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FOR 2022

International Energy Agency
Implementing Agreement for a
Programme of Energy Technology Systems Analysis

ANNEX XV - ENERGY SYSTEMS
AND SUSTAINABLE GOALS
(2020-2022)
“The views opinions, findings, and conclusions or recommendations expressed in this report are strictly those of the author(s). They do not necessarily reflect the views of any single or all Contracting Parties of ETSAP. The Contracting Parties of ETSAP take no responsibility for any errors or omissions in, or for the correctness of, the information contained in papers and articles presented in this report.”
The year 2022 brought many challenges, as the world emerged from the Covid 19 Pandemic, we tried to grapple with the Russian invasion into Ukraine. In addition to the devastation this brought to Ukraine, it also had significant implications for energy supply dynamics globally, in terms both of physical supply and energy prices. The European Union sought to radically wean itself off its dependency on Russian fossil fuel imports by accelerating the energy transition, introduction of new energy demand reduction measures and secure alternative sources for imported piped and liquefied natural gas. The USA introduced very significant new legislation to stimulate the energy transition and address rising inflation.

For IEA-ETSAP, 2022 marked the final year of our Annex focusing on Energy Systems and Sustainable Development Goals. In terms of outputs and productivity, 2022 was again very significant for IEA-ETSAP. We delivered strongly on our core focus i.e. i) to assist energy policy decisions by modelling future energy pathways, ii) to develop and maintain the TIMES modelling tools used by nearly 200 teams in 70 countries and iii) to build capacity through our training sessions and workshops.

This report highlights how TIMES models were used around the world to concretely support policy making, such as: the Plan for a Green Economy 2030 (PEV) of the Quebec Ministry of Finances & Quebec Ministry of Environment and Climate Change (Canada), the energy tax roadmap of the Finland Ministry of Finance & Government of Finland, the carbon neutrality target of the Finland Ministry of Economic Affairs and Employment & Government of Finland, the carbon budgets of the Ireland Climate Change Advisory Council, Carbon Budgets Committee, industrial carbon neutral targets by the Korea Institute for Industrial Economics & Trade, the National Energy and Climate Plan (NECP) of the Government of Moldava and Serbia.

In addition, successful stakeholder engagement sessions have been organized around TIMES modelling results to support decision making, by the Energy Model Expert Council and the Korea Energy Agency, the Energy Efficiency and Conservation Authority (EECA) in New Zealand and the Business NZ Energy Council (BEC), PSI (Switzerland), the Techno-economic of Energy Systems laboratory (TEESlab) and the Swiss Federal Office of Energy.

The report also highlights some of the specific hot topics undertaken by IEA-ETSAP Contracting Parties, including pathways to achieve a net-zero Belgium by 2050 (Belgium), impact assessments of the climate and energy policies formulated by the Prime Minister (Finland), the ETSAP Deutschland project to describe a global hydrogen infrastructure (Germany), decarbonisation of passenger light-duty vehicles and low energy demand scenario for feasible deep decarbonisation (Ireland), achieving net-zero emissions by 2050 (Italy), carbon neutral energy system analysis (Japan), estimation of GHG reduction potential in the industrial sector by 2050 (Korea), residential energy use (New Zealand), the role of transmission and energy storage in European decarbonization towards 2050 (Norway), circular economy in the pulp and paper industry (Spain), impact of technology availability on the transition to net-zero industry and optimized transition towards low-temperature and low-carbon district heat (DH) systems (Sweden), energy efficiency, decarbonisation of industry and pathways to net-zero GHG emissions (Switzerland), energy demand reduction in achieving net-zero (United Kingdom).

Regarding TIMES tools and modelling developments, the year 2022 saw significant advances, including nine new versions of the TIMES code were released, continuous improvements of the VEDA2.0 interface (local and online), the development of the TIMES Cloud Service and the TIMES/MIRO model management system. These developments improve
the capacity, transparency and user-friendliness of TIMES models and mark a significant step change. There were significant developments in web-based visualisation tools improvements that enabled further openness and more effective stakeholder engagement in many countries. This allowed policy makers, academics, consultants, and other stakeholders to engage with the TIMES scenario results and also in many cases with the model documentation and input assumptions. Examples provided in this report are from Norway, Sweden, Switzerland, New Zealand, Belgium, and Ireland.

Finally, the report also summarises some of the key IEA-ETSAP capacity building activities during 2022, including two regular workshops (with an average 50 participants per workshop), and two special workshops on incorporating human behavior in energy system models and improving representation of energy trade (with an average 25 participants per workshop), and six ETSAP VEDA 2.0 TIMES training courses (with a total of 69 trainees). The Tosato Grant, established in 2017 provided financial support for trainees from less developed countries to attend ETSAP’s training courses and workshop.

Further capacity building was delivered through the ten IEA-ETSAP webinars that focussed on a range of topics including a technical webinar on CPLEX\Barrier options for TIMES models and a series of three webinars on integrating sustainable development goals into energy systems modelling: i) resilience and sustainability of power systems with high shares of renewables, ii) energy and land-use nexus, and iii) energy poverty and energy access.

I commend this IEA ETSAP Annual Report to you as a source of information about both existing and new IEA ETSAP energy systems modelling developments, research collaborations and policy impacts in member countries and beyond.

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Established in 1980, the Energy Technology Systems Analysis Programme (ETSAP) is one of the longest running Technology Collaboration Programme (TCP) of the International Energy Agency (IEA).

Twenty-one countries, as well as one private sector sponsor formed the contracting parties to ETSAP in 2022. National teams in nearly 70 countries also collaborate for energy scenario modeling needs, as part of an ETSAP initiative to develop a common, comparable and combinable methodology mainly based on the MARKAL/TIMES family of models. The work program of IEA-ETSAP is organized in three-year projects called ‘Annexes’. This report focuses on the outputs of IEA-ETSAP activity during 2022 delivered during Annex XV: Energy System and Sustainable Development Goals.

Studies from Contracting Parties that are highlighted in this report includes multiple pathways to achieve net-zero targets by 2050 (Belgium, Italy, Japan, Sweden, Switzerland, United Kingdom) or even before (Finland), while other studies focus on specific sector, such as hydrogen (Germany), transport (Ireland), industries (Korea, Spain), residential (New Zealand), storage (Norway), district heat (Sweden). Finally, low energy demand scenario and energy efficiency were also analysed in more details in some studies (Ireland, Switzerland).

A section is dedicated to the link between science and policy, illustrating how MARKAL/TIMES models were used worldwide to support policy making, in particular:

- Quebec Ministry of Finance & Quebec Ministry of Environment and Climate Change (Canada) – The SEQUENCE (TIMES) model has been used to support the conception and the implementation of the Plan for a Green Economy 2030 (PEV).
- Finland Ministry of Economic Affairs and Employment & Government of Finland - The TIMES-VTT model has been used to highlight the uncertainties and needs for additional policies to reach the new mitigation targets by 2030 set by the European Union for Finland and the national carbon neutrality target by 2035.
- Finland Ministry of Finance & Government of Finland – The TIMES-VTT model has been used to conduct a background study for the energy tax roadmap of Finland which has been included in the Government Programme by the Prime Minister.
- Ireland Climate Change Advisory Council, Carbon Budgets Committee – The TIMES Ireland model has been used to assist the Committee in defining and quantifying Ireland’s carbon budgets.
- Korea Institute for Industrial Economics & Trade, with various Korean industrial associations - The TIMES-K21 and TIMES-K22 models were used to determine GHG reduction potentials by mitigation measures for each industry and to establish carbon neutral targets for each industry.

- Moldava Government - In the context of the National Energy and Climate Plan (NECP), the TIMES-MD model was used to develop scenarios and quantitative targets for renewable energy, energy efficiency, and greenhouse gas emissions reductions by 2030.

- Serbia Government - In the context of the National Energy and Climate Plan (NECP), the SEMS model (TIMES) was employed to define the targets of the country for renewable energy, energy efficiency and GHG emissions reduction by 2030.

Successful collaborative efforts and stakeholder engagement sessions are presented in the report, namely:

- The Korea Energy Economic Institute and the Korea Institute of Energy Research have joined hands to establish the Energy Model Expert Council with the Korea Energy Agency and to foster discussions on energy analysis methods and energy policy using modelling results.

- The TIMES NZ 2.0 Project, a collaborative effort between the Energy Efficiency and Conservation Authority (EECA) in New Zealand and the Business NZ Energy Council (BEC), is dedicated to the sustained advancement and adoption of the TIMES-NZ 2.0 model and associated scenarios.

- PSI (Switzerland) led to the Invited talks to key Swiss stakeholders’ initiatives, aiming to disseminate Swiss long-term scenarios to achieve net-zero emissions in 2050 using the Swiss TIMES energy systems model.

- The POLIZERO project successfully organized a Stakeholder Workshop hosted by the PSI and the Techno-economic of Energy Systems laboratory (TEESlab). This workshop aims to address Switzerland’s path towards achieving net-zero CO2 emissions by 2050.

- The SWEET SURE project, sponsored by the Swiss Federal Office of Energy and coordinated by PSI, is an inclusive body of the project, which shall represent major actors that shape the Swiss energy transition.

During 2022, the ETSAP community has also continued its collaboration with the International Renewable Energy Agency (IRENA) on Long-term energy scenarios (LTES) and with other TCP of the IEA (industrial energy systems and storage in particular). Several TIMES modellers participated in the Energy Modelling Forum (EMF37) study on High Electrification Scenarios in North America.

The report also summarizes the most notable new features implemented since January 2022 and their associated documentation, diverse projects funded by ETSAP to enhance TIMES modelling methodologies, including the update of the global ETSAP-TIAM model, as well as the capacity building activities that were organized in both developed and developing countries (trainings, workshops, webinars, etc.).
Finally, multiple initiatives aiming to increase the transparency of TIMES models and their results were again pursued in 2022. For example, there were extensive discussions on the availability of ETSAP-TIAM as an open-source model and a MoU was proposed to ETSAP for the next steps of developing and maintaining ETSAP-TIAM. Regarding country specific initiatives, it is worth mentioning in particular:

- The online documentation of the IFE-TIMES-Norway model.
- Three datasets published by the Swedish Energy Agency on techno-economic parameters, for processes for different industry sectors, fuel production technologies, with a focus on biofuels, and heat plants, specifically tailored for use in TIMES models.
- A Swiss joint modelling project for making model data transparent and accessible to other modelling teams using the SWEET-CROSS data platform (CROSSDat), designed to provide users with unified access to energy-related research data, as well as data related to SWEET, regardless of where it is stored and curated.
- A web-based visualisation tool developed in New Zealand to help users explore the TIMES-NZ results that includes pre-formatted and interactive charts that aim to help users find the information they are after.
- An online working documentation of the EnergyVille TIMES-BE model has been published on a dedicated website, within the frame of the most recent project (‘PATHS2050 for Belgium’).
- The TIMES-Ireland Model (TIM) became open-source and available to download under a Creative Commons licence to support transparency and openness in decision-making.

More information on IEA-ETSAP activities, tools and users can be found at www.iea-etsap.org.
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Appendix A - An international modelling collaboration for 40 years

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References
INTRODUCTION TO THE MODELLING COMMUNITY OF THE ETSAP-IEA

The Energy Technology Systems Analysis Programme (ETSAP) is one of the longest running Technology Collaboration Programme (TCP) of the International Energy Agency (IEA). Formally established in 1980, it eventually became a Technology Collaboration Programme of the International Energy Agency (IEA) dedicated to advancement of integrated energy system modelling platforms for 40 years.

... a modelling community engaged in energy and climate actions

Twenty-one countries, as well as one private sector sponsor formed the contracting parties to ETSAP in 2022. These partners meet minimally twice a year to share knowledge, discuss the research agenda and carry out a common program of work, aiming to actively cooperate to establish, maintain, and expand a consistent multi-country energy-economy-environment-engineering (4E) analytical capability.

National teams in nearly 70 countries also collaborate for open source solutions for energy scenario modeling needs, as part of an ETSAP initiative to develop a common, comparable and combinable methodology mainly based on the MARKAL/TIMES family of models.

... using a common and open-source methodology to support decision making at the global, continental, national and local scales.

