



**Technology Collaboration Programme on
Energy Technology Systems Analysis (ETSAP TCP)
End-of-Term Report
2020-2025**

KEY ACHIEVEMENTS 2020-2025

The ETSAP TCP made significant progress in supporting global energy transitions during the 2020-2025 period, despite the challenges posed by the global COVID-19 pandemic and escalating geopolitical tensions. These disruptions had profound impacts on energy systems, emphasizing the urgent need for resilient and flexible energy planning. Throughout this period, ETSAP played a pivotal role in guiding policymakers with evidence-based analyses of energy security and energy transition pathways aimed at achieving low-carbon energy systems.

Particular highlights in this period were:

- ETSAP TCP book *Aligning the Energy Transition with the Sustainable Development Goals*, which was launched in June 2024 as a side event during the International Energy Workshop (IEW) hosted by IRENA.
- ETSAP also continued to advance its TIMES model generator, implementing new features to enhance the representation of ancillary services markets, demand-response mechanisms, and energy storage technologies. These improvements enabled better modeling of the flexibility needs in future energy systems.
- A key focus during this time was increased transparency, as ETSAP made the TIMES model generator open-source in 2020. Efforts were made to open source the ETSAP-TIAM model to further enhance accessibility. Contracting Parties continued to pursue initiatives aimed at increasing the transparency of TIMES models, as well as their documentation, datasets and results, namely via online platforms.
- Substantial additional capacity worldwide in energy systems modelling, by training hundreds of new energy systems modellers, organising about 10 workshops attended by 50-130 participants, welcoming new Contracting Parties into the ETSAP TCP including Singapore and New Zealand, and reactivating participation of Canada.

1. STRATEGIC DIRECTION

The objective of the ETSAP TCP is to assist decision-makers in the assessment of new energy technologies and policies in meeting the challenges of energy needs and economic development, environmental concerns and technology development. The ETSAP TCP's strategy in achieving the objectives is twofold:

- a) through a common research programme, the ETSAP TCP established, maintains and enhances the flexibility of consistent energy/economy/environment analytical tools and capability (the TIMES model generator). This is an open source economic model generator for local, national

or multi-regional energy systems, which provide a technology-rich basis for estimating energy dynamics over a medium to long-term, multi-period time horizon.

- b) ETSAP TCP participants assist and support government officials and decision-makers by applying these tools for energy technology assessment and analyses of a wide range of energy and environment related policy issues.

The work of the ETSAP TCP focuses on supporting policy making through the analysis of alternative technology pathways in achieving the long-term target for a low carbon energy system. All ETSAP TCP participants are actively involved with policy making in their own countries and also on an international level. Through their involvement in national energy and environmental policy, the ETSAP TCP participants are in constant communication with policy makers. Furthermore, ETSAP Tools are used in many other countries and the collaboration among ETSAP partners and institutions in these countries is continuing.

2. SCOPE

The 2020-2025 period of ETSAP's activities is marked by the implementation of two distinct annexes, both focused on energy systems. Annex XV (2020-2022) - **Energy Systems and Sustainable Development Goals**, centered on exploring how energy systems can contribute to achieving global sustainability targets. Annex XV (2023-2025) - **Aligning Energy Security with Zero Emissions Energy Systems** focuses to include energy security, especially in light of geopolitical changes in 2022, after receiving a relatively lower focus of attention in recent decades. This reinforces the need to align the dual goals of achieving energy security and net zero emissions energy systems. In the period 2020-2025 the main objectives of the ETSAP TCP were:

a) **Tools maintenance.** Maintaining and improving ETSAP Tools and methodologies and capacity building on the use of these tools, were the minimum objective of both annexes. Key goals included:

- **Tools Maintenance and Improvement:** Updating the TIMES model generator to meet future energy system analysis needs, while continuing to support existing MARKAL users.
- **Transparency and Accessibility:** Increasing the openness of TIMES models, software, and datasets by making technology cost and performance data publicly available.
- **Model Interface Enhancement:** Continuously improving the VEDA and ANSWER model shells used for data input and analysis.
- **Capacity Building:** Expanding training opportunities and improving documentation to support proper use of ETSAP tools across developed and developing countries. This includes regular training courses, supporting energy system analysis, and collaborating with non-OECD countries for NDC development.
- **Support and Documentation:** Regularly updating user documentation and improving online support systems to assist new and existing users.

