ETSAP is a Technology Collaboration Programme of the International Energy Agency since 1980.

ANNEX XV - ENERGY SYSTEMS AND SUSTAINABLE GOALS (2022-2022)

Editor: Kathleen Vaillancourt
With collaboration from: Simon Langlois-Bertrand
"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 years 2020 and 2021 were very challenging globally, as we responded as best we could to the terrible COVID-19 global pandemic. Many of us became ill, lost people close to us, and significantly changed how we lived and worked. Within IEA-ETSAP, we adhered to travel restrictions that were introduced in response to the pandemic, transitioning quickly to online energy systems modelling workshop, training and Executive Committee meetings. We missed the in-person meetings and what they brought, impromptu conversations over coffee and new collaborations fostered over evening meals. We took advantage however of some of the opportunities associated with the virtual world, enhancing our digitilisation strategy through the introduction of a series of webinars with topics selected by the IEA-ETSAP modelling community, which we subsequently made available as recordings on ETSAP’s YouTube channel.

In terms of outputs and productivity, 2020 and 2021 were 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 National Energy and Climate Plan in Serbia, the Energy Sector Development Strategic Programme in Armenia, supporting the Ministry of Industry and Trade (MOIT) in Vietnam, improving government capacity in the development of the national energy planning in Peru, supporting Government departments in Finland to develop policies to reach carbon neutrality by 2035, underpin New Zealand’s first Emissions Reduction Plan, Ireland’s first 5 yearly carbon budgets, Italy’s 2030 targets under EU policy and transport mitigation in Switzerland’s Västerbotten region.

The report also highlights some of the specific hot topics undertaken by IEA-ETSAP Contracting Parties, including the roll out of local energy communities in Belgium, implications of the national climate targets in Germany on the energy water nexus, comparing zero carbon emissions scenarios with 100% renewable energy targets in Ireland, assessing the impacts of the EU Fit for 55 package on Italy, the Stanford Energy Modeling Forum (EMF) 35 study for Japan’s long-term climate and energy policy, estimating the cost of decarbonisation in New Zealand, exploring the transition from a petroleum economy in Norway to a low-carbon society through hydrogen, assessing industrial sector GHG reduction potential in South Korea, the impacts of technology availability on the transition to net-zero industry in Sweden, impact assessment of the UK’s sixth carbon budget and net-zero pathways for the Swiss cement industry.

Regarding TIMES tools and modelling developments, the years 2020 and 2021 saw significant advances, including making the TIMES model generator open source (the TIMES source code is available under a GNU General Public Licence v3.0), and the launching of VEDA 2.0, the new user interface that was completely rebuilt after 2019. 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 Switzerland, New Zealand, Belgium, Norway, Sweden, Germany, Ireland and the United Kingdom.
Finally, the report also summarises some of the key IEA-ETSAP capacity building activities during 2020-2021, including four workshops (with an average 102 participants per workshop), twelve ETSAP VEDA 2.0 TIMES training courses (with a total of 126 trainees) along with bespoke training for 20-25 trainees in Peru. 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 high resolution modelling, building a multi-regional TIMES model, introducing ancillary services markets in TIMES and Modelling clean energy transitions: approaches and tools for the World Energy Outlook and the Energy Technology Perspectives.

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.

Brian Ó Gallachóir
Chair, Executive Committee
IEA-ETSAP
Formally 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). 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. Twenty-one countries, the European Commission, as well as one private sector sponsor formed the contracting parties to ETSAP during the 2020-2021 period. 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.

Work under the auspices of the ETSAP led to a considerable number of studies conducted during the 2020-2021 period covering a large variety of topics (Section 2). Studies done by the Contracting Parties led to the modelling of several net zero emission pathways (Ireland, Italy, Switzerland, United Kingdom, Sweden), deep decarbonisation pathways (Germany, New Zealand) or intermittent renewable energy scenarios (Belgium, Ireland, Norway), with sensitivity analysis around techno-economic parameters. Other topics researched by Contracting Parties included the Energy-Water Nexus interactions (Germany), the role for hydrogen in different jurisdictions (Norway, The Netherlands), the GHG emission reduction potential in the industrial sector (Korea) or the transportation sector (Sweden) and the role for colac communities (Belgium). Some contributions were related to the assessment of energy and climate policy packages such as the Fit for 55 package on the Italian National Energy and Climate Plan (Italy) and the Carbon Budget 6 Impact Assessment (United Kingdom). Moreover, participation to the Energy Modelling Forum... the Contracting Parties in action
was covered (Japan). Finally, new models were also introduced (Spain) for the development of Climate and Energy Strategies and Plans. A more extensive list of these studies is found in the reference section at the end of this report.

... supporting decision making with optimal energy and climate strategies

Models were also developed and used concretely by Contracting Parties and other organisations to support policy making (Section 3) around: the development of Energy and Climate Plans (Armenia, Serbia, Italy, Vietnam), energy planning and renewable energy integration (Peru), the evaluation of policies and measures for reaching carbon neutrality targets (Finland, Switzerland), support the definition of carbon budgets (New Zealand, Ireland, United Kingdom), inform the nuclear debate (Belgium), support local policy planning (Sweden). With a strong stakeholder engagement component, the Paris Reinforce project aims to create an open-access data exchange platform, I2AM PARIS, to support the effective implementation of Nationally Determined Contributions (NDC) and the reinforcement of the 2023 Global Stocktake. It supports the TIMES Integrated Assessment Model (TIAM), the EU-TIMES model, and several regional or national models (Hungary, India, Canada, USA, Mexico, Central Asian Caspian region).

... collaborating with high profile organisations worldwide

ETSAP activities also included various collaboration with other organizations (Section 4). First, activities were conducted in collaboration with the International Renewable Energy Agency (IRENA), a recognized intergovernmental organisation that supports countries in their transition to a sustainable energy future. Several ETSAP Contracting Parties partnered with IRENA for the “Long-term Energy Scenarios Network” (LTES Network) initiative. The objective of the initiative was to have a platform for national and regional energy scenario practitioners to share experience and good practices in using and developing scenarios. Activities were also conducted in collaboration with other IEA-TCps: a collaboration was initiated with TCP Hydrogen, a joint workshop that took place with TCP Storage, while an activity was organized with TCP Combustion on energy systems analysis, including de-fossilized transport/new mobility, gas turbines with hydrogen, and co-firing of hydrogen in stationary applications. Other collaborations are initiating with TCP Bioenergy and TCP-IETS. Other activities were done in collaboration with the Energy Modelling Forum (EMF) at different times, as well as with the Intergovernmental Panel on Climate Change (IPCC).

... and supporting the development of best-in-class modelling tools

The work conducted by various actors during the 2020-2021 period led to the development and advancement of several tools and methodologies, including modelling with the open-source TIMES model generator, maintenance and improvements of TIMES, user interfaces’ improvements and maintenance, notably VEDA2.0 and VEDA Online, as well as various updates to documentation and other reference material (Section 5). Numerous capacity building activities occurred to support the new generation of modellers including trainings, webinars and sessions dedicated to stakeholder engagements. Finally, multiple examples of open-source initiatives were put in place during the 2020-2021 period, such as online model documentations and result platforms as examples of transparency.
Models were also developed and used concretely by Contracting Parties and other organisations to support policy making (Section 3):

- **Serbia**: The Serbian Energy System Model – SEMS was developed to help the development of the National Energy and Climate Plan of Serbia.

- **Armenia**: TIMES-Armenia was prepared by the experts at the Scientific Research Institute of Energy (SRIE) to guide the preparation of the Armenia Least-Cost Energy Development Plan (LCEDP) as part of the USAID funded Market Liberalization and Electricity Trade (MLET) Program.

- **Viet-Nam**: TIMES-Vietnam was assembled as part of a World Bank / Program for Market Reform low-carbon development pathway analysis in support of the Ministry of Industry and Trade (MOIT) of the government of Vietnam.

- **Peru**: A partnership with GET.Transform, a Global European program, led to the development of a TIMES model to support the Ministry of Energy and Mines of Peru (MINEM) with energy planning and renewable energy integration.

- **Finland**: Modelling work was used in several instances to directly support policy making in different Government departments to reach carbon neutrality in Finland by 2035 and to fulfill the EU’s proposals included in the FitFor55 policy package. This includes Carbon neutral Finland 2035 – impact assessments of climate and energy policies and measures (project HIISI, 2020–2021); impact assessments of the alternative emissions targets of the new climate law in Finland; and sustainable growth scenario for the Finnish bioeconomy.

- **New Zealand**: Details provided by the TIMES-NZ 2.0 NZ Energy Scenarios contributed to the broader policy development and consultation process across government and industry in the broader context of the ‘Emissions Budgets’ developed and proposed by the independent Climate Change Commission (CCC).

- **Belgium**: The development of Long-term electricity system scenarios for Belgium ordered by ENGIE/ Electrabel, with the 1-region EnergyVille TIMES BE model, aims to provide fact based, objective input for all involved stakeholders and policy makers in the nuclear debate going on in Belgium, including policy makers (national local governments, etc.) and the federal Government of Belgium.

- **Italy**: The TIMES-RSE and s-MTSIM models are used to assess the 2030 targets under FF55 Directives for the Ministry of Ecological Transition (Fit for 55 targets) and to support the definition of the Hydrogen Strategy.

- **Switzerland**: The Swiss TIMES Energy Systems Model (STEM) is used to help the Swiss Innovation Agency assess realistic net-zero CO2 emissions pathways for Switzerland in the context of the Swiss Competence Centre for Energy Research Joint Activity Scenarios and modelling.

- **Sweden**: Modelling with the TIMES-City model applied to the transport sector in the Västerbotten region was used to support a deeper understanding among local policy-makers and to help underpin local decarbonisation strategies. Different collaborations involved the TIMES_URBAN_LT model, with scenarios developed together with municipality stakeholders, and the TIMES_URBAM_Qbg model, used to assess the sensitivity of district heating as the most cost-effective heating option.

- **Ireland**: TIMES-Ireland Model (TIM) has been used to better inform increased national climate mitigation ambition; Ireland’s legislation (Climate Action and Low Carbon Development (Amendment) Act 2021) established a 5 yearly carbon budget process for the periods 2021-2025 and 2026-2030.

- **United Kingdom**: The Climate Change Act requires the government to set the sixth carbon budget as a limit on the net UK carbon account over 2033-37; the modelling, and the majority of monetised cost and benefits, use the UK TIMES model (UKTM).
# TABLE OF CONTENTS

Foreword from the chair .......................................................... 3
Summary ................................................................................. 5

### Highlights – Supporting climate actions using ETSAP tools

1. Introduction to the modelling community of the ETSAP-IEA ........................................... 11

2. Contracting Parties in action with studies on hot topics .................................................. 13

   2.1 Sample of studies on hot topics .................................................................................. 14
   2.2 Spain - Improving TIMES-SINERGIA model characteristics and technologies ........ 15
   2.3 Japan - EMF 35 JMIP study for Japan’s long-term climate and energy policy .......... 16
   2.4 Belgium – The Bregilab project ................................................................................. 17
   2.5 Belgium - Roll Out of Local Energy Communities (ROLECS) ................................. 18
   2.6 Germany - Implications of national climate targets for Energy-Water Nexus .......... 20
   2.7 Germany - How to reach the New Green Deal targets using a multi-model approach 21
   2.8 Ireland – Comparing 100% renewable energy scenarios with zero CO2 emissions scenarios 22
   2.9 Italy - Zero emissions scenarios for the long term strategy ........................................ 23
   2.10 Italy - The impact of the Fit for 55 package on the Italian NECP ................................ 24
   2.11 New Zealand - TIMES-NZ 2.0 NZ energy scenarios ............................................. 25
   2.12 New Zealand - Estimating the cost of decarbonisation in New Zealand ................ 26
   2.13 Norway - Stochastic modelling of variable renewables in energy system models .... 26
   2.14 Norway - The transition from a petroleum economy to a low-carbon society through hydrogen ................................................................. 27
   2.15 South Korea - 2040 Industrial sector GHG reduction potential assessment ............ 28
   2.16 Sweden - The impact of technology availability on the transition to net-zero industry in Sweden ................................................................. 29
   2.17 Sweden - Exploring transitions to fossil independent transportation in Denmark .... 29
   2.18 Switzerland - Long-term energy transformation pathways ..................................... 31
   2.19 Switzerland – Net-zero pathways for the Swiss cement industry ........................... 33
   2.20 The Netherlands - An electricity and hydrogen partnership between Europe and North Africa ................................................................. 34
   2.21 United Kingdom - Carbon Budget 6 Impact Assessment ............................................ 35
   2.22 United Kingdom - The Net Zero Strategy ................................................................. 36

3. Decision making with optimal energy and climate strategies ......................................... 37

   3.1 Serbia - The National Energy and Climate Plan ......................................................... 37
   3.2 Armenia – The Energy Sector Development Strategic Program to 2040 .................... 38
   3.3 Vietnam - Least-cost low-carbon development pathways ......................................... 38
   3.4 Peru - GET.Transform, a Global European program ................................................. 38
   3.5 Finland - Policy making to reach carbon neutrality by 2035 .................................... 39
   3.6 New Zealand - An Emissions Reduction plan with emission budgets ...................... 39
   3.7 Belgium - Long-term electricity system scenarios ...................................................... 40
   3.8 Italy – Assessing 2030 targets ................................................................................. 41
3.9 Switzerland - Realistic net-zero CO₂ emissions pathways
3.10 Sweden - CO₂ mitigation action plans for the transport sector in Västerbotten
3.11 Sweden - Local policies using local models
3.12 Ireland - Supporting the Climate Change Advisory Council
3.13 United Kingdom - Defining carbon budgets
3.14 The Paris Reinforce project