The overarching objective of the partnership is to promote and support the application of technical economic tools at the global, regional, national and local levels. ETSAP aims at preparing sustainable strategies for economic development, energy security, climate change mitigation and environment. The ETSAP tools help the Contracting Parties to advise their national governments at the highest levels through joint research efforts.
In terms of applications, IEA-ETSAP energy system analysis is ideal for long-term energy-environment modeling in the context of energy security and climate change. The methodology has been used for applications at different levels, including global, regional, and multiple national and local applications for energy systems planning and analysis. The work program of IEA-ETSAP is organized in three-year projects called ‘Annexes’. This report focuses on the outputs of IEA-ETSAP activity during 2022 delivered during Annex XV: Energy System and Sustainable Development Goals.

The report is organized as follow. Section 2 provides examples of studies done by the Contracting Parties on specific topics highlighted in the Annex XV research program. Section 3 reports on the link between science and policy, i.e. how the models were used concretely to support policy making in different countries worldwide. Section 4 mentions collaboration activities with other high profile organisations. Section 5 summarizes the most recent developments on the ETSAP tools and user interfaces, as well the capacity building activities that occurred to support the new generation of modellers including trainings, webinars and sessions dedicated to stakeholder engagements. Section 5 also concludes by showing multiple examples of open-source initiatives such as online model documentations and result platforms as examples of transparency.

More information on IEA-ETSAP activities, tools and users can be found at [www.iea-etsap.org](http://www.iea-etsap.org).
This Annual Report – Annex XV includes a list of references published during 2022, including multiple publications in a large variety of peer-reviewed journals, book chapter, PhD. thesis, research reports, as well as technical papers. Multiple publications also exist in national languages and are not reported here

... peer-reviewed articles on TIMES model developments and applications are published in a large variety of prestigious journals

Sections below summarize relevant studies done by the Contracting Parties on these topics.

- Pathways to net zero GHG emissions systems
- Interaction of energy systems with materials use, land use, water and agriculture
- Integrate issues of sustainability of biomass in the analyses
- Improved modelling of variable renewables and short-term system operational issues in long term energy systems modelling
- Improved modelling of the consumption side of energy systems, demand side flexibility, integrating human behaviour and societal aspects into energy systems modelling
### 2.1 SAMPLE OF STUDIES ON HOT TOPICS

This section shows excerpts of studies done by the Contracting Parties on the specific topics highlighted in the Annex XV program. A much larger number of interesting pieces of works were generated in 2022 (see the list of references). Many studies involved experts from several countries; studies have been identified with the countries/affiliations of the first author.

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<td><strong>FINLAND</strong>&lt;br&gt; VTT Technical Research Centre of Finland Ltd.</td>
<td>• Impact assessments of the climate and energy policies formulated by the Government of Prime Minister Sanna Marin</td>
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<td><strong>GERMANY</strong>&lt;br&gt; Universität Stuttgart, Institute of Energy Economics and the Rational Use of Energy - IER</td>
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<td>• Modelling energy efficiency and decarbonisation of Swiss industry&lt;br&gt; • SWEET CROSS pathways to net-zero GHG emissions system in Switzerland</td>
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<td><strong>UNITED KINGDOM</strong>&lt;br&gt; Department for Business, Energy &amp; Industrial Strategy&lt;br&gt; University College London</td>
<td>• Role of energy demand reduction in achieving net-zero</td>
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There might be different roads leading to a climate neutral Belgium, but the window of opportunity to walk any of them is narrow. We developed three main pathways to explore possible routes to achieve a net-zero Belgium by 2050.

In the Central scenario assumptions consist of a balanced-out array of possible technological options when it comes to energy efficiency, fuel substitution, electrification, the use of synthetic molecules like hydrogen and carbon removal technology.

In the Electrification scenario, Belgium has the possibility to acquire additional access to a large offshore wind zone in the North Sea as of 2030, adding 16GW of offshore wind power by 2050. In addition, this scenario allows for investment in a new generation of nuclear Small Modular Reactors (SMRs) operational as of 2050.

In the Clean Molecules scenario Belgium has the possibility to have access to green hydrogen and other synthetic molecules at a very low cost (1.7 €/kg in 2050). Belgium has no natural locations to store future captured CO2 emissions, and will therefore need to rely on locations in the North Sea and Norway. Under this Clean Molecules Scenario, Belgium’s access to cross-border CO2 storage is limited to 5 million ton per year.

**Sample.** Electricity generation and demand profile of a typical summer day in 2050.

All results and more sensitivity scenarios can be found on the PATHS2050 website.
The TIMES-VTT model was used to implement long-term integrated assessments scenarios for Finland to reach carbon neutrality by 2035 and carbon negativity after that. The policy scenario WAM (With Additional Measures) was compared with reference scenario WEM.

The main results are the following:

- Impact assessments of new climate and energy policies on energy systems, GHG emissions and on national economy. TIMES-VTT model was soft-linked with the national CGE model FINAGE to analyse the impacts of new policies on national economy.
- Analysis of the GHG emission gaps and needs for additional measures to reach the national GHG targets in 2030, 2035, 2040 and 2050.
- Impact assessments of the EU’s FitFor55 climate and energy policies for Finland, including the new 2030 GHG targets for the effort-sharing sector.

2.4 GERMANY - ETSAP DEUTSCHLAND

The goal of ETSAP Deutschland was to describe a global hydrogen infrastructure and to integrate it into ETSAP TIAM, as well as the given feasible potentials of renewable energies and the associated technologies. The project was accompanied by the IER (leadership), the Institute of Techno-Economic Systems Analysis (IEK-3) and the technical university of Munich (TUM).

In a first step, the technical potentials for renewable energies (especially PV and wind onshore) were determined globally. This was done by FZJ and TUM with the tools Reskit and PyGreta.

In a second step, supply curves for hydrogen and synfuels were derived globally from the determined technical potentials for PV and wind onshore. These were divided into 8 price levels and aggregated for the existing 16 TIAM-IER regions, for both hydrogen and synfuels. Within TIAM, a hydrogen and synfuel infrastructure was created. Globally, the hydrogen infrastructure was implemented using LH2. Synfuel transport can be implemented with existing technologies. In the framework of the hydrogen modelling, technologies were also implemented in the sectors industry, transport, households, commercial and agriculture.

Furthermore, scenarios for security of supply are implemented. The results show that the 1.5°C case based on the Paris Agreement is feasible within all considered scenarios. Four scenarios were considered. One is without climate policy (for reference) and three take climate policy into consideration. Aim is the 1.5°C agreement therefore a budget based on the 1.5°C conform IPCC report is taken. In addition, different security of supply scenarios are taken into account for the three different climate policy scenarios.

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<td>No climate policy.</td>
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<tr>
<td>2</td>
<td>1.5D</td>
<td>1.5°C conform scenario based on given CO2 Budget.</td>
</tr>
<tr>
<td>3</td>
<td>SoS1</td>
<td>Security of Supply scenario, based on 1.5D scenario. Further implementation: At least 50% of hydrogen and synfuels must be out of domestic production. No restriction for trading.</td>
</tr>
<tr>
<td>4</td>
<td>SoS2</td>
<td>Security of Supply scenario, based on 1.5D scenario. Further implementation: At least 33% of hydrogen and synfuels must be out of domestic production. At least 2 trading partners. Each trading partner can satisfy a maximum share of 33% of the local demand.</td>
</tr>
</tbody>
</table>
The results show that the transformation paths of the «climate policy» scenarios hardly differ from each other in terms of global emissions and electricity generation. This means that the 1.5°C is possible in all cases.

There are clear differences in the overall allocation of hydrogen and synfuel generation with respect to security of supply. Without security of supply (1_5D) it is obvious from the results that Europe becomes energy dependent. The export of hydrogen is mainly via MEA. Synfuels are exported via Africa, MEA, CSA and Australia. SoS1 shows that the production shifts towards hydrogen due to the input intensity (1.7x input for hydrogen and 2.2-2.5x input for synfuels). The export regions are not noticeably different from 1_5D. In the case of SoS2, a reallocation of export regions is evident. For hydrogen, Africa and MEA become dominant. Since synfuels are globally more diverse, this shows less change.

Finally, the highlight are the following:

- no synfuel and low hydrogen use in “no climate policy” scenario.

- Africa and middle east Asia are the cheapest spots for hydrogen. Africa, MEA, CSA and Australia are cheapest for Synfuels. The global diversification is better for synfuels compared to hydrogen.

- Europe could be energy dependent in case of cost optimal 1.5°C solution without security of supply policies applied (total system cost will rise by applying security of supply);

- Emissions do not differ that much along the different climate policy scenrios. Same for Electricity production.

- Allocation of hydrogen and synfuels differ a lot due to different security of supply scenarios.

IRELAND – DECARBONISATION OF PASSENGER LIGHT-DUTY VEHICLES

This paper develops a multi-regional transport sector within the system-wide TIMES-Ireland Model (TIM). The transport sector is divided into 26 sub-regions, and each region is characterised by the existing vehicle fleet, public transport availability, scrappage rate, annual mileage, vehicle fuel economy and the corresponding passenger and freight mobility demand. The consumers (car buyers) are disaggregated based on their income level to incorporate a more realistic representation of their behaviour in vehicle purchasing decisions. While TIM ensures carbon neutrality across the whole energy system by mid-century, this study mainly explores the decarbonisation of passenger Light-Duty Vehicles (LDVs). It shows to what extent different measures (i.e. LDV improvements, monetary incentives, modal shift, biofuel obligation, carbon tax and occupancy rate) can contribute to meeting ambitious mitigation targets by 2030.

Main results: Keeping EV monetary incentives until the end of 2024 increases this number to 20 regions, and between 2- to 3-fold increase in EV share of national car stock is observed in most regions. This drives higher electricity demand in the Eastern regions, the South, and the West coast regions of Ireland.
Highlights (3-5 bullet points):

- Region-specific characteristics of transport technologies and infrastructures along with consumer heterogeneity have remained under-investigated.

- Spatially resolved analysis as the main novelty of this research presents valuable insights into regional electric vehicles (EVs) diffusion and their electricity consumption.

- A key message from this analysis is that monetary incentives, applied individually, are unlikely to achieve the national decarbonisation targets.

Sample. EV adoption and CO2 emissions from LDV stock by 2030, impact of monetary incentives on the REF scenario (e.g., in MIR2025 monetary incentives are kept until the end of year 2025 and then removed from the beginning 2026).

IRELAND – LOW ENERGY DEMAND SCENARIO FOR FEASIBLE DEEP DECARBONISATION

Irish Low Energy Demand (LED) mitigation narrative is developed and applied to the TIMES-Ireland Model (TIM), an energy systems optimisation model. The Irish LED represents a scenario where energy service demands are decoupled from economic growth by shifting travel, increasing end-use efficiency, densifying urban settlement, focusing on low-energy intensive economic activities and changing social infrastructure.

Main results: The marginal abatement costs, in the near-term (2025-2030), are less than half in the LED pathways relative to standard mitigation projection pathways. The investments needed to transform the energy system are about 45% lower in the LED pathways in 2030 and about 42% lower in 2050. Personal investments as well are 45% lower in 2030 and about 34% lower in 2050 in LED pathways compared to standard projection pathways.

Highlights (3-5 bullet points):
- This LED scenario presents a possible future energy system evolution pathway which is often ignored in energy policy discussions
- The LED scenario enables the achievement of steep decarbonisation targets with a less rapid energy system transformation, lower capital and marginal abatement costs, and with lower reliance on the deployment of novel technologies.
- The transformation required to meet climate targets must therefore must expand beyond technologies and also encompass societal and economic domains, which has wide-ranging implications for policymakers and state institutions.

This paper contributes to the climate policy discussion by focusing on the challenges and opportunities of reaching net zero emissions by 2050 in Italy. To support Italian energy planning, we developed energy roadmaps towards national climate neutrality, consistent with the Paris Agreement objectives and the IPCC goal of limiting the increase in global surface temperature to 1.5 °C. Starting from the Italian framework, these scenarios identify the correlations among the main pillars for the change of the energy paradigm towards net emissions by 2050. The energy scenarios were developed using TIMES-RSE, a partial equilibrium and technology-rich optimization model of the entire Italian energy system. Subsequently, an in-depth analysis was developed with the sMTISIM, a long-term simulator of power system and electricity markets. The results show that, to achieve climate neutrality by 2050, the Italian energy system will have to experience profound transformations on multiple and strongly related dimensions. A predominantly renewable-based energy mix (at least 80–90% by 2050) is essential to decarbonize most of the final energy consumption. However, the strong increase of non-programmable renewable sources requires particular attention to new flexibility resources needed for the power system, such as Power-to-X. The green fuels produced from renewables via Power-to-X will be a vital energy source for those sectors where electrification faces technical and economic barriers. The paper’s findings also confirm that the European “energy efficiency first” principle represents the very first step on the road to climate neutrality.