b) **Research and Development.** With Annex XV ETSAP aimed to explore pathways to net zero emissions by incorporating technologies such as CCS, BECCS, and DACCS, while managing emissions from hard-to-abate sectors like industry and agriculture. Another priority was examining how energy systems interact with materials, land use, water, and agriculture, with a particular focus on recycling and the use of alternative materials. The sustainability of biomass was emphasized, ensuring that its cultivation does not compromise food production or lead to excess emissions or water usage. Additionally, ETSAP worked to improve the modeling of variable renewable energy sources and address system flexibility issues, such as demand response and storage, in long-term energy models. On the demand side, ETSAP seek to better capture demand-side flexibility, material efficiency, and the

impacts of human behavior and societal change on energy consumption. The interaction between energy systems and social systems, including structural changes and job creation, is also being studied, with efforts to link energy models with macroeconomic frameworks. With Annex XVI, ETSAP continues to study the interaction of energy systems with materials use, with a particular focus on critical minerals and agriculture, sustainability of biomass, improved modelling of the consumption side of energy systems and demand side flexibility, as well as interactions between energy systems and social systems, structural changes, and circular economy. In addition, new modelling topics were added such as energy security and energy resilience. Finally, the continuous improvement of the ETSAP-TIAM model is a priority since 2020, ensuring it remains a cutting-edge tool for global integrated assessment and long-term energy planning.

Many activities have been undertaken to achieve these objectives. During the 2020-2025 period, the ETSAP community has evolved from the production of Final Reports covering the whole 3-years Annex to Annual reports: [Final report 2020-2021](#), [Annual Report 2022](#), Annual Report 2023 (being finalized). These reports begin by highlighting the work of contracting parties through a variety of studies, including peer-reviewed journal articles, book chapters, PhD theses, and technical reports. A critical section focuses on how ETSAP models are used to support decision-making in energy and climate strategies, showcasing the concrete application of scientific models to inform policy. The reports address the development and maintenance of **ETSAP** tools and methodologies, and capacity-building initiatives across both developed and developing countries.

3. PARTICIPATION

The [Contracting Parties](#) of the ETSAP TCP in the term 2020-2025 were the following:

Contracting Parties	
Australia	CSIRO Energy Centre
Belgium	VITO; Service Public Wallonie; Bruxelles Environnement
Canada	CanmetENERGY in Varennes (re-joined 2024)
Denmark	DEA - Danish Energy Agency
Finland	Business Finland
France	Ministère de la transition écologique et solidaire ADEME - Agence de l'Environnement et de la maitrise de l'Energie École des Mines, Paris
Germany	Forschungszentrum Jülich GmbH IER -Institute for Energy Economy & Rational Use of Energy (University of Stuttgart)
Greece	CREC - Center for Renewable Energy Sources and Saving
Ireland	SEAI - Sustainable Energy Authority of Ireland
Italy	RSE - Ricerca sul Sistema Energetico ENEA - Italian National Agency for New Technologies
Japan	IEEJ - Institute of Energy Economics
Korea	KEA -Korea Energy Agency
Netherlands	TNO - Energy Transition Studies
New Zealand	EECA - Energy Efficiency and Conservation Authority
Norway	Research Council of Norway IFE - Institute for Energy Technology
Russia	ERI - Energy Research Institute
Singapore	Singapore Institute of Manufacturing Technology
Spain	CIEMAT - Centre for Energy, Environmental and Technological Research
Sweden	SEA - Swedish Energy Agency Chalmers University of Technology Luleå University of Technology

Switzerland	Swiss Federal Office of Energy PSI - Paul Scherrer Institute
United Kingdom	Department for Energy Security & Net Zero
United States	EIA - Department of Energy, Energy Information Administration
Sponsors	
Italy	Enel Foundation (withdraw in 2023)

The ExCo regularly discuss possible invitations to potential new member countries. During the period, discussions have been initiated amongst others with Austria, Kazakhstan, KAPSARC (Saudi Arabia), New Zealand, Portugal, Singapore Turkey, Ukraine, Vietnam, World Bank. The ETSAP management team is also focussing outreach efforts with existing ETSAP teams on countries that have recently joined or reengaged with ETSAP. The purpose is to explore how ETSAP can best support members in their modelling activities. As a result, there were some changes to the list of contracting parties as well as outreach efforts.