4. Collaboration with high profile organizations worldwide
4.1 Activities in collaboration with IRENA
4.2 Activities in collaboration with other IEA-TCPs
4.3 Activities in collaboration with EMF
4.4 Activities in collaboration with IPCC

5. Sophisticated tools and methodologies
5.1 Modelling with the open-source TIMES model generator
5.2 TIMES maintenance, update and improvement
5.3 User interfaces’ maintenance, update and improvement
  5.3.1 VEDA2.0
  5.3.2 VEDA Online
5.4 Documentation and other reference material
5.5 Capacity building in both developed and developing countries
  5.5.1 Trainings
  5.5.2 Webinars
5.6 Engagement with stakeholders
  5.6.1 Training ministry energy experts in Algeria by CRES (Greece)
  5.6.2 General public outreach in New-Zealand
  5.6.3 Consultation with experts in South Korea
  5.6.4 Invited talks to key Swiss stakeholders
  5.6.5 Engaging local transport decision-makers in Sweden
  5.6.6 Stakeholder engagement in Ireland
5.7 Project funded to enhance methodologies
  5.7.1 A TIMES Cloud Service
  5.7.2 A TIMES-MIRO App
  5.7.3 Defining regions and time slices by period
  5.7.4 Use of the online platform of KAPSARC as a repository
  5.7.5 Improving the modelling of energy behaviour in TIMES models
  5.7.6 Improving the modelling of crossborder electricity trade in national TIMES-based energy system models
  5.7.7 Best Practice Guide for Applying FAIR Principles to TIMES Models
  5.7.8 Update the technology repository of the TIMES-Starter
5.8 Status and updates for ETSAP-TIAM
5.9 Transparency through open-source models and result platforms
5.9.1 New open-source user interface for TIMES-based models
5.9.2 New Zealand Energy Scenarios TIMES-NZ 2.0
5.9.3 Belgian long term electricity system scenarios
5.9.4 Online documentation of the IFE-TIMES-Norway model
5.9.5 Switzerland Joint Activity Scenarios and Modelling (JASM)
5.9.6 Swedish Energy Agency
5.9.7 Germany
5.9.8 United Kingdom
5.9.9 Ireland

Appendix A - An international modelling collaboration for 40 years
A.1 About IEA-ETSAP
A.2 Executive Committee
A.3 Official ETSAP workshops
A.4 Budget
A.5 Ongoing research program

References
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.

Twenty-one countries, the European Commission, as well as one private sector sponsor formed the contracting parties to ETSAP during the 2020-2021 period. 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.

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 over the years 2020 – 2021 delivered during Annex XIV: 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 XIV 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 XIV includes a list of references published between 2020 and 2021 only, 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

- Applied Energy
- Energy
- Nature Energy
- Climate Policy
- Energy Economics
- Energy Policy
- Energy Strategy Reviews
- Nature Climate Change
- Low Carbon Economy
- Transport Policy
- Climatic Change
- Procedia Computer Science
- Global Environmental Change
- Economy of Ukraine Journal
- Transport Policy
- Resources
- Atmospheric Environment
- Futures
- Energy Procedia
- GCB Bioenergy
- Annals of Nuclear Energy
- Renewable and Sustainable Energy Reviews
- International Journal of Hydrogen Energy
- Environmental Modeling and Assessment

- Journal of Cleaner Production
- Energy Conversion and Management
- Technological Forecasting & Social Change
- International Journal of Electrical Power & Energy Systems
- Transportation Research Part D: Transport and Environment
- International Journal of Climate Change Strategies and Management
- Transportation Research Part A: Policy and Practice
- Clean Technologies and Environmental Policy
- Mitigation Adaptation Strategy Global Change
- Energy Research & Social Science
- Environmental Modelling & Software
- International Journal of Greenhouse Gas Control
- International Journal of Global Energy Issues
- Transportation Research Procedia
- Energy for Sustainable Development
- Agricultural and Forest Meteorology
- Conservation and Recycling
- Geoscientific Model Development
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 during the 2020-2022 period (see the list of references). Many studies involved experts from several countries; studies have been identified with the countries/affiliations of the first author.

<table>
<thead>
<tr>
<th>CONTRACTING PARTIES</th>
<th>STUDY</th>
</tr>
</thead>
</table>
| **BELGIUM**<br>VITO | • The Bregilab project  
• Roll Out of Local Energy Communities - ROLECS |
| **GERMANY**<br>Universität Stuttgart, Institute of Energy Economics and the Rational Use of Energy - IER | • Implications Of national climate targets on Energy-Water Nexus  
• How to reach the New Green Deal targets using a multi-model approach |
| **IRELAND**<br>MaREI Research Centre | • Comparing zero carbon with 100% renewable energy scenarios for Ireland  
• Modelling pathways to meet Ireland’s long-term energy system challenges with the TIMES-Ireland Model (v1.0) |
| **ITALY**<br>ENEA - RSE | • Zero emissions scenarios for the Italian long term strategy  
• The impact of the Fit for 55 package on the Italian NECP |
| **JAPAN**<br>The Institute of Energy Economics  
The Institute of Applied Energy | • EMF 35 JMIP study for Japan’s long-term climate and energy policy |
| **KOREA**<br>Korea Energy Agency (KEA) | • 2040 Industrial sector GHG reduction potential assessment |
| **THE NETHERLANDS**<br>ECN part of TNO | • An electricity and hydrogen partnership between Europe and North Africa |
| **NEW ZEALAND**<br>EECA | • TIMES-NZ 2.0 NZ energy scenarios  
• Estimating the cost of decarbonisation in New Zealand |
| **NORWAY**<br>Institute for Energy Technology - IFE | • Stochastic modelling of variable renewables in energy system models  
• The role of hydrogen in the transition from a petroleum economy to a low-carbon society |
| **SPAIN**<br>CIEMAT | • Improving TIMES-SINERGIA model characteristics, processes and technologies |
| **SWEDEN**<br>Luleå University of Technology  
Chalmers University of Technology | • The impact of technology availability on the transition to net-zero industry in Sweden  
• Exploring cost-effective transitions to fossil independent transportation in the future energy system of Denmark |
| **SWITZERLAND**<br>Swiss Federal Office of Energy  
PAUL SCHERRER Institute - PSI | • Long-term energy transformation pathways with the Swiss TIMES energy systems model  
• Decarbonization pathways of the Swiss cement industry towards net zero emissions |
| **UNITED KINGDOM**<br>Department for Business, Energy & Industrial Strategy  
University College London | • Carbon Budget 6 Impact Assessment  
• The Net Zero Strategy |
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

## 2.2 SPAIN - IMPROVING TIMES-SINERGIA MODEL CHARACTERISTICS AND TECHNOLOGIES

This project was titled “Improving TIMES-SINERGIA model characteristics, processes and technologies.” The study aims to assist the Spanish Ministry for the Ecological Transition and the Demographic Challenge (MITECO) and other public stakeholders to improve the main modelling tool for the Spanish Climate and Energy Strategies and Plans, TIMES-SINERGIA, as well as to develop a detailed model of the Spanish power system, also to be employed in the development of the Climate and Energy Strategies and Plans. The upgraded TIMES-SINERGIA and the new model of the Spanish power system will support the implementation and monitoring of Spanish energy transition plans, in order to achieve a carbon neutral economy at least-cost and in a timely manner, in coordination with the EU and other Member States, within the framework of the Governance of the Energy Union. The project was conducted by Trinomics in collaboration with CIEMAT and IIT, and ran from October 2020 and to June 2021.

This work was performed under the framework contract with the EC REFORM/SC2020/069 – «Improving energy system modelling tools and capacity» in cooperation with TRINOMICS and IIT. It used the TIMES-SINERGIA model, with two main categories of results: first, a CIEMAT contribution (disaggregation of the industrial sector has been improved, adding nine new subsectors, heat in the industrial sector has been disaggregated in temperature ranges, modelling of cogeneration units has been improved, modelling of heat pumps for heating and cooling has been improved, and disaggregation of the commercial sector into six subsectors has been achieved); second, an IIT contribution (improved representation of the electricity sector, soft linking of TIMES SINERGIA with the electricity model OPEN TEPES, updated SubRes, increasing of the time resolution to 96 TS, modal shift representation in the transport sector, improved representation of demand response and storage technologies).
Five energy-economic and integrated assessment models, including TIMES-Japan, were used in this project to evaluate the nationally determined contribution and mid-century strategy of Japan. The study conducted a suite of sensitivity analyses on dimensions including emissions constraints, technology availability, and demand projections. Scenarios included 80-100% reduction by 2050 with different technology costs and potentials, demand levels, and energy import prices. Among the main results, the median carbon price for the main mitigation scenario (80% reduction by 2050) rises to 819 (2010USD/t-CO2) by 2050.

The results imply that Japan needs to deploy all of its mitigation strategies at a substantial scale, including energy efficiency, electricity decarbonization, and end-use electrification. They also suggest that with the absence of structural changes in the economy, heavy industries will be one of the hardest to decarbonize. Partitioning of the sum of squares based on a two-way analysis of variance (ANOVA) reconfirms that mitigation strategies, such as energy efficiency and electrification, are fairly robust across models and scenarios, but that the cost metrics are uncertain.

2.4 BELGIUM – THE BREGILAB PROJECT

The 4-year BREGILAB project aims to gain a better understanding of the renewable energy potential in Belgium and the integration of high resolution data sets in terms of temporal and spatial resolution in energy (system) models. The model used is TIMES BE – Bregilab, and the main result is high resolution renewable generation sources profiles.

An important aspect is the successful exchange of available data and linking of the respective modelling approaches in the different research domains collaborating within this project: meteorological models, spatial model/analysis applications (GIS), generation forecast tools and energy (system) models.

Simplified representation of data flow

The TIMES BE model plays an integral part in the testing of the develop data sets and serves as a benchmark for other model applications.
ROLECS is a unique cooperation between all Flemish research institutes active in the energy sectors and 25 companies all working towards gaining a deeper understanding and maximizing the potential of Local Energy Communities (LECS). These communities, following up EU policy on energy, create a landscape that is more sustainable and with active participation of the end-consumer/producer (the so-called prosumer).

A TIMES model, limited to the residential and commercial sector model and with temporal high resolution, has been developed to analyze various levels of engagement by the end user: consumer profile, prosumer profile, LEC soft and LEC hard. The TIMES model application provides insights into EV charging patterns, investments in PV and electric storage and corresponding peak load in the low voltage grid. Scenarios include the impact of Local Energy Communities (LEC) with collaborative Prosumer profiles.
There are several implications of LEC roll-out from a national scale energy systems perspective, notably that flexible EV charging has an important impact on peak loads and battery storage in LECs or individual buildings, and that prosumer potentials matter, but LEC impact is hard to quantify. Further work includes system perspective, electrification scenarios, additional flexibility options, and uncertainty with regard to grid constraints and costs as well as user behavior.
This project used the TIMES PanEU model on energy-water interactions. First, with regard to water demand for cooling technologies: thermal power stations are highly dependent on cooling water mostly taken from rivers. Due to greenhouse gas mitigation strategies and the decided nuclear power phase-out in Germany, the number of fossil power stations will strongly decrease in the future. Second, with regard to the irrigation of energy crops: irrigation will become more important not only due to climate warming but because it could be an option to increase the yield of energy and food crops. Therefore, the optimal amount of irrigation could enhance the land productivity, which is an appealing option for countries with land scarcity. Since investment decisions are necessary for building the irrigation infrastructure to take advantage of the increased biomass potential, this interaction was integrated in the energy system model.

Another dimension is total water demand: to get an overall picture of the total future water resource use, the public and industrial water supply and its outlook was considered based on a literature assessment. Finally, total renewable water supply: a regression analysis based on the last 25 years of renewable water supply was conducted in order to estimate the future limits of a water-stress free resource use.

Three climate policy scenarios were calculated and compared: an EU-ETS Scenario; a national 90% Greenhouse Gas (GHG) reduction target; a cumulative GHG cap over the years 2025-2050, which corresponds to a 95% GHG mitigation scenario for Germany. Among the main results, the total future water demand in 2050 in Germany varies according to different climate policy scenarios between 15.6 and 22.5 billion m³ of water and is declining in all scenarios of 4-32 %. When the total water demand is compared to the regression analysis of the past renewable water availabilities, the risk of future water stress can be calculated to a probability of 30% for the highest climate target, if the standard deviation of past data points is taken into account. The total water demand changes from mostly river water withdrawals for cooling purposes to more groundwater water consumption for irrigation purposes. Using these results to inform thinking on how recycled waste water could be applied for irrigation, it leads to measures where the risk of future water stress could be nearly eliminated.
Overall, these results contain a few highlights, notably that the more ambitious the GHG reduction target, the further decline can be observed in the cooling water demand; that a trade-off relation between future water use for irrigation and high GHG reduction can be observed for strong climate goals; and that the future possibility of irrigating biomass plants to increase the yield should be avoided in the more water scare region like Brandenburg by increasing the price for groundwater or by using recycled water.