Sample: Expected evolution of final energy consumption by sector: comparison between the current state (2019) and the decarbonization scenario.

Two scenarios regarding long-term CO2 reduction pathways were developed, considering the government’s old and new GHG reduction targets: The first scenario assumes GHG emissions are reduced by 26% by 2030 and by 80% by 2050 from 2013 levels, while the second scenario assumes a reduction of 46% by 2030 and 100% by 2050. In the latter scenario, 40 million tons of CO2 emissions can be offset by land-use sequestration.

The study shows that, in order to achieve the ambitious GHG reduction targets, in addition to electricity and hydrogen, new zero-emission carriers called carbon-neutral fuels, including offsets from overseas, will be used, which is a common trend in all sectors. The importance of importing CO2-free energy carriers, such as hydrogen and other gaseous and liquid fuels, was also implied, given the limited domestic renewable energy resources in Japan. Even though the net-zero CO2 emission scenario allows for emissions offset by sinks, negative emissions such as Bioenergy with carbon capture and storage (BECCS) and Direct Air Carbon Capture and Sequestration (DACCS) were used, implying the importance of these technologies. By sector, CO2 reduction in the industrial sector is especially challenging, with the lack of drastic alternatives for high-temperature heat demand. It is suggested that carbon-neutral fuels will play essential roles in reducing CO2 emissions. The future share of carbon-neutral fuel imports in Japan’s primary energy supply would reach around 10%, although the share would be dependent heavily on various conditions. Mobility would be the primary application for hydrogen and ammonia for industry and navigation use, while carbon offset LNG could be used in the industry sector.

In summary, the highlights of the study are the following:

- It linked a detailed power supply planning model, as well as a building sector model with TIMES to analyze Japan’s decarbonization targets by 2050.
- Importing CO2-free energy carriers, such as hydrogen and other gaseous and liquid fuels, would be essential to achieve ambitious GHG reduction targets.
- The use of new zero-emission carriers such as carbon-neutral fuels would also be important.

Using the model TIMES-K22, three types of mitigation measures to reduce carbon emissions were tested:

- The improvement of energy efficiency:
  - Replacement of high-efficiency energy facilities: When replacing facilities such as boilers and pumps, replace with high-efficiency facilities
  - Improvement of heating efficiency: Higher efficiency of heating boilers
  - Digitization: Improvement of power unit by technology
  - Lighting Efficiency Improvement: Expansion of industrial high-efficiency lighting supply and improvement of high-efficiency lighting efficiency

- The substitution of raw material:
  - Steel Industry: Hydrogen direct reduced iron, Increased production of electric Arc furnace
  - Petrochemical Industry: Mechanical recycling, Chemical recycling, Bio Naphtha, CCUS
  - Cement Industry: Increased use of slag cement, Increased ratio of mixtures in Ordinary Portland Cement
  - Oil Refining Industry: Increased use of green hydrogen, CO2 based fuel production

- The substitution of fuel:
  - Steel Industry: Replacing Bunker-C oil, bituminous coal with LNG, waste synthetic resin
  - Petrochemical Industry: Introduction of Electric cracker(electrification), Replacing Bunker-C oil with LNG
  - Cement Industry: Replacing bituminous coal with LNG
  - Oil Refining Industry: Replacing Bunker-C oil with LNG

Results establish that the 2050 greenhouse gas reduction potential in the industrial sector is up to a reduction of 55% of direct emissions compared to BAU scenario (Business As Usual, based on the 3rd Energy Master Plan).

<table>
<thead>
<tr>
<th>Ratio of greenhouse gas reduction by mitigation measure in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of Energy efficiency</td>
</tr>
<tr>
<td>Substitution of Raw Material</td>
</tr>
<tr>
<td>Substitution of fuel</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio of greenhouse gas reduction by industry in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>Petrochemical</td>
</tr>
<tr>
<td>Oil refining</td>
</tr>
<tr>
<td>cement</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

Reference not provided
NEW ZEALAND - RESIDENTIAL ENERGY USE IN TIMES-NZ 2.0

Pathways to decarbonisation of the NZ energy system between 2018 and 2060 are modelled. The study expands on the explanation of TIMES-NZ 2.0 residential sector inputs, assumptions and interactions to provide a higher level of detail than in the TIMES-NZ 2.0 release documentation.

A bottom-up model which accounted for the key drivers of differences in energy end use for an ‘individual dwelling’ was developed. This individual dwelling was of either detached or joined type, and located in one of the 18 climate regions defined by the National Institute of Water and Atmospheric Research (NIWA). Three categories of energy end use were modelled at this stage: space heating, water heating, and ‘other’.

It was found out that:

- Space heating was driven by differences in floor area between dwelling types, and differences in climate and heating technology use between regions;
- Water heating was driven by regional differences in dwelling occupancy; and
- Other uses of energy were assumed to be independent of dwelling type and region.

The final step in this first stage of analysis was to produce totals for the three energy end use categories, and for detached and joined, in each of the 18 regions, thus producing 108 totals. This was achieved by considering the number of detached and joined dwellings in each region, and arranging for national totals (across both detached and joined) to match the value from the EEUD, thus calibrating the bottom-up model.

Reference not provided.

NORWAY - THE ROLE OF TRANSMISSION AND ENERGY STORAGE IN EUROPEAN DECARBONIZATION TOWARDS 2050

With TIMES-Europa model, the study demonstrates the strength of using a stochastic modelling approach that considers the short-term uncertainty of intermittent supply and electricity demand to provide better decision support. A deterministic model provides 24% lower grid capacity and 41% lower battery capacity in 2050 than the stochastic model and thus underestimates the need for flexibility.

Moreover, it shows that the European power sector can be decarbonized with a 65%-70% share of electricity supply from wind power and solar PV in 2050. The joint cost-optimal share of wind power and solar PV depends on technology development and grid expansion policies, whereas electricity demand variability is of less importance.

Lastly, the techno-economic investment in batteries highly dependent on the learning rates for electric batteries and solar PV. The transmission grid capacity in 2050, measured relative to the capacity of 2015, ranges from 4.3 to 6.0. The expansion is primarily dependent on the technology learning rate of solar PV.
To summarize, the highlights are the following:

- stochastic modelling of the 2050 EU electricity market;
- equilibrium model of the EU energy markets soft linked with an energy-system model;
- identify trade-offs between investments in energy storage and transmission capacity;
- deterministic model underestimates optimal battery capacity by 41%;
- optimal intermittent share of electricity production is 65–70% in 2050.

Sample. Share of electricity generation, and impact on relative system cost, in 2050 for Low, Reference and High electricity demand variability.

Using TIMES–SINERGIA, two scenarios were developed for different paper recyclability and availability of wood for pulp. The study indicates that demand for paper is now a driver for the availability of used paper, closing the loop for what previously was a linear RES. Scenarios for different paper recyclability and availability of wood for pulp are being analysed to understand the needs and externalities of the short and mid-term development of this industry.

The key facts of the study are the following:

- A circular relation has been introduced between the demand of paper and the availability of used paper for recycling.
- The wood for pulp material has been disaggregated into eucalyptus wood and pine wood in order to model present and future regulations of eucalyptus plantations.
- Modelling of biogenic carbon retained in recycled paper
- Different scenarios containing pathways have been created to understand how these regulations and the capacity to collect used paper impact the energy needs and externalities of this industry.

Reference not provided.

Reaching net-zero emissions without relying on CO2 offsetting requires technologies of at least TRL 6. Two key technologies making this possible for the Swedish case are black liquor gasification for biofuel production and hydrogen-based steelmaking using electrolysis. Carbon capture and storage (CCS) technologies allows for a net-zero emissions industry using technologies of TRL 9 when offsetting is allowed but requires technologies of TRL 6 and availability of low-cost negative emissions to be competitive.

Two scenarios with different conditions for reaching net-zero emissions were modelled using TIMES–Sweden: one allowing CO2 offsetting, one limiting CO2 offsetting. Each scenario was run in five cases, each case allowing more advanced technologies, which, in turn, was grouped according to their technology readiness level (TRL).

The result indicates the importance of having a process detailed technology database when analysing net-zero pathways for industry. Moreover, including TRL in the technology description allows simpler assessment of when technologies become available, which improves transparency.

In summary, the highlights of the study are the following:

- Visualises how technologies affect and enables net-zero pathways in industry
- Introduces a process detailed database of industrial technologies
- Uses TRL to assess uncertainties in technology availability
- Emphasises the importance of sector coupling for efficient biomass use

**Sample.** Comparison of resulting emissions in industry with (left column) and without (right column) carbon pricing in cases that includes technologies which had a technology readiness level (TRL) of 1 or higher in 2020.
2.14 SWEDEN - OPTIMIZED TRANSITION TOWARDS LOW-TEMPERATURE AND LOW-CARBON DISTRICT HEAT (DH) SYSTEMS (OPTITRANS)

A local TIMES model, representing the heat sector at the city level, was further developed. The model was applied to a case city with a medium scale DH system in Sweden. The model was used as our tool to analyse the long-term optimal transition pathway toward low-temperature district heat (DH).

Model name: TIMES-CityHeat model. Time horizon and division: 2018-2052, 72 timeslices per year, spatial resolution: 5 regions

Scenario description: Three scenarios are included and they are based on the climate policy scenario of Carbon Neutral Nordic (CNN) of the Nordic Clean Energy Scenarios while they are different in regard to the supply and return temperature levels of DH system as below:

Main results:

- Low-temperature DH distribution can contribute to increased competitiveness of DH compared to individual heating solutions such as boilers and ambient-temperature source heat pumps (HPs) in buildings.

- With low-temperature DH distribution (the both supply and return flows) large-scale HPs, having high coefficient-of-performance, could replace individual HPs in buildings. In turn, decreases electricity consumption for buildings’ heating.

- Low-temperature DH distribution could increase the cost-effectiveness of an existing centralized heat storage.

- Low-temperature DH distribution can reduce CO2 emissions associated with the power sector. Moreover, it can reduce system cost of building’s heating

Reference not provided.

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Scenario Description</th>
<th>Supply temperature (°C)</th>
<th>Return Temperature (°C)</th>
<th>Starting/ Ending year</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASE</td>
<td>Current DH temperature</td>
<td>90</td>
<td>45</td>
<td>2018/ 2052</td>
</tr>
<tr>
<td>Lo Re</td>
<td>Low return temperature DH</td>
<td>90</td>
<td>30</td>
<td>2030/ 2052</td>
</tr>
<tr>
<td>Lo Sup &amp; Re</td>
<td>Low supply and return temperature DH</td>
<td>60</td>
<td>30</td>
<td>2030/ 2052</td>
</tr>
</tbody>
</table>

SWITZERLAND - MODELLING ENERGY EFFICIENCY AND DECARBONISATION OF SWISS INDUSTRY

Industry plays an important role to reach climate and energy policy goals by contributing to emission mitigation and energy efficiency improvement. Furthermore, the industry sector, as a part of the energy system, cannot be seen in isolation. It needs to be integrated into the complex system of the energy sector with its several technical, economic environmental and regulatory framework conditions. This study presents cost-optimal pathways for the Swiss industry to improve energy efficiency, reduce CO2 emissions and finally contribute to reaching net-zero CO2 emissions in the long term by 2050. For this purpose, the Swiss TIMES Energy System Model has been expanded with a novel modeling methodology and applied to a scenario analysis of the Swiss industry sector.

The existing techno-economic modeling technique is enhanced with a novel methodology that includes detailed material flows and production processes in addition to a rich portfolio of energy technology. In this modeling approach, heat consumption and waste heat potential are assigned to single production steps with the corresponding tempe-
nature levels. These advancements in the model structure allow us to directly account for improvements in the entire production process, material efficiencies and material substitution options as well as energy technology deployment.

Furthermore, waste heat recovery within the production process has been analyzed and energy technologies are implemented with their temperature-dependent application range and efficiency. By dis-aggregation of the industry sub-sectors, the model is able to account for differences in structure, energy requirements and processes. The detailed modelling ultimately contributes to an improved understanding of the industry sector and its inter-connection to the entire energy system. This research was part of the project SWEET-SURE (www.sweet-sure.ch) funded by the Swiss Federal Office of Energy.