4. MEETINGS, WORKSHOPS, REPORTING AND TRAINING ACTIVITIES

In the period, the following activities took place in the framework of the ETSAP TCP (until end of 2024):

Meetings/Workshops/Training Courses	Quantity	Participants
Workshops	10	50-130
Training courses for ETSAP Tools	28	10-12
Executive Committee meetings	20	On average 14-16 CPs

Furthermore, the ETSAP organized workshop series on *Human dimension and Energy trade* in TIMES models: September 2022 (Norway), November 2022 (USA), March 2023 (Sweden). All the presentations from the workshops are available on the [ETSAP TCP's website](#). Finally, ETSAP started online webinars on topics which are related to energy modelling in general and specific topics related to the use of ETSAP tools. The webinars are organized every one or two months with topics selected by the modelling community. The recordings of the webinars are available on ETSAP's YouTube channel accessible via this [page](#).

The community working with ETSAP tools **published a third book** during the reporting period on *Aligning the Energy Transition with the Sustainable Development Goals*. Featuring 16 chapters and a foreword by Dr. Fatih Birol, the book was introduced as a side event during the International Energy Workshop (IEW) in June 2024, hosted by IRENA. To enhance its global reach, the Executive Committee decided to make the book available online as open access to maximize its impact and contribute significantly to the field of energy systems analysis.

The ETSAP TCP functions under a cost-sharing model. An annual participation fee which is set at €20,000 is used to cover the expenses of the development of the TIMES model generator and the related shell (VEDA). Furthermore, the fees are used to fund research activities by ETSAP participants through common collaborative projects. The level of participation fees is discussed and agreed unanimously in the Executive Committee every year. The Executive committee of the ETSAP TCP meets twice per year and on average the participation is around 80% of the Contracting Parties. Since the ETSAP TCP operates only one Annex, the Executive Committee meetings serve as Annex meetings and are always accompanied by workshops where the results of common projects are presented.

5. ADDED VALUE IN THE FIELD OF ENERGY TECHNOLOGY RESEARCH, DEVELOPMENT AND DEPLOYMENT.

The added value of participation in ETSAP is achieved through the following activities:

- **The most advanced energy system model generator:** TIMES is the most advanced energy system optimisation model generator, with ongoing improvements that enhance its capacity to analyze complex energy system dynamics. It plays a crucial role in exploring innovative technology pathways and roadmaps, while also assessing the techno-economic and environmental feasibility of various energy technologies. Amongst the key developments, there was i) the endogenous representation of ancillary services markets allowing for better modeling of the flexibility needs of future energy systems, ii) enhanced representation of demand-response through load-shifting and flexible constraints across seasons, iii) the addition of maximum storage cycles for battery storage, improving the accuracy of modeling replacement investments when the cycle limits are reached.
- **Capacity building:** ETSAP plays a key role in training and building the capacity of energy professionals, researchers, and policymakers in both developed and developing countries. Through these efforts, participants gain the skills needed to apply cutting-edge techno-economic modeling methodologies that support energy transitions.
- **Promoting Collaboration:** ETSAP fosters collaboration among its participants, allowing them to discuss, analyze, and solve shared challenges related to future energy systems. This collaboration extends to working with other IEA Technology Collaboration Programmes (TCPs) and institutions like the International Renewable Energy Agency (IRENA) on Long-Term Energy Scenarios (LTES) and the Energy Modelling Forum (EMF) in North America.
- **Promoting transparency:** ETSAP fosters transparency, with the TIMES model generator being made open-source since January 2020. Since then, ETSAP continued to pursue initiatives aimed at increasing the transparency of TIMES models and their results. Notably, extensive discussions were held regarding the availability of ETSAP-TIAM as an open-source model, and a Memorandum of Understanding (MoU) was proposed to guide the future development and maintenance of ETSAP-TIAM.

Notable country-specific initiatives include online documentations of their TIMES models, the publication of datasets on techno-economic parameters for technologies, the creation of a unified data platform for energy-related research, the development of web-based tools for visualizing TIMES results, and the release of open-source models under a Creative Commons license to promote transparency in decision-making.

- **Policy-making support:** ETSAP's models provide decision-makers with evidence-based analyses to design optimal energy and climate strategies, aiding the deployment of clean technologies. Contracting Parties and other countries have used these models to support the development of Energy and Climate Plans (e.g., Armenia, Serbia, Italy, Vietnam), energy planning and renewable integration (Peru), policy evaluation for carbon neutrality (e.g., Finland, Switzerland), and the definition of carbon budgets (e.g., New Zealand, Ireland, UK). Additionally, the models have informed debates on nuclear energy (Belgium) and supported local policy planning (Sweden).