Total water use


2.7 GERMANY - HOW TO REACH THE NEW GREEN DEAL TARGETS USING A MULTI-MODEL APPROACH

Another use of the TIMES PanEU (in combination with the CGE model NEWAGE) was applied with regard to the Green Deal of the European Union, defines extremely ambitious climate targets for 2030 (-55% emissions compared to 1990) and 2050 (-100%). The question of which sectors contribute how much has already been discussed, but is far from decided, while the question of which countries shoulder how much of the tightened reduction targets has hardly been discussed. The project wants to contribute significantly to answering these policy questions by analysing the necessary burden sharing within the EU from both an energy system and an overall macroeconomic perspective.

Three main scenarios were examined for this study: optimal (reaching the primary climate targets without additional restrictions); ETS first (reaching the climate targets, but with a major contribution from the ETS sector); and ESR more (meeting the climate targets, but with a major contribution from the ESR sectors). Results show that excessively strong targets for the Emission Trading System (ETS) in 2030 are not system-optimal for achieving the 55% overall...
target, reductions should be made in such a way that an emissions budget ratio of 39 (ETS sector) to 61 (Non-ETS sector) results. Economically weaker regions would have to reduce their CO2 emissions until 2030 by up to 33% on top of the currently decided targets in the Effort Sharing Regulation, which leads to higher energy system costs as well as losses in gross domestic product (GDP). Depending on the policy scenario applied, GDP losses in the range of -0.79% and -1.95% relative to baseline can be found for single EU regions.

In the long-term, an equally strict mitigation regime for all countries in 2050 is not optimal from a system perspective; total system costs would be higher by 1.5%. Instead, some countries should generate negative net emissions to compensate for non-mitigable residual emissions from other countries.


**Deviation of the annualised system costs in 2050 compared to the reference scenario.**

**2.8 IRELAND – COMPARING 100% RENEWABLE ENERGY SCENARIOS WITH ZERO CO2 EMISSIONS SCENARIOS**

Most studies focusing on 100% renewable energy systems tend to focus only on the power sector using exploratory approaches. This research resulted in the first journal paper on 100% renewable energy scenarios by 2050 for Ireland using a least-cost whole energy systems approach. The paper was selected as ‘Editor’s Choice’ by Energy journal editor and compared 100% Renewable Energy Supply (RES) Pathways with 100% Decarbonisation Pathways for Ireland’s energy system in 2050. The research addressed a number of key questions:

- Is 100% RES possible for Ireland? Our findings suggest YES but it requires (1) very high levels of variable renewable electricity (>75%) and (2) high levels of bioenergy (biogas, biomass, bioliquids) in all sectors (heat, electricity, transport).
• Pathways to 100% RES and pathways to 100% decarbonisation pathways are mostly similar (lots of wind energy, energy efficiency, heat pumps, etc) but to achieve deep decarbonisation (>90%), CCS in electricity generation is a key differentiating technology

• None of the RES or decarbonisation pathways are cheap, though neither is the alternative (doing nothing). As a % of GDP, decarbonisation costs are an additional 1-2% of GDP. In renewable energy only pathways, decarbonisation costs are slightly higher (due to absence of CCS).

Cost of decarbonisation – higher RES versus lower CO2 scenarios

ITALY - ZERO EMISSIONS SCENARIOS FOR THE LONG TERM STRATEGY

To support Italian energy planning, this project used the TIMES-RSE model to develop 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. These scenarios identify the correlations among the main pillars for the change of the energy paradigm towards net emissions by 2050. The project identified the best mix of energy sources and technologies that allows to meet the projected demand for energy services over the entire time horizon, and to achieve the goal of a complete decarbonization by 2050 at a minimum system cost. A predominantly renewable-based energy mix is essential to decarbonize most of the final energy consumption. However, the strong increase of non-programmable renewable sources requires particular attention to power system management and new flexibility resources. Therefore, an in-depth analysis was developed with the sMTISIM, a long-term simulator of power system and electricity markets, to analyze variable renewables and short-term system operational issues.

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.

To achieve climate neutrality by 2050, the system will have to resort to fundamental levers with strong synergies between them: energy accompanied by behavioral changes (more public passenger mobility and consumption awareness in residential buildings) and a circular economy; a new energy mix consisting of renewable sources and carbon-free energy carriers such as hydrogen, but also all synthetic fuels derived from hydrogen and electricity (Power-to-X); complete power sector decarbonization with renewable sources, but also the use of carbon capture and storage and use (CCS/CCUS) associated with biomass plants (BECCS) to achieve negative emissions; a significant electrification of up to 55% of final consumption: in particular, electrification increases in buildings, especially for heating and cooking, and in the transport sector, driven by the high penetration of electric vehicles for cars and buses.

Evolution of hydrogen energy uses in LTS scenarios


2.10 ITALY - THE IMPACT OF THE FIT FOR 55 PACKAGE ON THE ITALIAN NECP

To support the National Energy and Climate Plan updating, this project made an assessment of the Fit for 55 package: in particular, the impacts on the Italian energy system by 2030 were analyzed with the TIMES-RSE model, with the aim of accelerating Italian complete decarbonisation.
The results show that, in order to increase the decarbonisation target to 2030, the Italian energy system will have to make a greater effort than the PNIEC and anticipate decarbonisation options such as the diffusion of hydrogen, and the high diffusion of renewable sources. The electrification will have to spread faster than expected in the NECP. The increase in non-programmable renewable sources will be allowed by the new flexibility resources of the electricity system, such as electrolysers to produce hydrogen. The study’s findings also confirm that the European “energy efficiency first” principle represents the very first step on the road to climate neutrality. To accelerate decarbonization by 2030, it will be necessary to resort increase electrification (heat pumps, electrical cooking…), greater diffusion of renewables (FV, on-shore and off-shore wind), and the development of a hydrogen and e-fules supply chain.

Reference: Gaeta et al. (2021)
Rapporto RdS nNo 21009850 [https://www.rse-web.it/rapporti/]

2.11 NEW ZEALAND - TIMES-NZ 2.0 NZ ENERGY SCENARIOS

This project used the TIMES-NZ model to develop scenarios, which included two equally plausible and internally coherent scenarios that were tested across the period 2018 to 2060 to understand possible decarbonisation pathways, differences and similarities. The results show that both scenarios projected significant reductions in energy emissions and uptake of low-emissions technologies. Energy efficiency, electrification and use of plantation biomass were key demand side technologies, while wind and solar were prominent on the supply side. Residual emissions from international shipping and aviation, and heavy industry were highlighted as lacking current technological solutions.

Results were largely uncontroversial despite arriving at a key point in a high-profile process (development of New Zealand’s first emissions budgets for 2021-2025, 2026-2030, and 2031-2035). Moreover, the project enabled informed discussion on many key issues relating to decarbonisation of the energy system. Launch events and in-depth topic webinars were very well attended, and a partnership approach to the project demonstrates that industry and government can work collaboratively on decarbonisation.
2.12 NEW ZEALAND - ESTIMATING THE COST OF DECARBONISATION IN NEW ZEALAND

Using TIMES-NZ to test two pre-defined scenarios with a changing carbon price, this project’s results show that it appears to be possible to quantify the incremental costs of different degrees of decarbonisation using TIMES-NZ. Modelling input assumptions (for example behavioural factors such as reduced travel demand) can have a greater than expected impact on the cost of decarbonisation. Decarbonisation cost curves in response to changing carbon price followed a similar slope across the two scenarios, however the overall level of cost was defined by key scenario input assumptions.

Moreover, increased cumulative emissions reductions are generally proportional to system cost increases. The slope of the system cost relative to cumulative emission reductions varies between pre-defined scenarios. Some scenario constraints and variable interactions were fragile when a very aggressive carbon price or carbon constraint was applied. The paper has yet to be finalised/released.

2.13 NORWAY - STOCHASTIC MODELLING OF VARIABLE RENEWABLES IN ENERGY SYSTEM MODELS

Using IFE-TIMES-Norway, this study presents a stochastic approach to analyze variable wind and PV generation in long-term energy models and demonstrates this approach on a TIMES model of the Norwegian energy system. Results show that: for Norway, there is a satisfactory match between satellite-based data with historical generation for PV but not for wind power; it is challenging to select the best performing scenario generation method by solely investigating the statistical properties of the scenarios; the runtime of the energy-system model highly depends on number of scenarios; the stochastic optimal scenario generation method is the method that provides stability by using as few
scenarios as possible; the performance ranking among the scenario generation methods differs if a moment-based or a Wasserstein distance is used; and the moment-based iterative sampling method, Iterative sampling, performs best related to moment-based distance, whereas k-means performs best related to the Wasserstein distance. Stability tests are used to evaluate the quality of model results, and the number of scenarios needed to achieve good quality depends on scenario method.

![Diagram showing PV capacity in 2040 for all instances](image)

*PV capacity in 2040 for all instances*
Seljom et al. (2021)

2.14 NORWAY - THE TRANSITION FROM A PETROLEUM ECONOMY TO A LOW-CARBON SOCIETY THROUGH HYDROGEN

The IFE-TIMES-Norway was used to analyse a low carbon scenario where the present Norwegian petroleum export is gradually phased out. The scenario includes the option to establish an international hydrogen market. Three analytical perspectives are combined in the study. The first uses energy models to investigate the role of hydrogen in an energy and power market perspective, without considering hydrogen export. The second perspective uses an economic equilibrium model to examine the potential role of hydrogen export in value creation. The third analysis is a socio-technical case study on the drivers and barriers for hydrogen production in Norway. The main conclusions are that access to renewable power and hydrogen are prerequisites for decarbonization of transport and industrial sectors in Norway, and that hydrogen is a key to maintaining a high level of economic activity.

From these results, it appears that hydrogen is a pre-requisite for reaching decarbonization targets in Norway, that renewable power will be used for hydrogen production, that hydrogen has a potential to be a source for new income for Norway, that national and European coordination is needed to build a hydrogen economy, and that combining models and socio-technical perspectives should be further explored.
Use of different fuels in transport sector in 2030 and 2050 in the IND scenario (TWh/year).


2.15 SOUTH KOREA - 2040 INDUSTRIAL SECTOR GHG REDUCTION POTENTIAL ASSESSMENT

This project is the result of analysis using government policy technical data prior to the announcement of the net zero policy. It uses the TIMES-K20 model, with a scenario where the reduction measures applied for the reduction potential analysis are three-fold. First, efficiency improvement with the replacement of high-efficiency common facilities, the improvement of heating efficiency through a higher efficiency of heating boilers, the digitization leading to the improvement of power unit by technology, and lighting efficiency improvement. Second, raw material conversion with the expansion of slag cement (reduction of clinker production through expansion of slag cement production), an increase in admixture ratio (reduce clinker production by expanding the use of admixture for cement products), and an expansion of waste glass recycling (reduction of energy consumption by increasing the use of waste glass in the glass industry). Third, fuel conversion, with LNG fuel conversion (replace BC oil in petrochemical and steel industries with LNG), replacing waste plastic fuel (replacing bituminous coal fuel in the steel industry with waste plastic), replacing waste synthetic resin fuel (replacing bituminous coal fuel in the cement industry with waste synthetic resin), and biomass fuel replacement (replacing anthracite fuel in the steel industry with biomass).
Results show that the 2040 greenhouse gas reduction potential in the industrial sector is 13.4% reduction rate compared to BAU* (based on the 3rd Energy Master Plan), taking into account that industrial process emissions are not included. Moreover, the proportion of reduction potential by 2040 reduction means efficiency improvement 89.3%, fuel conversion 7.8%, raw material conversion 2.9%. The proportion of reduction potential by industry in 2040 is petrochemical 21%, steel 15.1%, machinery 10.4%, oil refining 5.7%, cement 5%, etc. Finally, the 2040 Proportion of reduction potential by emission source is direct emissions 31.2% and indirect emissions 68.8%.

2.16 SWEDEN - THE IMPACT OF TECHNOLOGY AVAILABILITY ON THE TRANSITION TO NET-ZERO INDUSTRY IN SWEDEN

Using TIMES-Sweden, two scenarios with different conditions for reaching net-zero emissions, one allowing CO₂ offsetting, one limiting CO₂ offsetting were developed. 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).

Results show that 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. 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.

Furthermore, the project allows to visualise 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, and emphasises the importance of sector coupling for efficient biomass use. The report was submitted for publication in nov/dec 2021.

2.17 SWEDEN - EXPLORING TRANSITIONS TO FOSSIL INDEPENDENT TRANSPORTATION IN DENMARK

Using TIMES_DL, scenarios included two long-term stringent climate targets (same long-term target but two different intermediate targets) combined with different technology development scenarios. Results highlights include the exploration of the role of gas in transport for achieving intermediate climate targets; the chosen technologies sensitive to technology cost and fuel economy assumptions; the competition for limited biomass resources stimulates emerging transport technologies; niche markets for emerging transport technologies were captured; and delays in transportation decarbonisation increased marginal CO₂ abatement costs.
On a national level, Sweden has announced plans to have no net emissions of greenhouse gases in 2045. Furthermore, Gothenburg, a city in southwestern Sweden, has plans to phase out the use of fossil fuels in its heat and electricity production by 2030. Given that the development of a district heating (DH) system under dynamic and different climate policies and climate goals is a nontrivial problem, this study investigates two different policies of phasing out fossil fuels, either by introducing a fossil fuel ban, or by increasing the carbon tax to phase out the fossil fuel use in 2030 or 2045. The effects of the different phase out strategies on the future development of the existing DH system in Gothenburg has been investigated.