2.16 SWITZERLAND - SWEET CROSS PATHWAYS TO NET-ZERO GHG EMISSIONS SYSTEM IN SWITZERLAND

CROSS (CooRdination Of Scenarios for SWEET) is a part of the four projects sponsored by the Swiss Federal Office of Energy’s “SWEET” programme (Call 1-2020): DecarbCH, EDGE, PATHFNDR and SURE and coordinated by the Energy Science Center in ETH Zurich. The main goal of SWEET-CROSS is to increase the comparability of the simulation from the four consortia by coordinating assumptions and scenarios; and by providing a platform with model documentation (CROSS catalog) and a platform with open energy research data (CROSSDat). This facilitates collaboration among SWEET consortia, communication with different stakeholders, and improves transparency and reproducibility of the results.

In the final event of SWEET CROSS the SWISS TIMES Energy System Model quantified 3 pathways to net-zero CO2 emissions from fuel combustion and industrial processes for Switzerland:

- Abroad-together: net-zero CO2 emissions in 2050 by including Internationally Transferred Outcomes (ITMOs) of 5.7 Mt CO2-eq
- Abroad-alone: net-zero CO2 emissions in 2050 by including Internationally Transferred Outcomes (ITMOs) of 5.7 Mt CO2-eq, and additionally zero-imports of zero-carbon fuels and energy carriers by 2050
- Abroad-alone-strict: variant of the abroad-alone reducing overall import dependency on annual basis to almost 0 in 2050

The analysis found that electrification, energy savings, expansion of district heating networks and hydrogen are important elements in achieving the pathway to net-zero CO2 emissions in 2050. As electricity supply becomes more weather dependent, flexibility to energy system needs to be provided by all sectors of the energy system. This implies that additionally to the 4.5 GW of pump storage, 2.1 GW of batteries at all grid voltage levels are needed by 2050, together with 1.4 TWh of thermal seasonal storage and 1.6 TWh of hydrogen seasonal storage. In transport sector, 1 out of 10 electric cars contributes to vehicle-to-grid schemes. At the same time, the needs in operational reserve increase by 45% between 2020 and 2050, while 10% of the electricity demand in residential, services and industry sectors are shifted during the day to mitigate peak and relief the pressure on the electricity supply.

Sample. Milestones to net-zero emissions in 2050
Achieving net-zero CO2 emissions and import independency in 2050 is technically possible for Switzerland. However, this would imply that any synfuels needed in industry and other energy sectors would need to be produced domestically via Power-to-X. A carbon-neutral production of these synthetic fuels would require deployment of substantial wind power in Switzerland (around 5 times the amount required by a net-zero scenario without the import independency constraint), increasing the electricity supply to close to 110 TWh in 2050 from around 69 TWh today. This research was part of the project SWEET-CROSS (https://sweet-cross.ch) funded by the Swiss Federal Office of Energy.

**Sample.** Domestic Power-to-X and Synfuels reduce import dependency

SWEET-CROSS. (2023). *CROSS Final Event: From SWEET CROSS to Co-evolution*
UNIVERSITY OF LONDON - ROLE OF ENERGY DEMAND REDUCTION IN ACHIEVING NET-ZERO

This study was undertaken by the Centre for Research into Energy Demand Solutions (CREDS), and provides the most comprehensive assessment to date of the role of reducing energy demand to meet the UK’s net-zero climate target.

At present, there is no economy-wide description of the role of energy efficiency in GHG mitigation. This report brings together experienced modelling teams in the UK to construct several scenarios that demonstrate the contribution of energy demand reduction to achieving net-zero by 2050 and more importantly, a 78% reduction by 2035. More broadly, the report considers how reducing energy demand changes the need for emission reductions through the decarbonisation of energy supply and CDR.

Main results and highlights:

- The UK can more than halve its energy demand by 2050 while improving quality of life.
- Reductions in energy demands and energy demand services are possible and need to be ambitious across sectors in order to meet net zero in the UK.
- Taking this strategic approach helps to reduce reliance on high-risk engineered removals.
- Lower energy demands translate into a cheaper, and considerably smaller energy supply system.
- Reducing energy demand allows an increase in climate ambition – particularly in terms of cumulative emissions reduction.

Sample. Net GHG emissions by sector, 2050

Results available online at https://low-energy.creds.ac.uk/the-report/
DECISION MAKING WITH OPTIMAL ENERGY AND CLIMATE STRATEGIES

This section will report on the link between science and policy, i.e. how the models were used concretely to support policy making.

3.1 QUEBEC (CANADA) – USING THE SEQUENCE MODEL TO SUPPORT THE IMPLEMENTATION OF THE PLAN FOR A GREEN ECONOMY 2030 (PEV)

Quebec has set a target to reduce its greenhouse gas (GHG) emissions by 37.5% by 2030 compared to 1990 levels, with the aim of achieving carbon neutrality by 2050. To reach these goals, Quebec has implemented the Plan for a Green Economy 2030 (PEV), which includes a cap-and-trade system, reinvestment of revenues into various measures, and multiple actions for the transportation, building, and industrial sectors.

The Quebec Ministry of Finance and the Quebec Ministry of Environment and Climate Change used two models, a general equilibrium model (MEGFQ-E) and a TIMES energy system optimization model (SEQUENCE), to estimate GHG reduction potentials by sector and technology to reach both targets, and to compute the macroeconomic impacts of all the mitigation actions. In a sophisticated soft-link framework, these models are used on a regular basis to study the interrelations between climate change mitigation efforts and the economy for the Province of Quebec.

In 2022, three main scenarios were conducted to support decision-making by the Quebec government in the fight against climate change.

- The Business-as-usual scenario shows the evolution of GHG emissions considering economic growth and technological improvements without government interventions from 2021 onwards.
- The Reference scenario shows the projected level of GHG emissions based on actions proposed for the the Plan for a Green Economy 2030.
- The Potential scenario assumes the achievement of the 2030 target and illustrates the least-cost ways to achieve the required reductions from a technological perspective (optimization).

The models use data from the Quebec GHG emissions inventory, as well as other sources such as Statistics Canada, Environment and Climate Change Canada, Natural Resources Canada, and the Société de l’assurance automobile du Québec.

In the technological potential scenario, the models shows that in 2030, half of the technological potential of GHG reduction is related to the transportation sector (e.g., electrification of transportation, use of bioenergy). Then, the Industry would represent 30% of the technological potential and the remaining 20% is associated with other sectors such as building, waste and agriculture.

3.2 FINLAND – IMPACT ASSESSMENTS OF GOVERNMENT’S NEW CLIMATE AND ENERGY POLICIES TO REACH CARBON NEUTRALITY BY 2035 IN FINLAND

The TIMES-VTT Model has been used to help the Ministry of Economic Affairs and Employment Finland, and the Government of Finland in order, for the country, to reach the carbon neutrality by 2035.

The results were used as an official research based statement for the Government and Parliament to highlight the uncertainties and needs for additional policies to reach the new mitigation targets by 2030 set by the EU for Finland and the national carbon neutrality target by 2035. The results were presented for the ministerial working group and climate policy roundtable, which included policy makers, industrial stakeholders and NGOs.

IRELAND - IRELAND’S OIREACHTAS (PARLIAMENT) APPROVES CARBON BUDGETS IN MAY 2022

Ireland’s Climate Act in 2021 established a statutory obligation to achieve a 51% reduction in greenhouse gas emissions by 2030 relative to 2018 levels. This represents the highest level of ambition globally (apart from Denmark) for this 12 year period. The legislation further set out a requirement for five yearly carbon budgets and sectoral emissions ceilings as part of the policy governance mechanisms to deliver the target by 2030. The TIMES modelling analysis provided pathways for the energy system that were complemented with parallel modelling of agriculture and land use emissions. Ireland is unusual in that the energy system is responsible for close to 50% of GHG emissions, with agriculture, land use

Model used: TIMES Ireland Model

Two of Ireland’s leading TIMES modellers, Prof Ó Gallachóir and Prof Hannah Daly were invited members of the Carbon Budgets Committee established by the Climate Change Advisory Council to assist them in quantifying Ireland’s carbon budgets. The primary outcome of this work was the proposal to limit GHG emissions to 295 Mt CO2eq in the period 2021-2025 and 200 Mt CO2eq in the period 2026-2030. The TIMES modelling demonstrated that these carbon budgets while challenging, were technically feasible. This provided confidence in the Irish Oireachtas (Parliament) who adopted the proposed carbon budgets without the need for a vote. This confirms a high level of cross-party political support that is very significant in terms of the resilience of this political decision.

Reference:
1. Houses of the Oireachtas 2022 Joint Committee on Environment and Climate Action Report on the proposed Carbon Budgets, February 2022
2. Government of Ireland 2022 Ireland’s Carbon Budgets
The TIMES-VTT model has also been used to better inform the Ministry of Finance of Finland and the Government of Finland to conduct a background study for the energy tax roadmap of Finland. The formulation of the energy tax roadmap was included in the Government Programme by Prime Minister Sanna Marin.

The model was used to analyse the long-term impacts of alternative energy tax structures on GHG emissions, competitiveness of the industrial sector, tax income for the state budget, and energy costs. Case studies included also the potential impacts of the EU’s energy tax directive proposal for Finland.

3.5 KOREA - PROVIDED THE RESULT OF THE MODEL ANALYSIS TO ESTABLISH CARBON NEUTRAL TARGETS FOR EACH INDUSTRY

The Korea Institute for Industrial Economics & Trade, and various korean industrial associations (the Korea Iron & steel Association, the Korea Petrochemical Industry Association, the Korea Cement Association, etc.) were advised to determine GHG reduction potentials by mitigation measures of each industries.

The result of models analysis (TIMES-K21 and TIMES-K22) were provided to establish carbon neutral targets for each industry.

Reference not provided

3.6 MOLDOVA - NATIONAL ENERGY AND CLIMATE PLAN

For the National Energy and Climate Plan (NECP) of Moldava, the TIMES-MD model, a TIMES-based model designed for Moldova, was used to develop scenarios and quantitative targets for renewable energy, energy efficiency, and greenhouse gas emissions reductions by 2030. The modelling work has resulted in the calculation of these targets, and the narrative part of the NECP is currently under development.

Reference not provided

3.7 SERBIA - NATIONAL ENERGY AND CLIMATE PLAN

In the context of the National Energy and Climate Plan (NECP) of Serbia government, the Serbian Energy Modelling System (SEMS), a TIMES-based model specifically designed for Serbia, was employed to develop scenarios and quantitative targets. The quantitative outputs will be used to define the targets of the country for renewable energy, energy efficiency and GHG emissions reduction by 2030, which will be submitted to the Energy Community. Furthermore, a projection of the development of the energy system towards 2050 will also be analysed.

3.8 ENGAGEMENT WITH STAKEHOLDERS

3.8.1 Engagement with the Korea Energy Economic Institute and the Korea Institute of Energy Research

The Korea Energy Economic Institute and the Korea Institute of Energy Research have joined hands to establish the Energy Model Expert Council with the Korea Energy agency. The initiative aims to foster discussions on energy analysis methods and energy policy. One of the key outcomes of this collaboration is the annual discussion and supplementation of the TIMES-K results.

3.8.2 The initiative TIMES NZ 2.0 Project in New Zealand

The TIMES NZ 2.0 Project, a collaborative effort between the Energy Efficiency and Conservation Authority (EECA) in New Zealand and the Business NZ Energy Council (BEC), is dedicated to the sustained advancement and adoption of the TIMES-NZ 2.0 model and associated scenarios. With an objective to maintain, develop, and promote the use of this model, the initiative aims to provide robust insights into energy decarbonization pathways within New Zealand. As a result of the project, TIMES-NZ remains at the forefront of energy decarbonization modeling tools in the country. Furthermore, EECA and BEC have actively engaged with various stakeholders interested in utilizing the TIMES-NZ results and functionalities for diverse purposes. The project also involves continuous model development, regular data updates, and comprehensive deep dive analyses to ensure its accuracy and relevance over time.

