marti	Switzerland	IEA Wind Task 11 / Planair

John	Mc Cann	Ireland	Sustainable Energy Authority of Ireland
Madeleine	McPherson	Canada	University of Victoria
Denis	Mende	Germany	Fraunhofer Institute for Energy Economics and Energy System Technology
James	Merrick	Ireland	Geal Research
Fabian	Neumann	Germany	Technical University Berlin
Emer	O'Connor	Ireland	Commission for Regulation of Utilities
Antje	Orths	Denmark	Energinet
Jonathan	O'Sullivan	Ireland	ESB Electricity Supply Board
Abbas	Rabiee	Canada	Laval University
Jan	Remund	Switzerland	Meteotest AG / Task Manager of IEA PVPS Task 16
Jean-Pierre	Roux	Ireland	Sustainable Energy Authority of Ireland
Andrew	Smith	Ireland	University College Cork
Tyler	Stehly	United States	National Renewable Energy Laboratory
Phil	Swisher	Denmark	Ea Energy Analysis
Ryuya	Tanabe	Japan	Central Research Institute of Electric Power Industry
Fabian	Wagner	Denmark	Technical University of Denmark
Magnus	Wold	Norway	Norwegian Water Resources and Energy Directorate
Yoh	Yasuda	Japan	Kyoto University

A total of 45 participants & observers were registered to TEM#113, coming from 14 countries.



APPENDIX FIVE - IEA Agreement

International Energy Agency Agreement

Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems (IEA Wind)

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977 and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 26 contracting parties from 22 countries, the European Commission, and Wind Europe, participate in IEA Wind. Austria, Belgium, Canada, CWEA, Denmark, the European Commission, Finland, France, Germany, Greece, Ireland, Italy (two contracting parties), Japan, Republic of Korea, Mexico, Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, United Kingdom, the United States and WindEurope are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Three Subtasks

The task includes three subtasks.

The objective of the first subtask is to develop recommended practices (RP) in collaboration with the other IEA Tasks.

The objective of the second subtask is to conduct Topical Expert Meetings (TEM) in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, TEMs are arranged four times a year. Additional TEM types that would allow shorter reaction times, broader audience and augmented visibility are currently being researched.

The objective of the third subtask is to provide room for exchanges within the wind energy expert community.

Documentation

Since these activities were initiated in 1978, more than 90 volumes of proceedings have been published. In the series of Recommended Practices, 20 documents were published and six of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task. Some documents are publicly available one year after first publication.

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COUNTRIES PRESENTLY PARTICIPATING IN TASK 11 (2024)	
COUNTRY	INSTITUTION
Belgium	**Government of Belgium**
Canada	**Natural Resources Canada (NRCan)**
CWEA	**Chinese Wind Energy Association (CWEA)**
Denmark	**Danish Energy Agency (DEA)**
Finland	**Business Finland**
Germany	**Federal Ministry for Economic Affairs and Climate Action (BMWK)**
Ireland	**Sustainable Energy Authority of Ireland (SEAI)**
Italy	**Ricerca sul Sistema Energetico (RSE S.p.A.)**
Japan	**New Energy and Industrial Technology Development Organization (NEDO)**
Netherlands	**Rijksdienst voor Ondernemend Nederland (RVO)**
Norway	**The Norwegian Water Resources and Energy Directorate (NVE) and The Research Council of Norway, Norges Forskningsråd**
Republic of Korea	**Korea Institute of Energy Research (KIER)**
Spain	**Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)**
Sweden	**Energimyndigheten (Swedish Energy Agency)**
Switzerland	**Swiss Federal Office of Energy (SFOE)**
United Kingdom	**Offshore Renewable Energy Catapult (ORE Catapult)**
United States	**U.S. Department of Energy (DOE)**