The results show that the total amount of heat supplied by the DH system is unaffected by the phase out policies, while the amount of natural gas used to supply the DH system is dependent on what kind of policy is implemented. A yearly linearly increasing carbon tax introduced in 2021 phases out fossil fuel use earlier than the target year, while a ban phases out the fuels only from the actual target year.
2.18 SWITZERLAND - LONG-TERM ENERGY TRANSFORMATION PATHWAYS

The study demonstrated the technical feasibility of carbon neutrality in Switzerland despite the limited domestic resources. Using the Swiss TIMES Energy Systems Model (STEM), scenarios included a suite of net zero CO₂ emissions pathways for Switzerland under different contexts related to social acceptance, consumer behaviour, technology progress, energy markets integration and resource availability. In this light, achieving the Swiss energy and climate goals would require: a) increasing electrification and efficiency, backed-up with zero-carbon fuels; b) exploiting domestic renewables’ sustainable potentials; c) maintaining carbon-free electricity supply and keeping hydropower’s current levels; d) deploying carbon capture from bioenergy and wastes; e) fostering international energy markets integration; f) lifting socio-economic barriers in clean and low-carbon technologies’ deployment; g) securing access to European CO₂ storage sites. Clean energy supply, low-carbon energy consumption, and green investment go hand in hand on the road to carbon neutrality.

The findings of the analysis suggest that a balance is required between the need to bring sectoral emissions reductions forward and avoid increased energy system costs due to uncoordinated sectoral policies. While increased technology innovation and energy market integration could offset identified policy inefficiencies to a large extent, on the other hand even the more cost-efficient and coordinated sectoral policies could become prohibitively expensive if the population is not mobilised to accept them or due to other inefficiencies from non-energy sectors (e.g., long license procedures for renewable projects).
Key milestones in reaching the net-zero CO₂ emissions targets for Switzerland

Industry (-5Mt)
- Improved heat integration & savings
- CHP and district heat (incl. hydrogen)
- CO₂ capture related to cement production

Transport (-16Mt)
- 4 out of 5 cars are electric
- Heavy duty transport: two thirds hydrogen-based, half to run on synthetic and biogenous fuels, one out of ten electric

Services (-5Mt)
- Building insulation
- Heat pumps deliver 64% of heat demand

Residential (-9Mt)
- Building insulation
- 5 times more heat provided by heat pumps than today

Legend:
*In brackets, change of CO₂ emissions 2015-2050

Electricity needs 2015-2050
Final energy consumption 2015-2050
CO₂ capture in 2050

Transformation (-5Mt)
- 30 TWh new renewables for electricity
- 2.1 GW stationary batteries
- 3.5 GW pump storage
- 11 TWh hydrogen production
- 14 TWh of imported zero-carbon fuels
- CO₂ capture related to waste incineration and hydrogen production

How the Swiss energy system would look in 2050 and key required transformation changes

This project used the Swiss TIMES Energy System Model. In the cement industry module the conventional energy-flow-based modeling approach used in the TIMES framework is expanded with material and product flows in addition to energy flows. This combination allows a more accurate analysis with the advantage of analyzing individual process step improvements (with both material and energy substitutions) and to account for process related CO₂ emissions. Two scenarios were developed, energy efficiency and net-zero CO₂ emissions in the Swiss cement industry.

Results show that Swiss cement production in 2050 reduces its specific energy and CO₂ emissions to 2.3 GJ/t cement (vs. 3 GJ in 2015) and 466 kg/t cement in 2050 (vs. 579 kg in 2015). For a net-zero goal, the sectors relies on CO₂ capture because of the process related emissions. A minimum CO₂ tax of 70 EUR/tCO₂ is required for the CO₂ capture technologies to become economically competitive.

Future cement production improves its energy efficiency and decreases its CO₂ emissions due to the decreasing clinker content in cement and deployment efficient technologies. Moreover, a CO₂ tax between 70 and 100 EUR/tCO₂ makes it economically attractive to avoid CO₂ emissions with carbon capture technologies with the benefit of avoiding both, energy and process-related CO₂ emissions. No significant reduction of the CO₂ emissions is possible in the cement sector without carbon capture and the corresponding infrastructure to transport and sequestrate CO₂.

2.20 THE NETHERLANDS - AN ELECTRICITY AND HYDROGEN PARTNERSHIP BETWEEN EUROPE AND NORTH AFRICA

Because of differences in irradiation levels, it could be more efficient to produce solar electricity and hydrogen in North Africa and import these energy carriers to Europe, rather than generating them at higher costs domestically in Europe. From a global climate change mitigation point of view exploiting such efficiencies can be profitable, since they reduce overall renewable electricity capacity requirements. Yet the construction of this capacity in North Africa would imply costs associated with the infrastructure needed to transport electricity and hydrogen. The ensuing geopolitical dependencies may also raise energy security concerns.

With the integrated assessment model TIAM-ECN, this study quantifies the trade-off between costs and benefits emanating from establishing import-export links between Europe and North Africa for electricity and hydrogen. Results show that for Europe a net price may have to be paid for exploiting such interlinkages, even while they reduce the domestic investments for renewable electricity capacity needed to implement the EU’s Green Deal. For North African countries the potential net benefits thanks to trade revenues may build up to 50 billion €/yr in 2050. Despite fears over costs and security, Europe should seriously consider an energy partnership with North Africa.

Projections with TIAM-ECN for net imports.

Using UK-TIMES, this study examined 4 scenarios that displayed different possible solutions to reaching Carbon Budget 6 and Net Zero whilst meeting externally predicted energy demand. These scenarios were:

- Core pathway - based on the core “central” assumptions. This was developed into the High Electrification pathway in the Net Zero Strategy.
- High resource - to reflect an alternative plausible resource scenario this assumes an increase in afforestation planting rates and a primarily hydrogen-based decarbonisation route for heating in buildings.
- High CCS - to reflect upside technology uncertainty this assumes an increase in carbon capture and storage capture rates and higher availability of direct air carbon capture and storage. This was developed into the High Innovation pathway in the Net Zero Strategy.
- CCS Delay - to reflect downside technology uncertainty this assumes a delay to CCS availability and a decrease in capture rates. This is also the only scenario in which hydrogen imports are allowed to offset domestic delay in production at scale.

The study investigated the level that Carbon Budget 6 should be set at by doing 3 runs for each scenario: one with a 75% reduction in CO₂e (compared to the UK’s 1990 emissions), one with a 78% reduction (the CCC recommendation) and one with an 80% reduction. Results show the technical feasibility of the 78% reduction as recommended by the CCC. It also gave an illustration of the deployment of various key technologies required to meet this target. This was presented to senior decision-makers and formed a core part of the evidence base used for the UK government’s assessment of the proposed reduction. This workstream concluded with the UK government accepting the 78% reduction and passing it into law.

Modelled sixth carbon budget options in terms of five-year budget level (right axis) and per annum emissions (left axis) against the baseline “do-nothing scenario”, MtCO₂e

Using TIMES-UK, this study examined 3 scenarios that displayed different possible solutions to reaching Net Zero whilst meeting externally predicted energy demand. These scenarios were:

- High electrification - explores the impact of widespread electrification to support transport, heating, and industry decarbonisation, relative to other scenarios, with deep decarbonisation of electricity supply.
- High resource - explores the impact of using low carbon hydrogen more extensively, particularly for decarbonising buildings, power, and heavy vehicles. It also assumes higher levels of tree-planting are achievable, increasing the ‘negative emissions’ available from land-use sinks.
- High innovation - explores a world in which successful innovations enable lower residual emissions to be reached in aviation, while higher capture rates increase the impact of carbon capture technologies, with higher levels of DACCS deployed over the 2040s.

Three modelled scenarios are shown, all reaching net zero by 2050 through the same pace of decarbonisation, which demonstrate a range of practical ways in which net zero could feasibly be delivered with technology and resources known today. Results show that the Net Zero target was technically feasible and to give a broad approximation of its cost. Its results were used to illustrate how the deployment of key technologies might look in order to reach Net Zero. This was compared against the results from more detailed sector models. UK TIMES was also employed to help communicate the interactions between different energy sectors.

High innovation scenario: energy generation and end uses in 2050

3 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 SERBIA - THE NATIONAL ENERGY AND CLIMATE PLAN

In order to help the development of the National Energy and Climate Plan of Serbia, the Serbian Energy System Model – SEMS was developed in the framework of the project “Development of Energy Planning Capacity, Europeaid/135625/IH/SER/RS” and is operated by the Ministry of Energy and Mining of the Republic of Serbia.

The model covers a number of regions, with a national model for Serbia which is split into four regions. The time horizon is to 2070, with results analysed to 2050 mainly. Among the highlights of its most important features, there are a representation of building stock through a large number of typologies utilising the existing data, a regional level representation of electricity generation and RES potential, and a web interface for accessing model inputs and results.

Thirty-three working scenarios were developed with energy and climate projections of Serbia within the process of INECP development, with a projection until 2050 for the purpose of performing adequate analysis of various options for electric power sector development. On the basis of the working scenarios, several relevant options for further analysis will be defined, as well as for consideration of options and means for harmonization with the Green Agenda for the Western Balkans and the latest “Fit for 55 package”.

Within the process of the INECP preparation, a wide range of consultations has been conducted with the Working Group members and other interested parties. The Energy Community is involved in the consultation process while the Secretariat of EnC was provided with the draft version of several chapters and preliminary modelling results for peer review.
3.2 ARMENIA – THE ENERGY SECTOR DEVELOPMENT STRATEGIC PROGRAM TO 2040

TIMES-Armenia was prepared by the experts at the Scientific Research Institute of Energy (SRIE) to guide the preparation of the Armenia Least-Cost Energy Development Plan (LCEDP) as part of the USAID funded Market Liberalization and Electricity Trade (MLET) Program. Model development and the LCEDP analysis were conducted under the auspices of DecisionWare. The model covers Armenia as a whole, with a time horizon to 2050 and 12 time slices, 4-seasons and 3-daynite.

Its highlights on the most original features include a feature in TIMES-Armenia that underpin the model structure that are new to energy planning in Armenia, which includes the representation of a “gas for electricity” contract commitment between Armenia and its neighbour; aggressive options to shift from fossil fuels to electricity in the transport and residential sectors in particular; and wide-range introduction of solar, with integrated storage, as well as rooftop options.

3.3 VIETNAM – LEAST-COST LOW-CARBON DEVELOPMENT PATHWAYS

TIMES-Vietnam was assembled by DecisionWare with assistance of the Vietnam Institute for Energy (VIE), as part of a World Bank / Program for Market Reform low-carbon development pathway analysis in support of the Ministry of Industry and Trade (MOIT) of the government of Vietnam. The supply and power sectors are depicted aligned with the 3-distinct electricity transmission grids that are loosely interconnected. The siting of each power plant group is allocated into each region appropriately. However, data availability and time constraints necessitate that these supply regions feed a single demand and international imports/exports region. Results from the TIMES-Vietnam analyses were central to the ambitions expressed by MOIT at COP25 and COP26.

The time horizon is 2014-2032, with 3-seasons and 4-daynite. The highlights of the model include three supply and a single demand region; multi-grid and pipeline representation to support the regional nature of the supply; and +70 power plant types represented with 5-hydroelectric plant type and all renewable potential and grid connections reflecting the nature of the renewable resource.

3.4 PERU - GET.TRANSFORM, A GLOBAL EUROPEAN PROGRAM

The a partnership with GET.Transform, this initiative is Global European program assisting developing and emerging economies in advancing their power sector transformations. The objective is to support public sector partners, including in this case the Ministry of Energy and Mines of Peru (MINEM), to improve their capacity of in energy planning and renewable energy integration. In Peru this includes improving the scope, structure and application of the TIMES model for long-term energy system planning and the representation of relevant aspects for the national energy transition (e.g. renewable energy integration, energy efficiency, electromobility, etc.).

The main outcomes are to improve government capacity to advance efficiently in the development of the national energy plan with the TIMES model as the main tool for long-term energy system analysis.

Weblink: www.get-transform.eu
FINLAND - POLICY MAKING TO REACH CARBON NEUTRALITY BY 2035

There are several examples of policy decisions and strategy formulation driven by VTT modelling work in Finland, with direct support of policy making of different Government departments to reach carbon neutrality in Finland by 2035 and to fulfil the EU’s proposals included in the FitFor55 policy package. This includes Carbon neutral Finland 2035 – impact assessments of climate and energy policies and measures (project HIISI, 2020–2021); impact assessments of the alternative emissions targets of the new climate law in Finland; and sustainable growth scenario for the Finnish bioeconomy.

- Five ministries were involved (economy & employment, environment, transport & communication, agriculture & forestry, finance) as well as the Prime Minister’s Office. Decisions makers and modellers had different roles played in the process:
- The results and findings have been presented to the ministerial working groups, climate policy roundtable chaired by the Prime Minister to support their policy and strategy formulations
- A series of meetings were organized with ministries, stakeholders, experts, and research community to formulate the policies and measures for modelling the long-term scenarios
- The TIMES-VTT model was used for the quantitative scenario analysis, and the results have been used as supporting material for the national medium-term Climate Change Policy Plan and EU’s Governance reporting. TIMES-VTT model was soft-linked with sectoral models (transport, buildings, waste, F-gases, GE for agriculture), CGE for Finland, and LULUCF model.
- There are also hearings held to the Finnish Parliament, political parties, stakeholder events, ministries’ working groups, scientific community, etc.

The TIMES model used, TIMES-VTT, is a global model, with focus on the Nordic region and the EU (18 regions, of which 4 Nordic countries). The time horizon is 2010-2060, with 24 timeslices in the Nordic region.