3.8.3 Invited talks to key Swiss stakeholders

PSI led to the Invited talks to key Swiss stakeholders initiative, aiming to disseminate Swiss long-term scenarios to achieve net-zero emissions in 2050 using the Swiss TIMES energy systems model. Its main outcomes were invited talks to several stakeholder events, and seven publications:

The POLIZERO project successfully organized a Stakeholder Workshop hosted by the PSI and the Techno-economic of Energy Systems laboratory (TEESlab). This workshop aims to address Switzerland’s path towards achieving net-zero CO2 emissions by 2050. The workshop, held under the title «POLIZERO project Stakeholder Workshop», brought together over 20 stakeholders from various sectors, including Federal Offices, Utilities, NGOs, and consumer associations. Through collaborative discussions, the workshop sought to prioritize and co-create realistic policy packages that could drive Switzerland’s transition to a carbon-free energy system beyond 2025. The outcomes of the workshop have been instrumental in informing the JRC-EU-TIMES framework utilized within the POLIZERO project. By incorporating the insights gathered from the stakeholders, the project team has been able to develop alternate policy pathways that are both robust and flexible, effectively accounting for uncertainties surrounding Swiss and European policy, economic factors, technological advancements, and societal contexts. The main outcomes and key insights from the workshop can be found on the project’s website.
The SWEET SURE project is sponsored by the Swiss Federal Office of Energy and coordinated by PSI. The SURE Stakeholder Forum is an inclusive body of the project, which shall represent major actors that shape the Swiss energy transition. The involved stakeholders will support the process of scenario formulation and the selection of key assessment indicators. They will also engage in the evaluation of future transition pathways regarding their sustainability and resilience performance.

The initiative conducted two workshops in 2022. The first took place on 7th April 2022 where the SURE scenario team exchanged with stakeholders from the energy sector of Switzerland on future energy transformation pathways for Switzerland and possible disruptive events, which may impact the energy sector in future. The second workshop took place on 7th October 2022 where the SURE team exchanges with the Stakeholder forum on indicators on how to assess sustainability and resilience in the Swiss energy sector. The outcomes of the workshops are summarised in internal (for the moment) deliverables in the SWEET SURE project and will be published online on the project website.
The International Renewable Energy Agency (IRENA) is a recognized intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy.

The Breakthrough Agenda Report is in preparation. It is preparing jointly with IRENA and the UN High level Champions on progress in reducing emissions in five key sectors (power, hydrogen, road transport, steel and agriculture).

The CEM Mission Innovation network on Long-term energy scenarios (LTES) is a joint initiative between IRENA and Finland’s Ministry of Economic Affairs and Employment. Coordinated by IRENA, the objective is to facilitate the exchange of information on long-term energy scenarios between international partnering organisations and countries. Tiina Koljonen, representing VTT at ET SAP, has been Finland’s official representative for LTES since the beginning of its formulation. In network meetings and workshops, she has shared Finland’s approach to formulating long-term climate and energy strategies using the TIMES-VTT model. This model has been a central tool for impact assessments of the alternative scenarios to reach carbon neutrality.

ETSAP engagement with other Technology Collaboration Programme (TCP) took the form of several initiatives and efforts.

**Industries.** For example, the IEA IETS (Industrial Energy-Related Technologies and Systems) is an IEA TCP focused on the development and deployment of industrial energy-related technologies and systems. One of their initiatives is the IETS Task XXI, which is centered on the Decarbonizing industrial systems in a circular economy framework. LTU is participating in the initiative and this allows both parties to learn more about how to model circular carbon when assessing potential decarbonization of the industrial sector.

**Storage.** PSI, in its continued engagement building on the reporting of 2021, is partnering with the IEA TCP Energy Storage Task 32 initiative titled «Open Sesame». The primary objective of this initiative is to improve the representation of energy storage technologies in TIMES by collaborating with experts in key future electricity and thermal storage options. The initiative has already yielded significant outcomes, including a joint workshop that took place on September 9th, 2021, bringing together ETSAP and TCP Energy Storage Task 32. Furthermore, a best practice guide for representing energy storage in TIMES is currently under development.
ACTIVITIES IN COLLABORATION WITH EMF

As part of its outreach activities, ETSAP collaborates with many other research teams throughout the World and participates in various global forums. Participation of TIMES models in the Energy Modelling Forum (EMF), for instance, occurred at different times.

The EMF 37 study on High Electrification Scenarios in North America forum continued during 2022. This study initiated to help model builders and model users better understand the potential role of electrification in economy-wide decarbonization pathways in important economic sectors—transportation, buildings, and industry. This study is designed to explore the opportunities, limitations, trade-offs, and robustness of results associated with high electrification of the energy systems in North America.

More importantly, the study is designed to engage nearly all existing North American focused energy and economy-wide energy-economy models, as well as sectoral and technology experts forming study groups focused on transportation, industry, buildings and carbon management. Several MARKAL-TIMES models were among the participants, including EPAUSgr-TIMES: The Integrated MARKAL-EFOM System (EPA-ORD), MARKAL-NETL: MARKet ALlocation (NETL), and NATEM: The North American TIMES Energy Model (ESMIA, GERAD). NATEM also participated, studying the role of electrification in economy-wide decarbonization pathways for Canada, USA, and Mexico using the NATEM model and exploring the limitations and robustness of results by comparing with many other models.

ACTIVITIES IN COLLABORATION WITH IPCC

From last report:

Nadia Maizi (from the France Contracting Party) is an author for the Chapter 5 on demand side modelling in the Working Group III report of IPCC. The IPCC is currently in its Sixth Assessment cycle, during which the Panel will produce three Special Reports, a Methodology Report on national greenhouse gas inventories and the Sixth Assessment Report (AR6). She makes the link with ETSAP activities regarding a survey on ongoing work on demand side modelling.
TIMES\(^1\) is a technology rich, bottom-up model generator, which uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints, over medium to long-term time horizons. The TIMES source code is available under a GNU General Public Licence v3.0 since January 2020 and can be download from GitHub. Developing and running TIMES models require commercial softwares with valid license (available here).

- Any new user wishing to work with TIMES is encouraged to consider using the VEDA 2.0 interface. The user inputs the model (a set of data files, e.g. spreadsheets or databases) which fully describes the underlying energy system in a format compatible with the associated model generator.

- The TIMES model generator is written with the GAMS computer programming language, which contains a solver to produce the output of the model.

Interest for TIMES worldwide kept increasing since 2021. First, many interested new users requested a free trial version of GAMS/VEDA for use with TIMES via the ETSAP website, which is available for them to evaluate TIMES over a 2-month period.

\(^1\)ETSAP developed and coded two model generators - MARKAL and TIMES. TIMES is the successor to MARKAL, and all modelers are advised to use TIMES. The MARKAL code will continue to be supported in its current form but no further development will take place.
In 2022, several projects resulted in improvements to the TIMES codes. New features developed are presented in Table 3.

**TABLE 3 - SUMMARY OF NOTABLE NEW FEATURES IMPLEMENTED SINCE JANUARY 2022**

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>RELATED INPUT ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaping of capacity-related flows (defined by NCAP_COM) with FLO_FUNCX, enabling age-dependent capacity-related flows.</td>
<td>NCAP_COM</td>
</tr>
<tr>
<td></td>
<td>FLO_FUNCX</td>
</tr>
<tr>
<td>Improved the functionality of REG_BDNCAP(reg,lim), for more flexible bounding of capacities with a previous solution by region, as upper bounds, lower bounds, or fixed bounds. Requires using LPOINT.</td>
<td>REG_BDNCAP</td>
</tr>
<tr>
<td></td>
<td>NCAP_BND</td>
</tr>
<tr>
<td></td>
<td>control variable LPOIN</td>
</tr>
<tr>
<td>Reporting of the power levels (Var_Pout) of process flows is generalized to include also input flows (reported with negative values).</td>
<td>RPT_OPT(nrg_type,'1')</td>
</tr>
<tr>
<td></td>
<td>RPT_OPT(nrg_type,'3')</td>
</tr>
<tr>
<td>New input attribute G_RFRIR for defining a risk-free real interest rate, as a reference for calculating the risk premium impact of NCAP_DRATE.</td>
<td>G_RFRIR</td>
</tr>
<tr>
<td></td>
<td>NCAP_DRATE</td>
</tr>
<tr>
<td>New input attribute NCAP_AFSX for shaping seasonal availability factors, independently of the process level technical availability factors.</td>
<td>NCAP_AFSX</td>
</tr>
<tr>
<td></td>
<td>NCAP_AFS</td>
</tr>
<tr>
<td>Improved formulation for retrofit options that are forced to be implemented in amounts equal to any endogenous retirements.</td>
<td>PRC_REFIT</td>
</tr>
<tr>
<td>Support for ACT_FLO, ACT_EFF, FLO_EFF and FLO_EMIS parameters to be effectively levelized on the flow TSL levels, instead of only PRC_TSL level</td>
<td>ACT_FLO, ACT_EFF, FLO_EFF, FLO_EMIS</td>
</tr>
</tbody>
</table>
During 2022, nine new versions of the TIMES code were released. The improvements into the TIMES code implemented during 2022 were all rather minor in nature. None of the new features were designed or implemented within specific ETSAP R&D projects, but all of them were completed within the regular ETSAP TIMES maintenance activity. In addition to the minor new features, a few bugs discovered in the code during 2022 were fixed in the releases, as part of the regular maintenance.

The most notable improvement implemented during 2022 was the enhanced levelization of various process transformation parameters ACT_EFF, ACT_FLO, FLO_EFF and FLO_EMIS. In the original TIMES implementation, all the process transformation parameters were effectively levelized only onto the process timeslice level. Subsequently, the ACT_EFF parameter has been already levelized onto the level of the flow variables when specified for individual commodity flows. But now, starting from Version 4.6.9, any ACT_EFF specified for a group of flows, or an ACT_FLO specified for an individual flow, are also levelized onto the flow levels, and any FLO_EFF / FLO_EMIS are now levelized onto the level of the source flow(s). These enhancements thus provide better support for modelling timeslice-specific process efficiencies and other related transformation attributes even when the activity of a process is modelled on a level coarser than the level of its finest flows.
5.3 USER INTERFACES’ MAINTENANCE, UPDATE AND IMPROVEMENT

5.3.1 VEDA2.0

VEDA2.0 continued to be improved and experience enhancements during 2022.

VEDA is a software tool to convert modeler knowledge into input for models, and output from models into knowledge. VEDA is a proprietary commercial software designed and developed by KanORS-EMR, and supported by ETSAP since 2000. ETSAP contracting parties get a small group license for free, and others can purchase it from KanORS. Access to technical support and updates is subject to an annual maintenance fee (20% of the initial cost), after the first year.

Veda2.0 comes in three different versions: Academic, Standard and Advanced. The academic version works on a single core, but is still much faster than VEDA_FE/BE. Standard version uses multiple cores for certain operations. Advanced version has two additional features - Collaboration, and Reports.

COLLABORATIVE WORKING

Multiple users working on the same model on a server will be able to share model runs, input data GDX, results views definitions, and various groups and case definitions for Run Manager. Further, the JSON files in Appdata folder will also retain username information. So, users sharing model folders will be able to use or filter out groups, cases and views created by other users.

ADVANCED REPORTING

VEDA_BE and the Results functionality in Veda2.0 work well for interactive and production reporting. But there are two limitations, removing which can make this a lot more powerful and flexible. First, the reporting variables are trapped in tables – the user does not have direct control over them. Second, the user cannot add dimensions to the output views – the user is limited to process and commodity sets in terms of segmenting the output beyond the native indexes like attribute, region and time.
5.3.2 VEDA Online

VEDA Online makes the core Veda 2.0 functionality accessible via Internet browsers (https://vedaonline.cloud/). Individual users benefits include no software setup/updates needed, the possibility to enforce version control discipline via GitHub, model synchronization and runs on state-of-the-art servers, availability of model input/output no longer dependent on local machines, and far superior data visualization in Reports, Results, and Browse. For teams, a further benefit is to provide unobtrusive access to input/output to team members. It is also possible to deploy models, and create model users.