6. COLLABORATION WITH OTHER IEA'S TCP

ETSAP TCP engaged in several collaborative initiatives with other Technology Collaboration Programmes (TCPs) during the 2020-2025 period, aimed at enhancing energy system modeling with more details on key topics. Key activities include:

- **TCP Combustion:** Collaboration focused on energy systems analysis, including decarbonized transport, hydrogen gas turbines, and co-firing hydrogen in stationary applications. Discussions explored the potential for joint research projects, with a need for more detailed data to assess the impact of these technologies from an energy systems perspective.

- **TCP Storage:** A joint workshop was held in September 2021, bringing together ETSAP contracting parties and experts from TCP Storage. The collaboration aimed to improve the representation of energy storage technologies in TIMES models. Outcomes included ongoing discussions about an open data set for use by ETSAP and the development of a best-practice guide for energy storage representation, published in 2023.
- **TCP Bioenergy:** Collaboration explored the intersection of bioenergy and green hydrogen, with plans for joint workshops to identify opportunities for cooperation. There was ongoing dialogue on how to incorporate bioenergy's role into energy system models and understand its contribution to decarbonization efforts.
- **TCP Hydrogen:** Joint efforts focused on better integrating hydrogen into energy system models and understanding its role in decarbonization. A report on the status of hydrogen data and modeling was produced in 2022, with continued collaboration planned to reflect on the next steps in hydrogen modeling.
- **TCP IETS (Industrial Energy-Related Technologies and Systems):** Engagement centered on decarbonizing industrial systems within a circular economy framework. Multiple meetings and workshops were organized to explore how circular carbon flows could be modeled in TIMES, and joint activities on industrial decarbonization were planned in 2023, plus another potential workshop in late 2024 or early 2025.

New collaborative opportunities have recently emerged, thanks to the recent creation of six coordination groups focused on specific themes: carbon management, critical minerals, energy system flexibility, thermal networks, heat pumps, and hydrogen.

7. COLLABORATION WITH HIGH-PROFILE ORGANISATIONS WORLDWIDE

During the 2020-2025 period, ETSAP TCP expanded its collaboration with various other organizations worldwide, such as:

- The **International Renewable Energy Agency (IRENA)** continues to serve as a strategic partner for ETSAP, working together on initiatives to support countries' transitions to sustainable energy futures. One notable collaboration was through the "Long-term Energy Scenarios (LTES) Network," jointly led by IRENA and Finland's Ministry of Economic Affairs and Employment. The LTES Network provided a platform for national and regional energy scenario practitioners to exchange insights on the development and application of energy scenarios.
- ETSAP's experts collaborated with the **U.S. Environmental Protection Agency (EPA)** to enhance energy system modeling, particularly focusing on the migration from the City-based Optimization Model for Energy Technologies (COMET) from the MARKAL to the TIMES framework. Additionally, this collaboration also led to the development of a generic COMET model, designed for urban-scale energy planning. COMET allows comprehensive analysis of energy technology pathways and their cost and emissions implications in sectors like buildings and transportation.
- ETSAP maintained a strong presence in global modeling initiatives through its participation in the **Energy Modelling Forum (EMF)**. ETSAP's TIMES models contributed to the EMF 37 study on High Electrification Scenarios for North America, which explored decarbonization pathways in key sectors such as transportation, buildings, and industry. Key models from ETSAP included: EPAUS9r-TIMES, MARKAL-NETL, and NATEM models. These models participated in the analysis of electrification strategies, providing insights into the opportunities, limitations, and trade-offs associated with high electrification across North America.
- ETSAP continued its engagement with the **Intergovernmental Panel on Climate Change (IPCC)**, particularly through the contribution of Nadia Maizi (France Contracting Party), who served as an author for Chapter 5 on demand-side modeling in the Working Group III report of the IPCC's Sixth Assessment Report (AR6).

- ETSAP has maintained a strong commitment to sponsoring the **International Energy Workshop (IEW)** on an annual basis, a key global forum where energy researchers and practitioners from academia, government, and industry gather to discuss advancements in energy modeling and analysis. ETSAP's spring/summer meeting is always arranged back-to-back with the IEW, enabling members to engage with a broader international audience and share their latest advancements.