NEW ZEALAND - AN EMISSIONS REDUCTION PLAN WITH EMISSION BUDGETS

Emissions budgets have been developed and proposed by the independent Climate Change Commission (CCC) using their own models and assumptions. The additional and complementary viewpoints and details provided by the TIMES-NZ 2.0 NZ Energy Scenarios contributed to the broader policy development and consultation process across government and industry. The objective was to provide additional data points and perspective to the emissions budget setting process.

The main outcomes/decisions from modelling work will be the first Emissions Reduction Plan, due to be published in May 2022.
3.7 BELGIUM - LONG-TERM ELECTRICITY SYSTEM SCENARIOS

This project aims to provide fact-based, objective input for all involved stakeholders and policy makers in the nuclear debate going on in Belgium, including policy makers (national local governments, etc.) and the Federal Government of Belgium. The objective is the development of Long-term electricity system scenarios for Belgium ordered by EN-GIE/Electrabel, with the 1-region EnergyVille TIMES Be model.
3.8 ITALY – ASSESSING 2030 TARGETS

The TIMES-RSE and s-MTSIM models are used to assess the 2030 targets under FF55 Directives for the Ministry of Ecological Transition. The scenario analysis have supported the Italian government to understand the impact that the new Fit for 55 targets may have on the national energy system, to identify critical issues and support the negotiation phases between member states and the European commission on the definition of main directives of the FF55. With TIMES_RSE model, the targets and subtargets of the EE and RED III directives were analyzed individually and overall. The study indicated to public decision makers which objectives are in line with the peculiarities of Italy, but also those difficult to reach from our energy system.


Another contribution of the same models in Italy was for the Hydrogen Strategy, again for the Ministry of Ecological Transition. The Italian government has decided to use scenario analysis to define its hydrogen strategy. The sectors of greatest interest for the first diffusion of hydrogen by 2030 have been identified and the production needs quantified. An analysis on the possibility of producing all the hydrogen needed by 2030 from electrolysis from renewable sources was carried out using the s-MTSIM electric system model. The need for seasonal hydrogen storage was also highlighted if it is desired to produce only from renewable overgeneration.

Reference: work in progress

3.9 SWITZERLAND - REALISTIC NET-ZERO CO2 EMISSIONS PATHWAYS

The Swiss TIMES Energy Systems Model (STEM) is used to help the Swiss Innovation Agency assess realistic net-zero CO2 emissions pathways for Switzerland in the context of the Swiss Competence Centre for Energy Research Joint Activity Scenarios and modelling. The main outcomes from the modelling work include the need to include negative emissions technologies in Switzerland’s long-term energy strategy; as Switzerland’s CO2 storage potential is likely to be insufficient, the bulk of the required 9 Mt CO2/yr captured emissions will need to link up with foreign storage sites; hydrogen needs to be promoted and a hydrogen strategy is needed as annual net consumption of hydrogen would be around 11 TWh/yr in 2050 (at least) mainly to decarbonise long-distance transport.
Sweden has set ambitious national targets and adopted policies to decarbonise domestic transportation, but what role could local governments play? Modelling with the TIMES-City model applied to the TRA sector in the Västerbotten region was used to support a deeper understanding among local policy-makers and to help underpin local decarbonisation strategies.

These modelling efforts were carried out as an iterative process in which local city officials engaged in gathering input data, scenario definitions, evaluation/discussion of preliminary model runs and final results through a series of online workshops during 2020. Critical success factors and recommendations were also presented in a written report to all cities.

A final report was published and includes a ‘summary for policy-makers’ and comprehensive model results for all 15 municipalities and (in Swedish only).

There were two collaborations with local policy makers. The first involved the developing of a TIMES local model in close collaboration with local stakeholders, the TIMES_URBAN_LT model, with scenarios developed together with municipality stakeholders. A second collaboration involved the TIMES_URBAM_Gbg model, used to assess the sensitivity of district heating as the most cost-effective heating option, and various district heating supply configurations, under local climate policy aiming at locally phasing out fossil fuels.

3.10 SWEDEN - CO₂ MITIGATION ACTION PLANS FOR THE TRANSPORT SECTOR IN VÄSTERBOTTEN

3.11 SWEDEN - LOCAL POLICIES USING LOCAL MODELS
TIMES-Ireland Model (TIM) has been used to better inform increased national climate mitigation ambition: Ireland has one of the most ambitious near-term decarbonisation targets in the world, to achieve a 51% reduction of total GHG emissions in the period 2018-2030. Ireland’s legislation Climate Action and Low Carbon Development (Amendment) Act 2021 established a 5 yearly carbon budget process for the periods 2021-2025 and 2026-2030. The Act specified that the Climate Change Advisory Council would propose carbon budgets for these first two periods. The MaREI Centre at University College Cork developed mitigation scenarios with TIM to explore different options for energy system mitigation for consideration by the Council, focusing on the implications for energy system evolution, technology choices and demand pathways. This analysis formed a significant part of the evidence used by the Climate Change Advisory Council to propose the first set of carbon budget recommendations that were subsequently approved in May 2022 by the Irish Oireachtas (Parliament).

References:

The Climate Change Act requires the government to set the sixth carbon budget as a limit on the net UK carbon account over 2033-37. The Act requires this level must be set with a view to reducing emissions to net zero by 2050. The following options for the level of the budget have been considered, including a ‘do nothing’ option where no further emission reduction measures are pursued (for comparison purposes only) and also the level recommended by the independent Climate Change Committee (Option 3): Option 1 (Do nothing): 2100 million tonnes of carbon dioxide equivalent (MtCO₂e); Option 2: 1105 MtCO₂e; Option 3: 965 MtCO₂e; Option 4: 885 MtCO₂e.
When setting carbon budgets, the government must take account of the advice of the Climate Change Committee (CCC). The CCC recommends the sixth carbon budget is set at 965MtCO2e, implying a 78% reduction in emissions from 1990 to 2035. The government has conducted its own analysis, based on our own analytical assumptions, which includes consideration of this recommended budget level. Our assessment of this overall budget level is separate from our consideration of the CCC’s policy recommendations to achieve the emissions abatement needed to meet the budget.

The emission pathways modelling, and the majority of monetised cost and benefits, use the UK TIMES model (UKTM)27, a least-cost optimisation model for the whole UK emissions (including land use) and energy system covering the period 2010 to 2060. The team, part of the Department of Business, Energy & Industrial Strategy, works closely with policymakers through two key projects, contributing to the evidence base that the 6th Carbon Budget target of 78% was technically feasible.

<table>
<thead>
<tr>
<th>Emissions in MtCO2e</th>
<th>Baseline-Do-nothing</th>
<th>Option 2 - Looser</th>
<th>Option 3 - CCC</th>
<th>Option 4 - Tighter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic transport</td>
<td>83</td>
<td>41-49</td>
<td>30-37</td>
<td>21-28</td>
</tr>
<tr>
<td>Industry</td>
<td>37</td>
<td>20-21</td>
<td>15-17</td>
<td>15-17</td>
</tr>
<tr>
<td>Fuel supply</td>
<td>46</td>
<td>17-20</td>
<td>8-11</td>
<td>8-9</td>
</tr>
<tr>
<td>Buildings</td>
<td>98</td>
<td>48-53</td>
<td>44-47</td>
<td>41-47</td>
</tr>
<tr>
<td>Electricity</td>
<td>26</td>
<td>7-12</td>
<td>7-12</td>
<td>7-12</td>
</tr>
<tr>
<td>Agriculture</td>
<td>48</td>
<td>43</td>
<td>42-43</td>
<td>42</td>
</tr>
<tr>
<td>Waste</td>
<td>16</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>F-gases</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>LULUCF</td>
<td>18</td>
<td>(0-1)*</td>
<td>(0-1)</td>
<td>(0-1)</td>
</tr>
<tr>
<td>Engineered Removals</td>
<td>0</td>
<td>(13-19)</td>
<td>(13-19)</td>
<td>(14-22)</td>
</tr>
<tr>
<td>IAG</td>
<td>46</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total emissions</td>
<td>420</td>
<td>221</td>
<td>193</td>
<td>177</td>
</tr>
</tbody>
</table>

* Brackets indicate negative values

Illustrative emission ranges in 2035 under different sixth carbon budget levels, based on the modelled pathways

3.14 THE PARIS REINFORCE PROJECT

Paris Reinforce is a large-scale innovation project with a 6.5 million Euros funding from the European Commission and involving 18 modelling teams worldwide. The project aims to underpin climate policymaking with authoritative scientific methods and to enhance the science-policy interface in light of the Paris Agreement. The first goal is to develop a novel, policy demand-driven, Integrated Assessment Model (IAM)-oriented assessment framework for effectively supporting the design of climate policies. The second main goal is also to create an open-access data exchange platform, IZAM PARIS, to support the effective implementation of Nationally Determined Contributions (NDC) and the reinforcement of the 2023 Global Stocktake.

Among the MARKAL-TIMES models it supports are the TIMES Integrated Assessment Model (TIAM), the EU-TIMES model, the HU-TIMES (a partial equilibrium model), TERI’s MARKAL-India model (a bottom-up customised MARKAL model for the Indian energy and environmental policy context), the North American TIMES Energy Model (NATEM) (currently the only detailed optimisation model in North America), and the TiMES- Central Asian Caspian Model (TIMES-CAC).
The International Renewable Energy Agency (IRENA) is a recognized intergovernmental organization 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.

ITALY and other ETSAP Contracting Parties partnered with IRENA for the “Long-term Energy Scenarios Network” (LTES Network) initiative. The objective of the initiative was to have a platform for national and regional energy scenario practitioners to share experience and good practices in using and developing scenarios. Its main outcomes were a webinar, a publication, and discussions.

The webinar (titled IRENA - 2nd Webinar Series on National Experience in Long-Term Energy Scenario Use and Development) was held on November 24th 2021, and focused on strengthening scenario development, improving scenario use, and identifying capacity building approaches.
4.2 ACTIVITIES IN COLLABORATION WITH OTHER IEA-TCPs

ETSAP engagement with other TCPs took the form of several initiatives and efforts:

- Tom Kober, TCP Combustion, has initiated an activity on energy systems analysis, including de-fossilized transport/new mobility, gas turbines with hydrogen, and co-firing of hydrogen in stationary applications. The discussions included options for making a joint research project, and that ETSAP needs more detailed data. There also is the desire to see impact of their technologies from an energy systems perspective.

- Tom Kober/Evangelos Panos (PSI), TCP Storage organized a Joint workshop that took place in September with 16 ETSAP members and 12 from Storage. TCP storage will have a reflection meeting and come back to ETSAP. Hopefully, TCP Storage can provide an open data set that can be used by ETSAP.

- With PSI, an initiative named IEA TCP Energy Storage Task 32 «Open Sesame» took place, with the objective of improving the representation of energy storage technologies in TIMES by collaborating with experts in key future electricity and thermal storage options. The main outcomes were Joint workshop between ETSAP and TCP Energy Storage Task 32, which took place on September 9th, 2021, and a best practice guide for representing energy storage in TIMES (to be published within 2022).

- Tiina Koljonen, TCP Bioenergy (green hydrogen and bioenergy), wants to organise a joint workshop with ETSAP to see how we can benefit from joint activities. The timing would be the first half of 2022. ETSAP members that are interested to participate are encouraged to Tiina.

- Bioenergy TCP (Brian Ó Gallachóir) has ongoing dialogue with Task 44. According to Tiina Koljonen, the TCP has included the collaboration with ETSAP in their plan.

- Tom Kober is also interested in reaching out to explore collaboration with Fabian, for example on negative emissions from hydrogen production from bioenergy.

- Anna Krook-Riekkula (Swedish Energy Agency), IETS TCP: it is too early for them to participate in the next ETSAP WS. ETSAP partners can participate in IETS meetings, in the specific annex focusing on circular economy. Anna can coordinate ETSAP participation if people are interested in collaborating on modelling circular economy. Anna had dialogue with this TCP two weeks ago and will follow up with the TCP to investigate collaboration opportunities.

- IEA IETS TCP led the IETS-21Task Circular Carbon and Industrial Symbiosis initiative. The objective was to
learn from each other (TIMES and IEA IETS) on how to model Circular Carbon and Industrial Symbiosis. The main outcomes included several workshops.

- Paul Dodds, Hydrogen TCP, initiated the collaboration where they wanted to understand why hydrogen was not included (or a solution) in IEA-analysis. TCP hydrogen have an annex/task on data. The ETSAP hydrogen project will provide a short report on the status on data and on modelling of hydrogen. The ETSAP project is coming to an end, and a next step is to reflect and regroup. They are working on a paper on hydrogen modelling. The project will be finalized when the Hydrogen Sub Res for ETSAP-TIAM development is done.

- Users TCP (Brian Ó Gallachóir) is in an early state of collaboration with ETSAP, possibly having a common WS. The focus can be on the role of people and how users are represented in energy system models (energy behavior), the role of infrastructure and how infrastructure shape choices. Is it possible to move from least cost optimization to maximize welfare?

### 4.3 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.

One was the High Electrification Scenarios for North America forum, a 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. Much of the deep decarbonization literature points to the decarbonization of the power sector followed by the electrification of all major end uses in the economy, but there is a lack of consensus on the ultimate potential for electrification, and rate at which it can be implemented given technical, behavioral, regulatory and economic limits – and competition from other promising emission mitigation options. 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.