5.3.3 The development of the TIMES Cloud Service

A consortium led by GAMS Development Corporation, along with DecisionWare and KanORS-EMR, realized the TIMES Cloud Platform. The Platform is comprised of the GAMS-Engine, a cloud-based environment for solving TIMES (and any other) models that can receive TIMES model runs from VEDA/VEDA-Online as well as GAMS-MIRO. The GAMS-Engine was available until March 2023 for ETSAP Partners to evaluate. It provides the capability to greatly reduce turnaround time for large TIMES models when conducting an analysis by enabling (most) any number of model runs to be submitted to the cloud CPLEX solver in parallel, where a full set of sensitivity runs can be performed in about the same time as a traditional single model run done locally.
The development of the TIMES/MIRO model management system

A consortium led by GAMS Development Corporation, along with DecisionWare, PSI, and IER, realized the TIMES/MIRO model management system. TIMES/MIRO provides an open source alternative to VEDA for managing TIMES models. It requires that the user first create a complete TIMES model data descriptions as generated by VEDA in the form of the GAMS input data dictionary (DD) files. TIMES/MIRO reads these DD to into the “shell” where any of the basic functions are available in VEDA such as browsing input data, traversing the underlying RES, submitting model runs and assembling results reporting tables. TIMES/MIRO allows users to solve model locally or via the GAMS-Engine cloud platform.
5.4 DOCUMENTATION AND OTHER REFERENCE MATERIAL

A key strength of the IEA-ETSAP methodology is the detailed documentation, which is the result of a commitment to the highest levels of transparency by the IEA-ETSAP. The documentation of the diverse applications leads to knowledge sharing, benefitting from the fact that a large community is using it. The IEA-ETSAP methodology is the leading open source approach to energy scenarios modeling.

... a key strength of the IEA-ETSAP methodology is the detailed documentation, which is the result of a commitment to the highest levels of transparency!

The TIMES Documentation is structured in four parts:

- **Part I (TIMES concepts and theory)** provides a general description of the TIMES paradigm, with emphasis on the model’s general structure and its economic significance.

- **Part II (Comprehensive Reference Manual)** constitutes a comprehensive reference manual intended for the technically minded modeler or programmer looking for an in-depth understanding of the complete model details, in particular the relationship between the input data and the model mathematics, or contemplating making changes to the model’s equations (last updated in January 2023).

- **Part III (the Operation of the TIMES code – organization of the TIMES modelling environment)** describes the organization of the TIMES modeling environment and the GAMS control statements required to run the TIMES model. GAMS is a modeling language that translates a TIMES database into the Linear Programming matrix, and then submits this LP to an optimizer and generates the result files (last updated in January 2023).

- **Part IV (VEDA 2.0)**, published in Dec. 2020, provides a step-by-step introduction to building a TIMES model in the VEDA2.0 user interface for model management and results analysis.

Other documentation updates in 2022 include the following user notes:

- New user note on Stochastic Programming and Tradeoff Analysis in TIMES

- New discussion note on Experimental enhanced variant of the multi-level storage formulation (STS) in TIMES
5.5 CAPACITY BUILDING IN BOTH DEVELOPED AND DEVELOPING COUNTRIES

5.5.1 ETSAP Trainings

ETSAP offers training courses on building TIMES energy models with the VEDA user interface (Table 5). The courses are offered at the introductory, intermediate and advanced levels to introduce new users to its model generators and user interfaces. The base training course is offered twice a year next to ETSAP Workshop. Each course is free of charge for ETSAP Contracting Parties. Intermediate and Advanced Training courses are available upon request.

Starting in 2017 ETSAP established the Tosato Grant which will provide financial support for trainees from less developed countries to attend ETSAP’s training courses and the ETSAP workshop.

**TABLE 5 – SUMMARY OF TRAINING EVENTS**

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>DATES IN 2022 AND PARTICIPANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Training Course on VEDA-TIMES</td>
<td>January 31 - February 2, 9 participants</td>
</tr>
<tr>
<td></td>
<td>March 28 - 31, 15 participants</td>
</tr>
<tr>
<td></td>
<td>May 30 - June 01, 9 participants</td>
</tr>
<tr>
<td></td>
<td>July 11-13, 9 participants</td>
</tr>
<tr>
<td></td>
<td>September 26-28, 12 participants</td>
</tr>
<tr>
<td></td>
<td>November 28-30, 15 participants</td>
</tr>
</tbody>
</table>

5.5.2 ETSAP Special Workshops

IEA-ETSAP also organises workshops or events other than the official ones back-to-back with ETSAP meetings. In 2022, a workshop were organised two times in different location in hybrid mode.

**TABLE 8 – SUMMARY OF WORKSHOP**

<table>
<thead>
<tr>
<th>DATES</th>
<th>SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 2022</td>
<td>Day 1: <a href="#">Human behaviour</a></td>
</tr>
<tr>
<td></td>
<td>In Oslo, Norway. In-person and online participation</td>
</tr>
<tr>
<td>November 2022</td>
<td>Day 1: <a href="#">Human behaviour</a></td>
</tr>
<tr>
<td></td>
<td>In New York, USA. In-person and online participation</td>
</tr>
</tbody>
</table>

The average participation to these workshops was 15-20 persons.
IEA-ETSAP also organises webinars (Table 6) on topics which are related to energy modelling in general and specific topics related to the use of ETSAP tools. The webinars are organised every one or two months with topics selected by the modelling community. The recordings of the webinars are made available on ETSAP’s YouTube channel.

**TABLE 6 – SUMMARY OF WEBINARS OR LECTURES**

<table>
<thead>
<tr>
<th>DATES</th>
<th>SUMMARY</th>
</tr>
</thead>
</table>
| January 2022| Series of three webinars on “Integrating sustainable development goals into energy systems modelling”:  
1. Resilience and sustainability of power systems with high shares of renewables |
| January 2022| 2. Energy and land-use nexus. |
| February 2022| 3. Energy poverty and energy access. |
| March 2022  | 4. **CPLEX\Barrier options** for TIMES models |

The average participation in the online webinars was 30 persons.
Across the world, IEA-ETSAP contracting parties hosted a few webinars in 2022.

**TABLE 7 – SUMMARY OF WORKSHOP**

<table>
<thead>
<tr>
<th>DATES</th>
<th>SUMMARY</th>
</tr>
</thead>
</table>
| January 2022 | **What has energy system modelling ever done for us?**  
Hosted by UCL and organized by Paul Dodds |
| May 2022  | The open-source TIMES/MIRO App  
By PSI, talk within the workshop “Possibilities to achieve the 1.5°C Target under consideration of open energy system modelling” |
| May 2022  | **Open Energy System Modeling**  
Hosted by IER |
| October 2022 | **Energy Forum** – Roadmap to net-zero Belgium 2050  
Audience: Industry federations, companies, policy makers  
Outcomes (reports, proceedings): Methodology report, presentation |

**5.5.4** Other workshops or webinars

**5.5.5** TIMES-Starter

There were some 133 requests from new individuals for access to TIMES, and nearly 100 of said users obtained the ETSAP TIMES-Starter model to seed their model development endeavours.
5.6 PROJECT FUNDED TO ENHANCE METHODOLOGIES

Number of applicants: 10
Number of projects granted: 5
Annual budget allocated to ETSAP project: 204 700 €

The following projects got funding; decision made at the 88th ExCo-meeting 2 December 2022 in New York:

2. Times extension for electricity, gas, hydrogen and CO2 transport infrastructures (48 000€)
3. Model of industry sector and material efficiency (46 000€)
4. Review of the TIMES code in GAMS to identify areas for performance improvements (48 500€)
5. Open Source TIMES Excel Reader (50 000€)

In addition to the five projects above, the ExCo provided 40 000€ in funding for finalisation of the documentation of the ETSAP-TIAM model.

All contraction parties (CPs) can apply for research projects. The project proposals are submitted to the Operating Agent prior to the last ExCo-meeting every year. The ExCo-members vote on the different projects proposals, and the scoring is based on the following five criteria: participation, innovation, relevance to work programme, cost and benefits for ETSAP.

Other projects funded by ETSAP in previous years have also continued in 2022 such as: the TIMES Cloud Service, the ETSAP Deutschland project, and the Hydrogen modelling project. A few workshops were also organised in 2022 thanks to the financial help of IEA-ETSAP.

... Examples of ETSAP funded projects with high impacts
Third ETSAP book: Energy System Models and Suitable Development Goals

**Number of applicants:** 1 and more (Eneris Environment Energy Consultants, open to partnership with IEA-ETSAP members)

**Project duration:** 12/2022 - 07/2024

**Annual budget allocated to ETSAP project:** EUR 12,200

IEA-ETSAP already edited two collective books and the project aims at preparing the 3rd IEA-ETSAP Book reflecting the most recent development and application of MARKAL/TIMES family of models by IEA-ETSAP members. The book will be built to provide innovative insights into technology, behaviour, social and economic changes needed to reach the SDGs, and more particularly SDG7. The book will contribute to the visibility of the work of the project partners to a large scientific community, beyond the usual IEA-ETSAP community. Beyond the visibility given to the work of project partners, the book also reinforces the visibility of IEA-ETSAP tools and research work as a whole, by reflecting the diversity of tools, methods and their applications by the IEA-ETSAP community.
5.6.2 Times extension for electricity, gas, hydrogen and CO2 transport infrastructures

Number of applicants: 2 (PSI, VTT)
Project duration: 18 months from the signing of the contract
Annual budget allocated to ETSAP project: EUR 48,000

The energy transition to low-carbon systems presents challenges and interdependencies for grids and infrastructure. Energy infrastructures play a crucial role in ensuring a secure energy supply. Integrating infrastructure constraints into TIMES is important for understanding clean, affordable, secure, and reliable energy systems. The ETSAP community combines TIMES with detailed grid and infrastructure models to assess the feasibility of energy system configurations. However, this coupling is typically done for isolated periods with limited feedback on infrastructure constraints. In 2013, an extension was implemented to improve infrastructure modeling in TIMES by incorporating electricity transmission grids. This approach can be extended to include additional grids like gas, hydrogen, and CO2 transportation networks, as well as other transportation alternatives. The extension does not require changes to the spatial resolution or structure of the TIMES model, but the development of infrastructure elements would rely on linear approximations. This is because adding or modifying network elements affects the network’s physical properties.

5.6.3 Model of industry sector and material efficiency

Number of applicants: 3 (IER, VTT, LTU)
Project duration: 01/2023 - 06/2024
Annual budget allocated to ETSAP project: EUR 46,000

Economic growth and increasing wealth have led to unsustainable use of natural resources globally. The United Nations recognizes decoupling economic growth from environmental degradation as a major global challenge. The industry sector plays a vital role in addressing this challenge through sustainable and efficient technologies or material efficiency approaches. Material efficiency refers to measures that reduce the consumption of primary raw materials, including production and value chains. Assessing material efficiency can uncover interactions and quantify potential savings, including CO2 emissions. The ETSAP community has expertise in industry modeling and this project aims to combine their work and analyze specific industry sub-sectors and technologies. The project also evaluates value chains and holds workshops to describe the potential and impact of material efficiency measures and how to model them.

5.6.4 Review of the TIMES code in GAMS to identify areas for performance improvements

Number of applicants: 3 (PSI, GAMS, VTT)
Project duration: 12 months after the signing of the contract
Annual budget allocated to ETSAP project: EUR 48,500

The implementation of TIMES in GAMS provides state-of-the-art computational performance compared to other energy systems model codes. However, the increasing complexity of energy systems due to the energy transition requires a more detailed representation in TIMES. As a result, TIMES-based models have become more advanced, complex, and larger over the past decade. The larger model size is associated with increased data volume and pre-processing calculations, leading to longer computational times. This project aims to review the TIMES code to identify areas for reducing execution time. Large model instances will be created to detect performance bottlenecks, and suggestions for improvements will be provided. The implementation of these improvements will be done
under the regular maintenance contract issued by ETSAP. The project consists of three work packages, focusing on implementing large instances, reviewing and improving the TIMES code, and producing a synthesis report with recommendations. The project benefits the ETSAP community by advancing the TIMES code and providing insights into energy systems modeling programming with TIMES.

Open Source TIMES Excel Reader

**Number of applicants:** 8 and more (BEIS, CGEP, DEA, GAMS, IER, LTU, UCC, UCL, open to partnership with IEA-ETSAP members)

**Project duration:** 01/2023 - 12/2023

**Annual budget allocated to ETSAP project:** EUR 50,000

This project aims to develop an open source TIMES Excel Reader, allowing the use of excel-based TIMES models without a user interface. Currently, TIMES models are predominantly used with the VEDA user interface, which has limitations on usage and development patterns. The project was initiated by volunteers at Microsoft and has been developed on GitHub since early 2022. The tool already correctly matches 70% of inputs for the TIMES-Ireland Model (TIM). This project will finalize the TIMES Excel Reader in collaboration with the original developers and the ETSAP community’s expertise. It will be tested on at least three TIMES models, and a success rate of 90% correct input interpretation may be considered in some cases. A Future Development and Maintenance Outlook/Recommendations will be produced based on project challenges and insights. The project will integrate the TIMES Excel Reader into the TIMES-MIRO App and provide examples of GitHub actions for collaborative model development and automated result comparison. This project aligns well with other ETSAP initiatives such as TIMES MIRO App, TIMES Cloud Service, and Best Practice Guide for Applying FAIR Principles to TIMES Models, among others.

A TIMES Cloud Service

The TIMES Cloud Service offers a cloud-based solution for running TIMES models without the need for local installation and licensing of commercial software like GAMS and VEDA. It accepts jobs from various clients and provides a web user interface for job submission and administration. Jobs are placed in a queue and assigned to available GAMS workers, which solve the models. The service was launched in April 2021 and migrated to AWS Elastic Cloud in December 2021, providing powerful computing resources and enabling unlimited parallel jobs. ETSAP covers the licensing and hardware costs for the duration of the project, enhancing the accessibility and affordability of TIMES modeling tools. Future options for ongoing use and payment, including academic and commercial rates, will be discussed.
The goal of ETSAP Deutschland was to describe a global hydrogen infrastructure and to integrate it into ETSAP TIAM, as well as the given feasible potentials of renewable energies and the associated technologies. The project was accompanied by the IER (leadership), the Institute of Techno-Economic Systems Analysis (IEK-3) and the technical university of Munich (TUM).

In a first step, the technical potentials for renewable energies (especially PV and wind onshore) were determined globally. This was done by FZJ and TUM with the tools Reskit and PyGreta. In a second step, supply curves for hydrogen and synfuels were derived globally from the determined technical potentials for PV and wind onshore. These were divided into 8 price levels and aggregated for the existing 16 TIAM-IER regions, for both hydrogen and synfuels.

Within TIAM, a hydrogen and synfuel infrastructure was created. Globally, the hydrogen infrastructure was implemented using LH2. Synfuel transport can be implemented with existing technologies. In the framework of the hydrogen modeling, technologies were also implemented in the sectors industry, transport, households, commercial and agriculture.

Furthermore, scenarios for security of supply are implemented. The results show, that the 1.5°C case based on the Paris Agreement is feasible within all considered scenarios.

The results of the project were discussed in workshops and webinars and presented at the ETSAP workshop in New York in December 2022. In addition, 3 papers were written from the project.

**Workshops hosted by IFE and GCEP**

ETSAP project on "Improving the modelling of energy behaviour in TIMES models" has completed two out of three workshops:

- 15th of September by IFE in Oslo/online
- 29th of November by GCEP in NYC/online

ETSAP project on "Improving the modelling of crossborder energy trade in national TIMES-based energy system models" has completed two out of three workshops:

- 16th of September by IFE in Oslo/online
- 30th of November by GCEP in NYC/online
As defined by the United Nations, the sustainable development goals represent the “blueprint for achieving a better and more sustainable future for all”. Energy and climate are two of the many topics in the 17 Sustainable Development Goals (SDGs). There are interlinkages and trade-offs between several SDGs, which calls for holistic research approaches when investigating these goals. Integrated energy models have proven valuable in analysing the energy sector and related environmental and economic aspects. The objective is to develop and share knowledge on advanced energy and sustainability modelling to facilitate the cross-disciplinary understanding of the different resource and system interactions, including the energy system, water resources, agriculture, land-use, resilience and energy security, but also linkages to energy poverty, food security and health.

Three workshops were organised under the topic of “Integrating Sustainable Development Goals Into Energy Systems Models” which aim to trigger the expansion of TIMES-based energy systems models towards multiple SDGs other than purely related to energy and climate. The workshops provide insights on several SDG-modelling aspects, particularly on:

- methodologies for integrating sustainable development goals into energy systems modelling
- needs and requirements in associated data and identify potential data sources
- insights on the value-added gained for policy analysis by accounting for broader SDGs in the assessment of the energy transition and the instruments that enable it
- state-of-the-art synergies and trade-offs between SDGs and energy transition by exchanging robust evidence and research ideas.


The goal is to carry out a systematic comparison of hydrogen system modelling across the community and organise a joint workshop between IEA Hydrogen and ETSAP to improve the representation of hydrogen in TIMES models.

A report was published that summarises the comparison of model hydrogen inputs, the outputs for two typical decarbonisation scenarios, and makes recommendations for modelling hydrogen in the future.

The ETSAP management team organized the following three meetings with representatives for CPs involved in development of ETSAP-TIAM.

**TABLE 10 - MEETINGS TO INVOLVED CPS IN ETSAP-TIAM DEVELOPMENT**

<table>
<thead>
<tr>
<th>DATES</th>
<th>ETSAP-TIAM</th>
<th>PARTICIPANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 2022</td>
<td>Workshop, Review the ETSAP-TIAM v.2 model</td>
<td>ETSAP partners (UCC, UCL, IFE, CMA, IER, VTT, PSI, TNO, Imperial College, E4SMA, KANORS) ETSAP project head</td>
</tr>
<tr>
<td>May 2022</td>
<td>Meeting to discuss how to organize needed improvements to the ETSAP-TIAM model</td>
<td>ETSAP partners (UCC, UCL, IFE, CMA, IER, VTT, PSI, Imperial College, E4SMA) ETSAP project head</td>
</tr>
<tr>
<td>May 2022</td>
<td>Drafted a Memorandum of Understanding (MoU) to use ETSAP-TIAM</td>
<td>ETSAP partners (UCC, UCL, IFE, CMA, IER, VTT, Imperial College) ETSAP project head</td>
</tr>
</tbody>
</table>
In order to represent geographical high-resolution influences in TIAM, price potential curves developed based on GIS models and aggregated for the existing TIAM regions. At the same time, technical potentials for wind onshore and PV were estimated. Both information were transferred to the model. In the figure below the schematic of the modeling can be seen. 8 steps each for local and exportable hydrogen are considered. Within the steps, the total costs (electricity, electrolyser, local transport etc.) are included. In order to correctly represent price potential curves in TIAM, the power generation technologies (EWIN & ESOL) are integrated first, together with the RE power generation technologies, they share the maximum technical potentials using a UC. As output they provide electricity (ELCSOL & ELCWIN), which serves as input for the price potential curves. Furthermore, it gives the better Opportunity for final assessment.

Finally, hydrogen can be used locally in the end use sectors or as a global trading commodity. Therefore, a global trading scheme was developed, connecting all TIAM regions by liquid hydrogen (LH2) Transport. Each region has its own representative harbour. Which this scheme import and export of hydrogen can be investigated.
5.8 TRANSPARENCY THROUGH OPEN-SOURCE MODELS AND RESULT PLATFORMS

5.8.1 Discussion on the availability of ETSAP-TIAM as an open-source model

There is extensive discussion on the availability of ETSAP-TIAM as an open-source model. A group of users has been created and several meetings took place on the best way forward. An MoU was proposed to ETSAP for the next steps of developing and maintaining ETSAP-TIAM. The basic next steps are:

1. Development of comprehensive online documentation for the latest ETSAP-TIAM version.
2. Setup of ETSAP-TIAM on GitHub, initially as a private project.
3. Appoint a model gate keeper and decide on the model updating process and next steps.
4. Once a well-documented and robust model version is available and the updating process is established, ETSAP will decide on making it available as an open source tool.

5.8.2 Online documentation of the IFE-TIMES-Norway model

IFE-TIMES-Norway is a technology-rich model of the Norwegian energy system that is divided into five regions that corresponds to the current spot price areas of the electricity market. The model provides operational and investment decisions from the starting year, 2018, towards 2050, with model periods for every fifth year from 2020 within this model horizon. The model has a high detail level of end-use sectors (buildings, industry, and transport) in connection with the district heat and power sector. The energy system is also characterized by a hydropower dominated electricity supply, power intensive industries, and an electrified heating sector that is highly interconnected to the European power market. IFE-TIMES-Norway has a stochastic modelling options of weather-dependent supply and demand to provide investments that explicitly considers weather-dependency. additionnaly, modelling development of 2022 includes decarbonisation options in industry, end-use flexibility, energy efficiency options for buildings, offshore wind, transport technology details with focus on heavy freight transport.

IFE published a documentation report of the IFE-TIMES-Norway model in 2022 that is available online.

5.8.3 Swedish Energy Agency

The Swedish Energy agency published three different datasets on techno-economic parameters; (i) processes for different industry sectors, (ii) fuel production technologies with a focus on biofuels, (iii) Heat plants:


Those databases are compilations of information from literature, specifically tailored for use in TIMES models. Even though those specific databases have been developed for TIMES-Sweden, the data can also be applied for other regions. Those databases are continuously updated as work progresses with the TIMES-Sweden model.
Building on recent developments of the Swiss TIMES Energy systems Model (STEM), PSI contributed to a Swiss joint modelling project by making model data transparent and accessible to other modelling teams using the SWEET-CROSS data platform (CROSSDat).

The CROSSDat platform is designed to provide users with unified access to energy-related research data, as well as data related to SWEET, regardless of where it is stored and curated. By aggregating this data in one place, CROSSDat increases the efficiency of data access and contributes to the exchange, outreach, and development of SWEET-related research.

CROSSDat Structure
5.8.5 New Zealand Energy Scenarios TIMES-NZ 2.0

A web-based visualisation tool was developed to help users explore the TIMES-NZ results. The tool includes pre-formatted and interactive charts that aim to help users find the information they are after.

A new video tutorial on how to use the TIMES-NZ visualisation tool was published. It can be found on the "About" tab. There is also a button "Click here for a quick introduction tour" that triggers an interactive walkthrough of the visualisation tool.

5.8.6 Online documentation of the EnergyVille TIMES-BE model

Within the frame of the most recent project (‘PATHS2050 for Belgium’), a working documentation of the EnergyVille TIMES-BE model has been published on a dedicated website.

5.8.7 TIMES-Ireland Model (TIM is open-source)

This article describes a new Energy Systems Optimisation Model developed to inform Ireland’s energy system decarbonisation challenge. The TIMES-Ireland Model (TIM) is an optimisation model of the Irish energy system, which calculates the cost-optimal fuel and technology mix to meet future energy service demands in the transport, buildings, industry, and agriculture sectors, while respecting constraints in greenhouse gas emissions, primary energy resources, and feasible deployment rates. TIM is developed to take into account Ireland’s unique energy system context, including a very high potential for offshore wind energy and the challenge of integrating this on a relatively isolated grid, a very ambitious decarbonisation target in the period to 2030, the policy need to inform 5-year carbon budgets to meet policy targets, and the challenge of decarbonising heat in the context of low building stock thermal efficiency and high reliance on fossil fuels. To that end, model features of note include future-proofing with flexible temporal and spatial definitions, with a possible hourly time resolution, unit commitment and capacity expansion features in the power sector, residential and passenger transport underpinned by detailed bottom-up sectoral models, cross-model harmonisation, and soft-linking with demand and macro models.

The paper also outlines a priority list of future model developments to better meet the challenge of deeply decarbonising energy supply and demand, taking into account the equity, cost-effectiveness, and technical feasibility. To support transparency and openness in decision-making, TIM is available to download under a Creative Commons licence.

APPENDIX A
AN INTERNATIONAL MODELLING COLLABORATION FOR 40 YEARS

The Energy Technology Systems Analysis Programme (ETSAP) is one of the longest running Technology Collaboration Programme (TCP) of the International Energy Agency (IEA). It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy-economy-environment-engineering (4E) analytical capability.

More information on IEA-ETSAP activities, tools and users can be found at www.iea-etsap.org.

A.1 ABOUT IEA-ETSAP

Collaboration on energy modeling among different institutions started in 1976, leading to the formal establishment of the Energy Technology Systems Analysis Program (ETSAP) in 1980 initially as an Implementing Agreement and then a Technology Collaboration Programme of the International Energy Agency (IEA). It has been continually dedicated to the advancement of integrated energy system modelling platforms for 40 years.