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. These study groups were formed in early 2020 to help inform the study design for the very beginning of the study.
### BUILDING
- Basic/rapid end-use heating/cooling (water and space)
- Basic/rapid expansion of controllable load
- Mild/significant impacts attributable to climate change
- Complementary policies such as building codes

### TRANSPORTATION
- Basic/rapid EV adoption (there are a host of market- and policy-based drivers embedded here, any of them could be tested)
- Slow/fast EV charging profile evolution (from L1-dominated home charging to higher level public charging)
- Basic/rapid expansion of managed charging
- Basic/rapid reductions in battery costs
- Autonomous vehicles
- Significant mode shifting and micro-mobility
- Role of off-road vehicles and construction equipment
- Basic/rapid reduction in battery costs
- Complementary policies targeted at EV adoption

### INDUSTRY
- High/low technology availability and/or cost for electrification
- Slow/fast adoption of new process technologies
- High/low degree of electrification
- CCS on process technologies
- Structural change (e.g., offshoring, 3-D printing)

---

**The EMF 37 study on high electrification scenarios in North America**

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.

---

**4.4 ACTIVITIES IN COLLABORATION WITH IPCC**

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 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 was high since 2020. First, many interested new users requested a free trial version of GAMS/VEDA for use with TIMES via the ET-SAP website, which is available for them to evaluate TIMES over a 2-month period. 90 such users made the request in 2020, while 116 did so in 2021. Second, new users downloaded the TIMES-Starter platform, developed in 2019 using ETSAP R&D funding, which enables them to jump-start the process of assembling a quality new TIMES-model. 133 such new users obtained the download in 2020, while 169 did so in 2021, for a total of 464 to date.
5.2 TIMES MAINTENANCE, UPDATE AND IMPROVEMENT

Over the 2020-2022 period, 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 2020**

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>RELATED INPUT ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>The TIMES code integrated with the Ancillary Balancing Services (ABS) code extension, which was implemented under a separate ETSAP project, and is now fully integrated in the common code.</td>
<td>See the ABS documentation</td>
</tr>
<tr>
<td>The GAMS control variable DATAGDX has been improved by implementing automatic filtering of domain violations that may cause unexpected GAMS behavior in many models. In addition, model input data can now be read from GDX files instead of DD files.</td>
<td>control variable DATAGDX</td>
</tr>
<tr>
<td>Representing demand-response by Load-Shifting was improved, by implementing constraints on the total load shifting within each season, and asymmetric constraints for meeting loads in advance and with delay.</td>
<td>STG_SIFT, ACT_TIME</td>
</tr>
<tr>
<td>Users can now selectively request process flows to be reported on the ANNUAL level by commodity type and NRG subtype. In this way very large result data sets from model runs can in many cases be reduced.</td>
<td>RPT_OPT</td>
</tr>
<tr>
<td>Support for using dynamic timeslice trees in TIMES has been implemented (per user’s feature request), such that the timeslice tree can have a different disaggregation by period. The feature remains experimental until relevant user experience has been gathered.</td>
<td>TS_OFF, TS_CYCLE</td>
</tr>
<tr>
<td>A novel, linearized Macro formulation has been implemented, which addresses to some extent the performance issues when using the decomposed Macro-MSA formulation. The new formulation can be activated by the setting $SET MACRO MLF.</td>
<td>control variable MACRO ($SET MACRO MLF)</td>
</tr>
<tr>
<td>A new attribute REG_BDNCAP(reg,lim) has been implemented, for convenient bounding of capacities with a previous solution by region, as upper bounds, lower bounds, or fixed bounds. Requires using LPOINT.</td>
<td>REG_BDNCAP, control variable LPOINT</td>
</tr>
<tr>
<td>A new attribute for defining investment subsidies directly as a fraction of the investment costs has been implemented.</td>
<td>NCAP_ISPCT</td>
</tr>
<tr>
<td>New constraints for defining dynamic bounds for VAR_COMPRD and VAR_COMNET, between successive periods, have been implemented.</td>
<td>UC_COMPRD, UC_COMNET</td>
</tr>
<tr>
<td>Support for defining a non-vintaged process transformation relation has been implemented by using a non-vintaged FLO_FUNC multiplier.</td>
<td>FLO_FUNC, FLO_FUNCX</td>
</tr>
<tr>
<td>FEATURE</td>
<td>RELATED INPUT ATTRIBUTES</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>A new attribute for defining maximum storage cycles during its lifetime has been implemented, to improve the modeling of e.g. battery storage, and the related replacement investments when the cycles exceed limit.</td>
<td>STG_MAXCYC</td>
</tr>
<tr>
<td>Support for independent NCAP_AFC constraints for storage has been added (independent capacity availabilities for inputs and outputs).</td>
<td>NCAP_AFC</td>
</tr>
<tr>
<td>Support for auxiliary storage flows for NST storage with a predefined charging profile, and back injection from an NST storage to grid</td>
<td>FLO_FUNC COM_FR</td>
</tr>
<tr>
<td>Improvements for general storage: A more flexible STS variant has been implemented - activate by $SET STSFLX YES</td>
<td>Control variable STSFLX ($SET STSFLX YES)</td>
</tr>
<tr>
<td>Improved accounting of equilibrium losses for timeslice storage, which were previously underestimated at seasonal timeslices.</td>
<td>STG_LOSS</td>
</tr>
<tr>
<td>Support for shaping NCAP_COM by age has been implemented. The shape index can be defined by using FLO_FUNCX(r,y,p,'CAPFLO',com).</td>
<td>NCAP_COM, SHAPE</td>
</tr>
</tbody>
</table>

1ETSAP 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.

An example of results from a funded project is "Enhancing the flexibility in TIMES: Introducing Ancillary Services Markets", which had the objective of having endogenous representation of ancillary services markets in TIMES models. The main outcomes were new TIMES extension for capturing the flexibility needs of future energy systems, and a DEMO model on how to use the extension.

PSI designed a new extension of TIMES for endogenous representation of the ancillary services markets in TIMES models. With the new extension, the TIMES framework is equipped with also market-based flexibility mechanisms in integrated variable renewable electricity supply next to the already included in the model technical flexibility. This is important because the energy only markets and technical approaches do not offer sufficient remuneration for the flexibility actions, the associated costs of which have also to be sought in auxiliary services markets. The extension has been published on the ETSAP TIMES documentation web site (see Section 2.4).

Reference: Panos, et al. (2021)
5.3 USER INTERFACES’ MAINTENANCE, UPDATE AND IMPROVEMENT

5.3.1 VEDA2.0

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.

VEDA is built around a specific philosophy and core principles:

• Most of the data used by energy modelers is already in spreadsheets, or it can get there easily. The interface should be able to read formats that analysts find intuitive, rather than forcing them to enter information via a separate UI.
• Assumptions should be expressed in the original form; data pre-processing should be minimal.
• System should be modular – easy to activate/deactivate/replace sectors or regions. Different analysts should be able to work on different sectors or regions in parallel.
• Structures and data that is common across regions should be declared only once.
• Different layers of assumptions should coexist so that they can be activated/deactivated/permutated at run-time.

ETSAP has financed the development of VEDA2.0, after a complete rebuild from 2019. The new VEDA online has also been developed. VEDA2.0 helps handling data for TIMES, and uses C# .NET for UI and PostgreSQL as the backend. It is based on a modular approach that organizes the model input data, and results, into an integrated database. VEDA then submits the data to the TIMES code. Information is visible via tabular browsing (data cubes) and network diagrams. It is used to develop and manage model runs and to analyse model results.

All input data resides in Excel workbooks. XLSX/M format is recommended for Veda2.0. The modularity feature helps make major reconfigurations possible and efficient. It also makes it easier for multiple people to work on different parts of the model in parallel. This is achieved by segregating the input data into different sections (core definitions...
of regions, timeslices, modeling years, and commodities; technologies with existing stock; new technologies; demands; trades; and additional parameter definitions for technologies and commodities).

Data flow and files in Veda2.0

Figure 1 – Data flow and files in Veda2.0

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.
TABLE 4 – SUMMARY OF ENHANCED FEATURES IN VEDA2.0

- Various browse features, run manager, and even navigator, work very independently and can be used concurrently. Multiple models can be used concurrently.
- A new Start page makes it easy to work with models, also with different branches on Git. There is a section that pulls information from the Internet – to be used to display tips for users.
- All pivot grids have CSV export facility, which is very useful for creating input for visualization tools like Power BI and Tableau.
- Unit conversion is more advanced.
- Possible to write GAMS instructions in different locations of the RUN file and top or bottom of DD files.
- Milestone years can be specified directly, instead of using period lengths.
- All forms are extremely independent and allow very flexible layout changes. Users can continue using other modules even when the DD files are being written or the model is synchronizing.
- Three to ten times faster synchronization, depending on the model structure and number of cores available (guidance provided for reducing the processing time further)
- DD writing is an order of magnitude faster and scales directly with number of cores.
- Smart filtering available throughout the application.
- All data is rendered in a pivot grid for browsing, like before, but the pivot tool is much improved (handy charting facility available with all data views)
- Interdependence across scenario files (due to FILL/UPD/MIG tables) is tracked and reported.
- Column position of any tag, including FI_T and UC_T, is not important anymore, making it less error prone.
- Comprehensive documentation of all tags and columns supported by each.
- Set definitions are shared by input and results sections and it used to be difficult to keep things in sync. Now the sets file is synchronized seamlessly by both functions.
- Powerful sets playground feature allows interactive viewing, editing and creating new sets, which are automatically updated in the set definitions file.
- Open architecture: all user definitions like scenario groups, cases, results views etc are stored in (to be documented) json and CSV files. In principle, users can modify these files programmatically.
VEDA Online makes the core Veda2.0 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.

**VEDA Online provides the following functionality:**

- Upload Veda model folders (via GitHub)
- Synchronize
- Browse input data
- Veda Browse: multi-select dimensions in a pivot grid
- Veda Items view: sets, topology and parameters for individual items
- Define and run cases
- Solved on KanORS servers or the GAMS engine
- Results
- Reports
- Visualization features are much more powerful than those in Veda2.0

**In addition, VEDA Online allow the following:**

- Free version for pedagogical use, with support for hardware and GAMS licenses
- Controlled deployment of models
- Host open models
- Bulk runs, with large numbers of scenarios that can be run in the cloud in parallel
Figure 2 – Visualization features are much more powerful than those in Veda2.0

Figure 3 – Sample of result visualization
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.

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 (*Documentation-for-the-TIMES-Model-Part-II.pdf*, updated in April 2021)

- **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 (*Documentation-for-the-TIMES-Model-Part-III.pdf*)

- **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.

A new manual was also published for the Ancillary Balancing Services extension, which explains the mathematical formulation for introducing ancillary services in TIMES. As variable renewable generation increases to...
achieve energy and climate change strategy goals, so does the need for flexibility and balancing mechanisms. These mechanisms, commonly referred to as ancillary services, ensure the reliable operation of the electricity system by compensating for fluctuations in supply and demand. With the proposed extension, the TIMES framework can assess the true cost of variable in electricity supply and demand to the energy system and the implications on the investments decisions of having sufficient reserve capacity at hand.

Other documentation updates include the following user notes:

- Updated user note on load shifting in TIMES
- New user note on dynamic flexible timeslice hierarchy definition
- New user note on the linearized TIMES-Macro MLF formulation
5.5 CAPACITY BUILDING IN BOTH DEVELOPED AND DEVELOPING COUNTRIES