The main goal of ETSAP is to promote and support the application of technical economic tools at the global, regional, national and local levels. ETSAP aims at preparing sustainable strategies for economic development, energy security, climate change mitigation and environment. The Contracting Parties conduct joint research and employ the ETSAP Tools to advise their national governments at the highest levels.

The program can assist in the design of least-cost pathways for sustainable energy systems, and is ideally suited for the preparation of Low-Emissions Development Strategies (LEDS) and Intended Nationally Determined Contributions (INDC) and Nationally Determined Contributions (NDC) roadmaps.
Twenty-one countries as well as one private sector sponsor formed the contracting parties to ETSAP in 2022:

- Australia (CSIRO)
- Belgium (VITO/SPW/ Brussels)
- Denmark (DEA)
- Finland (VTT/TEKES)
- France (ADEME/EDMP/DGEMPEDAD)
- Germany (IER)
- Greece (CRES)
- Ireland (SEAI)
- Italy (ENEA)
- Japan (IEEJ)
- Kazakhstan (NURIS)
- Korea (KEA)
- The Netherlands (ECN)
- New Zealand (EECA)
- Norway (IFE)
- Spain (CIEMAT)
- Sweden (STEM)
- Switzerland (PSI)
- United Kingdom (DEEC)
- United States (DOE)
- ENEL Foundation

These partners meet minimally twice a year to share knowledge, discuss the research agenda and carry out a common program of work. Any country can petition to become a contracting party of ETSAP.

Beyond these partners, the ETSAP community leads a major initiative for open source solutions for energy...
scenario modeling needs. Its backbone consists of **individual national teams in nearly 70 countries**, and a common, comparable and combinable methodology, mainly based on the MARKAL/TIMES family of models, permitting the compilation of long term energy scenarios and in-depth national, multi-country, and global energy and environmental analyses.

The community **acknowledged the importance of gender and diversity representation** within ETSAP and how gender is treated in our modelling tools.

ETSAP currently develops and maintains the TIMES (The Integrated MARKAL-EFOM System) model generator. TIMES combines two different, and complementary, approaches to modelling energy: a technical engineering approach and an economic approach. TIMES is a technology rich, bottom-up model generator, which uses linear programming to produce a least-cost energy system, optimized according to a number of user constraints, over medium to long-term time horizons. TIMES is the successor of MARKAL, where the basic components of models are specific types of energy or emission control technology, each represented quantitatively by a set of performance and cost characteristics. Based on feasibility assumptions, the model selects that combination of technologies that minimizes total energy system costs in order to balance supply and demand constraints.

**... developing, using, and promoting elegant open source solutions**

**A powerful methodology for refined scenario analyses**

**A proven approach with convenience, confidence and flexibility**
Both the IEA-ETSAP methodology and applications based on it are well documented. This documentation reveals the real world issues that are being addressed using the IEA-ETSAP methodology and not just the technical details of the research. This makes the documentation very useful for policy makers who will have the opportunity to review how similar research has been done in the past. The methodology is open source which enables support, both formal and informal, from a large vibrant community.

ETSAP makes its Newsletter and its Workshop Proceedings available online to the public at large.

In terms of applications, IEA-ETSAP energy system analysis is ideal for long-term energy-environment modeling in the context of climate change. The analysis is highly detailed and there is a large community of users sharing innovations. The methodology has also been tried and tested exhaustively over the years, is very transparent and well documented, which enables any researcher to know exactly how the analysis is being done and make incremental changes if needed.

The IEA-ETSAP methodology has been used for applications at different levels, including global such as the Global Integrated Assessment models and Global Energy models, regional such as the Pan-European TIMES, and in various national and local applications for energy systems planning and analysis.
Participants from each of the 22 contracting parties form the Executive Committee (ExCo) meet in workshops and other events as well as online meetings. Table 1 shows a list of participants, along with their participation to each of the Executive Committee.

Any country can petition to become a contracting party of ETSAP. The ExCo approves the fee for participation: 20k€ fee per annum for member countries and 30k€ fee for sponsors. This includes privileged access to ETSAP Tools, the support systems and related services contracted on behalf of ETSAP or made available to Participants by the Operating Agent acting on decisions taken by the Executive Committee. This includes:

- a small group license to the ANSWER/VEDA model management systems for MARKAL/TIMES,
- access to the global ETSAP-TIAM model at no charge,
- discounted fees for the GAMS language in which the MARKAL and TIMES model generators are written for own and outreach purposes (if possible),
- as well as participation free of charge to the training courses organised by ETSAP.

<table>
<thead>
<tr>
<th>N.</th>
<th>COUNTRY</th>
<th>ONLINE (85TH) FEBR 2022</th>
<th>FREIBURG ONLINE (86TH) MAY 2022</th>
<th>ONLINE (87TH) SEPT 2022</th>
<th>NEW-YORK ONLINE (88TH) DEC 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Australia</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Belgium</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Denmark</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Finland</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Germany</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Greece</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>Italy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>Ireland</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>Japan</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>Kazakhstan</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>Korea</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>13</td>
<td>Netherlands</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
The ExCo regularly discuss possible invitations to potential new member countries. 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. Example of outreach efforts:

- **Centre for Strategic Energy and Resources (Singapore).** Communication with Dr Victor NIAN (Co-Founder & Chief Executive Officer for CSER) to participate as sponsor to IEA-ETSAP.

- **World Bank.** Two meetings to explore opportunities and barriers to creating in-house energy system modelling capabilities, potentially using TIMES. Raimund Malischek, Lauren Culver, Szilvia Doczi, Claire Nicolas.

- **Portugal,** communication with Dr Teresa Ponce de Leão, Chair of Executive Board of LNEG Laboratório Nacional de Energia e Geologia. Invitation sent to the Ministry of Energy. The invitation letter has been issued to Portugal to enable participation in ETSAP as a Contracting Partner. ETSAP is waiting for response.

- **Singapore,** communication with Dr Aloisius Rabata Purnama. Invitation sent to the National Climate Change Secretariat for the participation of the Agency for Science Technology And Research (“A*STAR”).

- **Ukraine:** The industry on energy has received the invitation, waiting for cabinet approval.

- **Israel** is still considering the invitation join ETSAP.

- **Kazakhstan:** ETSAP efforts continue.

- The participation of **Austria** will be further encouraged.
A.3 OFFICIAL ETSAP WORKSHOPS

IEA-ETSAP partners traditionally met twice a year in regular workshops to share knowledge, discuss the research agenda and carry-out a common program of work, notably to exchange experiences and discuss ways to improve the tools. During the pandemic, these regular workshops were replaced with a series of online meetings.

The workshops are open to all interested parties, including local experts, who are invited to these meetings so that they are exposed to the methodology and can interact with the IEA-ETSAP participants from their country. These meetings often lead to collaborative model building projects with local and third party funds. Meetings that happened in 2022 are listed below.

**TABLE 2 – LIST OF REGULAR WORKSHOPS AND SPECIAL EVENTS**

<table>
<thead>
<tr>
<th>DATE</th>
<th>VENUE</th>
<th>DESCRIPTION</th>
<th>PARTICIPANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st - 2nd December 2022</td>
<td>New York (USA)-Online</td>
<td>Winter 2022 - Semi-annual ETSAP meeting</td>
<td>50</td>
</tr>
<tr>
<td>23rd - 24th May 2022</td>
<td>Freiburg (Germany) Online</td>
<td>Summer 2022 - Semi-annual ETSAP meeting</td>
<td>50</td>
</tr>
</tbody>
</table>

A.4 BUDGET

The budget for 2022 is presented below. The proposed budget for 2023 was also presented to the ExCo. The ExCo decided to transfer €150,000 from 2022 budget to 2023 to contribute to essential costs, and agreed the budget expenditure of €239,600 for 2023, including the above items. The ExCo also decided to allocate up to €250,000 to project proposals and to hold €50,000 in reserve.

Expense by category in 2022
### TABLE – ETSAP BUDGET FOR 2021 AND 2022

<table>
<thead>
<tr>
<th>PLANNED AND ACTUAL</th>
<th>2021</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income Membership</td>
<td>Actual 380 000</td>
<td>Actual 313 000</td>
</tr>
<tr>
<td>Income Membership (late)</td>
<td>Late Actual 20 000</td>
<td>Late Actual 40 000</td>
</tr>
<tr>
<td>Income (training, change OA,</td>
<td>Actual 11 650</td>
<td>Actual 10 900</td>
</tr>
<tr>
<td>transfer funds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income from previous year</td>
<td>Actual 602 498</td>
<td>Actual 876 081</td>
</tr>
<tr>
<td>Base Activities</td>
<td>Actual 118 067</td>
<td>Actual 79 790</td>
</tr>
<tr>
<td>Coordinated Projects</td>
<td>Actual 20 000</td>
<td>Actual 91 455</td>
</tr>
<tr>
<td>Total costs</td>
<td>138 067</td>
<td>171 245</td>
</tr>
<tr>
<td><strong>BALANCE</strong></td>
<td><strong>876 081</strong></td>
<td><strong>1 068 736</strong></td>
</tr>
</tbody>
</table>

| TRANSFER OF INCOME                 |                  |                  |
| Transfer of funds for ETSAO-TIAM   | Budget 40 000    | Budget -         |
| development                        |                 |                 |
| Transfer Income (Core activities)  | Budget 150 000  | Budget 150 000  |
| Total transfer income              | 190 000         | 150 000         |

| COMMITMENTS                        |                  |                  |
| Base Activities (contracted not    | Commitments 31 000 | Commitments 126 965 |
| invoiced)                          |                 |                 |
| Coordinated Projects (new)         | Approved 129 000 | Approved -      |
| Coordinated Projects (from prev.    | Commitments 450 655 | Commitments 488 200 |
| years)                             |                 |                 |
| Total Commitments                  | 610 655         | 615 165         |
| **BALANCE**                        | **75 426**      | **303 571**     |

| Commitments transferred to next     | 610 655         | 615 165         |
| year                               |                 |                 |
| Income transferred to next year    | 686 081         | 918 736         |
| New Balance                        | 0               | 0               |
The work program of IEA-ETSAP is organized in three-year projects called ‘Annexes’. This report focuses on the published outputs of IEA-ETSAP activity in 2022 delivered during Annex XV: Energy System and Sustainable Development Goals. The main objectives for the Annex XV are:

**a) Tools Maintenance, Improving and Capacity Building**

ETSAP Tools and Methodologies development and maintenance for the long term analysis of the energy, economy, environment interactions, is the minimum objective of this Annex.

1. Maintenance, update and improvement of TIMES, together with the development of user interfaces (for data input to the TIMES / MARKAL models, and analysis of the model results);
2. Increasing the transparency, openness and affordability of the TIMES model generator, associated software and data sets.
3. Maintenance, extension and improvement of international and national capabilities on the use of ETSAP’ tools, across developed and developing countries;
4. Availability of online user’s support systems including tutorials, user’s forums, manuals and reference material.

**b) Research and Development**

ETSAP will support research and development activities in order to advance the state-of-the-art of energy systems analysis. A non-exhaustive list of topics includes:

1. Pathways to net zero GHG emissions systems;
2. Interaction of energy systems with materials use, land use, water and agriculture;
3. Integrate issues of sustainability of biomass in the analyses (e.g. biomass GHG overshoot problem);
4. Improved modelling of variable renewables and short-term system operational issues in long term energy systems modelling;
5. Improved modelling of the consumption side of energy systems, demand side flexibility, integrating human behaviour and societal aspects into energy systems modelling;
6. Improved modelling of the interactions between the energy system and social systems, structural changes, circular economy and SDG’s ;
7. Energy Technology Data Source (E-TechDS) updates. Focus on negative emission and renewable fuel technologies;
8. Continued development and improvement of the Global Integrated Assessment ETSAPTIAM model

In addition, ETSAP will explore and develop collaboration opportunities with IEA and IRENA building on and deepening existing collaboration.


Koljonen T., Lehtilä A., Honkatukia J., Markkanen J. (2022). Pääministeri Sanna Marinin hallituksen ilmasto- ja energiapoliittisten toimien vaikutusarviot: Hiilineutraali Suomi 2035 (HIISI) -jatkoselvitys. [Impact assessments of the climate and energy policies formulated by the Government of Prime Minister Sanna Marin: Carbon neutral Finland 2035 (HIISI) follow-up study]. VTT Technical Research Centre of Finland. VTT Technology No. 402


More information on IEA-ETSAP activities, tools and users can be found at www.iea-etsap.org