5.5.1 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 AND PARTICIPANTS</th>
</tr>
</thead>
</table>
| Online ETSAP VEDA2.0-TIMES Basic training | 24th – 26th June 2020, 8 participants  
29th June – 1st July 2020, 10 participants  
25th – 27th November 2020, 10 participants  
9th – 11th December 2020, 10 participants  
15th – 17th February 2021, 10 participants  
22nd – 24th March 2021, 11 participants  
26th – 28th April 2021, 12 participants  
7th – 9th June 2021, 11 participants  
30th August – 1st September 2021, 12 participants  
11th – 13th October 2021, 12 participants  
24th – 26th November 2021, 12 participants |
| In-person ETSAP VEDA2.0-TIMES Basic training | CEA, Saclay (France), 8th - 9th December 2021, 8 participants |
| Online TIMES-Peru training with VEDA-FE/BE and TIMES (organized by GET.transform for the Ministry of Energy y Mina in Peru) | 6-sessions of 2 hours each between November and December 2021, 20-25 participants |
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>DATE</th>
<th>SUMMARY</th>
</tr>
</thead>
</table>
| November 2020  | How to build a TIMES model from scratch - Building a multi-regional model using a single excel workbook and TFM_DINS  
**Weblink:** [https://www.youtube.com/watch?v=OUsMVC66qWo](https://www.youtube.com/watch?v=OUsMVC66qWo)                                                                                                                                                                             |
| December 2020  | Modelling clean energy transitions: approaches and tools for the World Energy Outlook and the Energy Technology Perspectives  
**Weblink:** [https://www.youtube.com/watch?v=giRpjUJweGU](https://www.youtube.com/watch?v=giRpjUJweGU)                                                                                                                                                                          |
| January 2021   | Version control in TIMES models  
**Weblink:** [https://www.youtube.com/watch?v=fyhdnzgA-Oo](https://www.youtube.com/watch?v=fyhdnzgA-Oo)                                                                                                                                                                                                   |
| February 2021  | High temporal and spatial resolution in TIMES models  
**Weblink:** [https://www.youtube.com/watch?v=QmlVz9vFspA](https://www.youtube.com/watch?v=QmlVz9vFspA)                                                                                                                                                                                                 |
| March 2021     | Modelling of variable renewable energy  
**Weblink:** [https://youtu.be/7MNJYhKHY3w](https://youtu.be/7MNJYhKHY3w)                                                                                                                                                                                                         |
| May 2021       | Climate variations, fluctuations and extreme impacts on future energy systems  
**Weblink:** [https://www.youtube.com/watch?v=gfWvaJnAyJM](https://www.youtube.com/watch?v=gfWvaJnAyJM)                                                                                                                                                                    |
| May 2021       | UK Times Expert User Group Annual Meeting. Topics included UK TIMES techniques, ways of visualising results and an update from projects where UK TIMES has been applied. One action from this meeting was to set up a Teams group for the UK TIMES Expert User Group to improve collaboration and understanding between UK TIMES users. This was set up in December 2021. |
| July 2021      | Methodologies and models for energy scenarios - TIMES_RSE (university lecture on the TIMES Italia model for PhD students)                                                                                                                                                                                                                   |
| September 2021 | Reports functionality in VEDA2.0  
**Weblink:** [https://www.youtube.com/watch?v=ri6asoxXcRg](https://www.youtube.com/watch?v=ri6asoxXcRg)                                                                                                                                                                                                 |
| October 2021   | Introducing Ancillary Services Markets in TIMES, speaker Evangelos Panos  
**Weblink:** [https://www.youtube.com/watch?v=kxUZvJkPbO8](https://www.youtube.com/watch?v=kxUZvJkPbO8)                                                                                                                                                                |
A series of webinars was prepared in 2021 and occurred in 2022, titled "Workshops series Integrating Sustainable Development Goals into Energy Systems". The objective was to have insights on methodologies, data and value-added from expanding the scope of the energy transition analysis beyond the energy system and the GHG emissions mitigation objective. Main outcomes from the event included three webinars on Sustainability & Resilience, Land-Use & Energy, Energy Poverty, with international experts as speakers and around 100 participants in each (Panos et al. 2021).

5.6 ENGAGEMENT WITH STAKEHOLDERS

5.6.1 Training ministry energy experts in Algeria by CRES (Greece)

There was a special training by the Centre for Renewable Energy Sources and Saving (CRES) in Greece in April-May 2021, for an introduction to TIMES and VEDA, and destined to energy experts from the Ministry of Energy and Mining of Algeria. The aim was to introduce users to the software that can be used for the performance and the analysis of medium to long-term energy demand forecasting scenarios for Algeria. The target was twofold: for the trainees to become familiar with the main functionalities of the software; and to provide an initial understanding of what can be performed by an energy system model like TIMES and what cannot be performed.

An ultimate objective was after this first training the trainees to be able to follow Part IV of TIMES documentation that provides a step-by-step introduction to building a TIMES model and where several models are described that progressively introduce the user to much more VEDA-TIMES principles and modelling techniques. Videos, a simple TIMES model with VEDA Front End software, a results database with VEDA Back End software, exercises with regard to changing model assumptions and also Excel templates for the analysis of results were prepared for the training.

In terms of results, the participants got familiar with the VEDA Front End for input data handling and in particular how to open a model, run a set of scenarios, and create new scenarios; define Commodities, Processes and their topology; enable the free of charge CBC solver; and add new technologies (SubRes). They also got familiar with the use of VEDA Back End and in particular how to open a results database, import results, and browse results tables and export results to Excel export/update results to a predefined Excel template.
5.6.2 General public outreach in New-Zealand

Another special training was conducted by the Energy Efficiency and Conservation Authority (EECA) in New Zealand, with the topic of how to use the interactive results tool.

Moreover, a series of 5 public Webinars on sub sectors (Industry, Electricity, Commercial/Residential, Primary sector, Transport) of the TIMES NZ model was held for industry participants, academics, policy makers, interested general public. Webinars generally ran for an hour with 50-100 attendees and dozens of questions asked and answered.

5.6.3 Consultation with experts in South Korea

In October 2021, South Korea hosted the another event on core technology trends to achieve 2050 net zero, with 11 attendees. The objective was consultation on major issues of domestic and overseas mid- to long-term energy transition, such as establishment of 2050 national LEDS and Nationally Determined Contribution(NDC) submission. There were announcements: South Korea carbon-neutral scenario and energy sector tasks; a feasibility study of using energy system analysis model to support 2050 carbon-neutral policy; and carbon neutrality and hydrogen system prospects.

5.6.4 Invited talks to key Swiss stakeholders

Finally, 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:

5.6.5 Engaging local transport decision-makers in Sweden

This event was a presentation of preliminary and final results from modelling of decarbonisation pathways in local transportation in region of Västerbotten, Sweden. Its main audience was local policy-makers and local government employees, and produced a final report to local decision-makers (in Swedish only). Date: 05/02/2020 (intermediate), 16-17/11/2020 (final).

5.6.6 Stakeholder engagement in Ireland

The MaREI Centre for Energy Climate and Marine Research at University College Cork organised and participated in a number of stakeholder engagements in Ireland to translate the results from energy systems modelling activities into insights for policy makers, energy industry and civic society, including:

- MaREI’s 9th Annual Energy and Climate Policy Research Webinar May 20th 2020 which focused on the impacts of coronavirus pandemic on the economy, energy and emissions, moving to net-zero GHG Emissions by 2050, and climate action, citizens, communities and infrastructure
- Collaborating with industry partners on decarbonising different sectors, including how to halve transport GHG emissions by 2030 together with the Irish Bioenergy Association, how to achieve zero emissions in electricity generation together with the Electricity Association of Ireland and the role of wind energy in achieving climate neutrality in Ireland by 2050 together with Wind Energy Ireland.

5.7 PROJECT FUNDED TO ENHANCE METHODOLOGIES

8 projects were funded, 4 in 2020 and 2021. The four projects granted funding in 2020 (based on the decision by the 80th ExCo meeting) were the following:

1. A TIMESCloud Service (58,600 €)
2. A TIMES/MIRO App (20,000 €)
3. Defining regions and time slices by period; Nesting spatial and temporal resolution in the TIMES source code and VEDA.2.0 to enable parametric scaling for exploration of structural uncertainty (55,000 €)
4. Utilisation of the online platform of KAPSARC as a repository of the SubRES data (22,500 €)

The four projects granted funding in 2021 (based on the decision in the 84th ExCo meeting) were the following:

1. Workshop series “Improving the modelling of energy behaviour in TIMES models: Approaches to include human and social dimensions in energy system modelling” (36,000 €)
2. Workshop series “Improving the modelling of crossborder electricity trade in national TIMES-based energy system models” (39,000 €)
3. Best Practice Guide for Applying FAIR Principles to TIMES Models (14,000 €)
4. Funding to Update the TIMES-Starter SubRES (10,000 €)

... Examples of ETSAP funded projects with high impacts
### 5.7.1 A TIMES Cloud Service

**Number of applicants:** 3 (GAMS/DWI/KanORS)

**Project duration:** 04/2021 - 03/2023

**Annual budget allocated to ETSAP project:** EUR 58,600

Usually, running TIMES requires installing commercial software (GAMS, VEDA) locally and obtaining a license to use that software. This project provides a new way to solve TIMES models “in the cloud”, without high upfront investment costs for GAMS.

The TIMES Cloud Service is based on the GAMS Engine technology and accepts jobs sent from a range of clients such as VEDA, VEDA-online, the TIMES/MIRO App, GAMS Studio, or custom clients written in programming languages supported by the OpenAPI standard. It also provides a simple web user interface, which allows submitting jobs and user administration. Submitted jobs are placed in a queue, and from there they are assigned to an available GAMS worker - a GAMS process that solves the model. Results from the model runs are collected and made available to the user.

The TIMES Cloud Service went online in April 2021. In December 2021 GAMS and ETSAP agreed to migrate the TIMES Cloud Service to the AWS Elastic Cloud that provides computing resources not limited to the configured hardware, as is the case in the single machine setup. With this migration, each job is executed on a dedicated instance whose resources are exclusively available to this job giving TIMES Cloud Service users get access to very powerful compute resources (up to 4TB of RAM). Furthermore, practically unlimited parallel jobs are possible.

The licensing and hardware costs for the TIMES Cloud Service are centrally covered by ETSAP during the duration of the project. Thereby, the service enhances the openness and affordability of the TIMES model generator and associated software and increases the accessibility of the TIMES modelling tools by lowering the upfront costs. By the end of the project different options for ongoing use of the TIMES Cloud Service need to be discussed, for example whether ETSAP will continue its payment for a compute time budget and/or if academic and commercial rates will be established.
5.7.2 A TIMES-MIRO App

Number of applicants: 4 (GAMS/DWI/IER/PSI)

Project duration: 01/2021 - 12/2021

Annual budget allocated to ETSAP project: EUR 20,000

An open-source interface to manage model inputs, draw Reference Energy System (RES) network diagrams, organize model runs and analyze model results will contribute to the open-source character of the overall TIMES modeling framework.

The TIMES/MIRO app is based on the deployment framework GAMS MIRO, which allows building intuitive and user-friendly interfaces to enable efficient interaction with GAMS models and provide extensive visualization capabilities. It can serve as an open-source GUI to TIMES models as it is published under an open-source license on GitHub. The TIMES-MIRO app can be installed locally or on a MIRO Server and be accessible through the web.

The starting point to establish a TIMES model under TIMES-MIRO a new user can either use the open source DemoS or TIMES-DK model input data as produced from VEDA, or use any complete model dataset for some other VEDA model.

5.7.3 Defining regions and time slices by period

There are increasingly new spatio-temporally granular data sets available that are useful for energy system model development. TIMES is a flexible framework to take advantage of individual unit process dynamics and incorporate their geospatial dimension with high temporal resolution in a TIMES reference energy system. Spatially there are TIMES models developed at the city level up to the global level. There are also sub-national TIMES models running at hourly resolution. However, there is a need to integrate high temporal and spatial resolution into more aggregated structures within the model time horizon for multiple reasons.

In this project the authors proposed to enhance the TIMES source code to allow time varying nested regional definitions alongside already tested and implemented time slice (TS) definition variation per period. This will enable TIMES modelers to model with higher spatial and temporal resolution in the short term while varying spatial resolution in the long term.

5.7.4 Use of the online platform of KAPSARC as a repository

When developing any TIMES model, the collection of data for the new technologies can be time consuming and is the most uncertain part, since there are many different data sources and estimations which change continuously. In the project called "Excel/SubRes technology database for an energy system model" the data related to the future technologies which should exist in a SubRES of a TIMES model are currently being collected.

However, the data for future technologies change continuously and have to be reviewed frequently in order to be up to date. In the ongoing SubRES project, the need for having parallel datasets was identified as an important feature of the database, in order to capture differences in model structure (e.g. different level of detail) as well as differences in modelling coverage (different geographical regions and/or different sectors/commodities/emissions). In order to ensure that the set
of data collected in the SubRES project are continuously updated in a structured way, this project proposed to utilize the KAPSARC Model Data Hub (https://apps.kapsarc.org/datahub/home). KAPSARC (King Abdullah Petroleum Studies and Research Centre) is a nonprofit organization based in Riyadh, KSA.

The proposal included the following tasks:

1. Uploading the data from the ongoing ETSAP SubRES project on the KAPSARC Model Data Editor platform.
2. Developing all the necessary processes (surveys, automatic data gathering etc) in order to ensure that the data are updated on a regular period (e.g. annually) with all the existing information.
3. Developing the necessary scripts to extract the data in a standard SubRES format readily useable by a TIMES model.
4. Look into different ways on how to – on an annual basis – facilitate a continuous review and update as well as enable possibilities to add new kinds of dataset for modelling.

5.7.5 Improving the modelling of energy behaviour in TIMES models

Individuals do not necessarily make decisions that are techno-economically optimal from an energy system perspective. If the energy behaviour is not considered in energy system models, the solutions can be too optimistic and underestimate the developing needs of the energy system.

There are several approaches to embed energy behaviour in TIMES models. This project will map the approaches that are used by the ETSAP community to consider energy behaviour. Furthermore, the aim is to identify the knowledge needs and gaps, and to discuss and exchange ideas related to the best practices of incorporating energy behaviour in TIMES models.

The project deliverables comprise of 3 workshops held and arranged by three different participating project members. The main findings from these workshops will be documented through a report that will be uploaded on the ETSAP webpage with the following title: “Approaches to include human and social dimensions in TIMES energy system modelling – practices, recommendations and further research needs”.

5.7.6 Improving the modelling of cross-border electricity trade in national TIMES-based energy system models

The use of crossborder electricity trade and other energy commodity trade becomes more important to ensure a costefficient and reliable lowcarbon transition of the energy system for many countries. For regional and national TIMES models it is however not straightforward to model the dynamics of the electricity and other energy markets that are outside the spatial scope of the model. In addition, the design of the TIMES models related to spatial resolution, temporal resolution, and the representation of shortterm uncertainty in supply and demand can influence the model results on trade. Different ETSAP members use different approaches to crossborder trade in national models.

This project aims to get an overview of the approaches that are used in the ETSAP community, to identify the knowledge needs and gaps, and to discuss and exchange ideas related to best practices of modelling of crossborder energy trade in national TIMES models. In addition to electricity trade, this project will also discuss trade of fuels that are a part of an international market, such as biofuels and hydrogen, that face the same modelling challenges as electricity trade.
The project deliverables comprise of 4 workshops held and arranged by four different participating project members. The main findings from these workshops will be documented through a report that will be uploaded on the ETSAP webpage with the following title: “Crossborder trade: Modelling practices, recommendations and further research needs”.

5.7.7 Best Practice Guide for Applying FAIR Principles to TIMES Models

This small project will develop a Best Practice Guide for applying FAIR principles to TIMES Models. FAIR stands for Findable, Accessible, Interoperable and Reusable and focuses on facilitating reuse and sharing of research outputs. Major national and international funding bodies promote FAIR data to ensure that the impact of their investment is maximised. The Best Practice Guide will review the approaches to applying FAIR within the broader energy system modelling community.

Informed by this, a set of recommendations that takes into account workflows typically used with TIMES will be proposed. If possible and relevant, examples (code) that illustrate (facilitate) application of FAIR will be developed. In particular, the use of Frictionless data package format and tools (developed by Open Knowledge Foundation) for results dissemination and/or input data documentation will be explored. The project will also work together with the on-going ETSAP SubRES project to determine how FAIR data principles could/should be applied to the database.

5.7.8 Update the technology repository of the TIMES-Starter

The TIMES-Starter platform has proved to be an important component of the ETSAP Tools. As of October 2021 there have been 148 downloads of the TIMES-Starter this year, over 440 to date. The effectiveness of the TIMES-Starter as a way for new users to embrace TIMES and move up the steep learning curve is clear.

In order for the TIMES-Starter to remain relevant and truly useful, the SubRES characterizations of new technologies (NT) really need to be as current as possible. The NTs in the TIMES-Starter now correspond to those from the 2016 US Annual Energy Outlook (AEO), now +5-years old. This critical component of the TIMES-Starter needs to properly reflect the rapid advancement of new technologies, in particular renewable options.
ETSAP has provided funding for the development of ETSAP-TIAM. Between 2019-2020, ETSAP experts have contributed to update the model base year and set up new data structure but still represent the same RES. The B-Y templates have been updated to 2015, and parametrically link to the IEA extended energy balance for rapid update cycles where the base year and regional aggregation can relatively easily be changed. The following base year templates have been completed for 31 regions: Agriculture (AGR), Commercial (COM), Residential (RES), Industry (IND), Transport (TRN) and Power (ELC).

There are open questions regarding i) possible use of the IEA energy balances and ii) whether the ETSAP-TIAM model should be open or not. There is an option to buy a license for using energy balances from IEA, however there may be a conflict with the license requirements if TIAM is open source.

The ExCo agreed that the ETSAP management team should engage with IEA regarding use of the IEA energy balances and that there will be a discussion at the next ExCo meeting on whether the ETSAP-TIAM model should be made open or not. It was further suggested that ETSAP-TIAM can be made open-source through e.g. GitHub. This will be discussed once an updated fully functional version of the model is available. The ExCo agreed to seek other volunteers to also test the model and that this would help determine current model operational status and next steps.
5.9 TRANSPARENCY THROUGH OPEN-SOURCE MODELS AND RESULT PLATFORMS

5.9.1 New open-source user interface for TIMES-based models

PSI contributed to the development of a new open-source user interface for TIMES-based models (see Section 2.6.2). The interface allows for data and code exploration, is suitable for scenario management and includes visually attractive and easy to use reporting facilities. Besides its open-source character, the interface allows modellers to solve TIMES-based model without having a costly GAMS and solver license by making use of the NEOS server. The interface was presented in two ETSAP workshops, including video demonstrations: Summer 2020 and Winter 2021.

The TIMES Cloud Service & The TIMES/MIRO app are currently running ETSAP R&D undertakings (Figure 4).

Figure 4 – New open-source user interface for TIMES-based models
5.9.2 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.

TIMES-NZ 2.0 is a technology-based optimisation model that represents the entire New Zealand energy system, encompassing energy carriers and processes from primary resources to final energy consumption. The model is based on the IEA ETSAP TIMES energy model generator, and models scenarios for the energy system, incorporating both technical, engineering and economic considerations. The scenarios were originally developed by the BEC2060 project - this updated TIMES-NZ model adds more detail and sophistication to sectors, subsectors, technologies and end uses.

The New Zealand Energy Scenarios TIMES-NZ 2.0 project grew out of BEC2060, which provided two plausible and coherent scenarios about New Zealand’s energy future: Kea (Cohesive) and Tūi (Individualistic). Kea represents a scenario where climate change is prioritised as the most pressing issue and New Zealand deliberately pursues cohesive ways to achieve a low-emissions economy. Tūi represents a scenario where climate change is an important issue to be addressed as one of many priorities, with most decisions being left up to individuals and market mechanisms.

![Figure 5 – TIMES-NZ results platform](image)

Also, the TIMES-NZ model was fully documented in a reference paper that sets out all relevant assumptions and inputs and explains many of the processes and sub-process in use.
5.9.3 Belgian long term electricity system scenarios

VITO developed an online Tableau viewer which is used to present detailed scenario results for the electricity supply sector and electricity demand. The user can select which scenario he/she wants to zoom in on, can compare scenario’s and download the data behind the graphs. The website gives a clear description of the modelled storylines and scenarios.

5.9.4 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. To capture operational variations in energy generation and end-use, each model period is split into 96 sub-annual time slices, where four seasons are represented by 24 hours each. The model has a detailed description of end-use of energy, and the demand for energy services is divided into numerous end-use categories within industry, buildings and transport.

IFE published a documentation report of the IFE-TIMES-Norway meeting in 2020 and 2021 that is available online.
Switzerland Joint Activity Scenarios and Modelling (JASM)

The Joint Activity Scenarios and Modelling (JASM) aims at providing a set of robust scenarios for the realization of the Swiss Energy Strategy 2050. The modeling groups of the 8 Swiss Competence Centers for Energy Research (SCCER) work together and bring in their respective experience in the field of electricity generation technologies, buildings, mobility, industry, grids, biomass, storage and economy.

The JASM Data Platform provides data that is relevant for Swiss energy economics modelling. The collection of data offered here includes modelling drivers, assumptions and results from the JASM modelling teams.
Work by the Swedish Energy Agency produced several contributions. A first series focuses on the transport sector, which improved the transparency by openly discussing key challenges and choices in TRA sector with the TIMES-City model with regards to i) Sector representation to ‘fit’ the challenges of local policy-makers and ii) Limitations in local level statistical data available for model calibration. See chapter 4 in (Forsberg, 2021) and Appendix II in (Forsberg and Krook-Riekkola, 2020). Another focused on the industry sector, and describes a general modelling approach for industry in national energy system models, with specific focus on TIMES-Sweden (Sandberg, 2020a).

To increase the transparency of published data sets and to applicate the FAIR data principles (Findable, Accessibility, Interoperability and Reuse) for published data sets, IER contributes to develop the Open Energy Ontology. The Ontology provides a precisely defined vocabulary to build a common and shared conceptualisation of the energy domain. The development of the Open Energy Ontology is a collaborative, open and ongoing process on GitHub.

https://github.com/OpenEnergyPlatform/ontology

Heterogeneous data, different definitions and incompatible models are a huge problem in many domains, with no exception for the field of energy systems analysis. Hence, it is hard to re-use results, compare model results or couple models at all. Ontologies provide a precisely defined vocabulary to build a common and shared conceptualisation of the energy domain. Here, we present the Open Energy Ontology (OEO) developed for the domain of energy systems analysis.

Figure 9 – Production pathways and technologiess for cement, quicklime and glass industry

Sandberg (2020b) also produced a publically available database of the industry called SubRES, which includes all industrial technologies in TIMES-Sweden, complete with sources and comments explaining assumptions and calculations. The database is a compilation of information from literature, specifically tailored for use in TIMES models.
The objective was easing cooperation and exchange of information across the energy systems analysis domain. The OEO was designed to map the complexity of the research area and to collect, connect and structure the ambiguous terminology of adjacent domains, the energy systems analysis domain needs information from.

![Open Energy Ontology](image)

**Figure 10 – Open Energy Ontology**

For the IER-TIAM model the results of the implementation of the renewable potentials were presented at an ETSAP workshop.

### 5.9.8 United Kingdom

Developing the policies needed to achieve net zero is challenging, with uncertainties ranging from the cost of fuel, when and whether certain technologies will be available, and how people will behave when they are asked to use new ways of heating their homes. Results from models can help if understood and used correctly, which means reflecting uncertainties, being clear on assumptions and combining modelling evidence with, and testing it against, other forms of evidence.

Many of the UK Government’s models have been developed in-house and in close collaboration with academia. The Government now wants to increase its ability to access the best modelling expertise available. It will implement a new modelling strategy that will increase transparency and collaboration.

The next phase of their modelling strategy will improve their approach to modelling and transparency. They will set up and test a protocol for publishing our models. There will be specified exemptions such as models in development or models including with sensitive commercial or security information commercially. This is all part of the ongoing development of UK TIMES version 2.0, in accordance with the UK Government’s pledge to increase the transparency of energy models, as featured in the [Energy White Paper](#).
The MaREI Centre for Energy Climate and Marine Research at University College Cork developed a web app in 2021 to share results for the period 2021-2050 for a range of different scenarios that were modelled with the TIMES Ireland Model (TIM). The TIM Carbon Budgets 2021 Web App visualises most of the scenarios included in the github repository that contains these energy system scenarios for Ireland meeting decarbonisation targets for 2030 and 2050. This data package. Up to two scenarios can be selected for comparison and the difference can be computed. In addition to the scenario results visualisation, TIM documentation and scenario description are also available from the web app. The app has proved to be a very effective communication tool when discussing scenario results with policy makers and with industry stakeholders.

Figure 11 – Ireland’s TIM Carbon Budgets 2021 Web App
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, the European Commission, as well as one private sector sponsor formed the contracting parties to ETSAP during the 2020-2021 period:

- 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)
- European Commission (until mid-2020)
- Korea (KEA)
- The Netherlands (ECN)
- New Zealand (EECA)
- Norway (IFE)
- Russia (ERI-RAS)
- 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.

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

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.

**A powerful methodology for refined scenario analyses**

**A proven approach with convenience, confidence and flexibility**
The multiple benefits of the TIMES model generator and its interface include the possibility of analyzing scenarios with thousands of technologies, tailored to a given region of interest and specific time periods.

A great strength of the IEA-ETSAP methodology is that details of each technology are available in an open source format. This allows the researcher all the flexibility required while maintaining very high levels of convenience. New technologies are added regularly and researchers can work on scenarios that involve taking into account recent technological innovations.

Moreover, the power of the IEA-ETSAP methodology helps manage uncertainties confidently, providing enough details to answer questions such as when wait and see is better than hedging.

The ETSAP tools are helpful in achieving the twin and potentially conflicting objectives of enabling fine detailing while maintaining high levels of transparency. This challenging objective is worthwhile to achieve because the methodology is often applied to issues that are critical for the future of our planet.

Moreover, the efficiency of the tools makes it possible to mitigate the effect of the inherent uncertainties involved. The efficiency of compiling the input data, processing it and interpreting the results makes it possible to relatively quickly evaluate a wide range of scenarios to provide for the uncertainties involved. This makes a confident final decision possible.

Applications based on the IEA-ETSAP methodology help make it possible for the assumptions to be known in fine detail and the output data to be visualized by well evolved means that make it easy to understand for people who are not researchers themselves.

... with a commitment to a high level of transparency

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.

... and validated via a plethora of applications for energy and climate actions

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 23 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 1 – Members and participants to regular ExCo meetings

<table>
<thead>
<tr>
<th>N.</th>
<th>COUNTRY</th>
<th>ONLINE (77TH) MAY 2020</th>
<th>ONLINE (78TH) JULY 2020</th>
<th>ONLINE (79TH) SEPT 2020</th>
<th>ONLINE (80TH) DEC 2020</th>
<th>ONLINE (81TH) MARCH 2021</th>
<th>ONLINE (82TH) JUNE 2021</th>
<th>ONLINE (83TH) SEPT 2021</th>
<th>OSLO-ONLINE (84TH) NOV 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Australia</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Belgium</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</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>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>EC</td>
<td>Yes</td>
<td>No</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>Finland</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>France</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Germany</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>Greece</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>Italy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>Ireland</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>11</td>
<td>Japan</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>12</td>
<td>Kazakhstan</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>13</td>
<td>Korea</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>N.</td>
<td>COUNTRY</td>
<td>ONLINE (77th) MAY 2020</td>
<td>ONLINE (78th) JULY 2020</td>
<td>ONLINE (79th) SEPT 2020</td>
<td>ONLINE (80th) DEC 2020</td>
<td>ONLINE (81st) MARCH 2021</td>
<td>ONLINE (82th) JUNE 2021</td>
<td>ONLINE (83th) SEPT 2021</td>
<td>OSD-ONLINE (84th) NOV 2021</td>
</tr>
<tr>
<td>----</td>
<td>-----------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>14</td>
<td>Netherlands</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>15</td>
<td>New Zealand</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>16</td>
<td>Norway</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>17</td>
<td>Russia</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>18</td>
<td>Spain</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>19</td>
<td>Sweden</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>20</td>
<td>Switzerland</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>21</td>
<td>UK</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>22</td>
<td>US</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>23</td>
<td>Sponsor</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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 from the 2020-2021 period 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>2nd - 3rd July 2020</td>
<td>Online</td>
<td>Summer 2020 - Semi-annual ETSAP meeting</td>
<td>129</td>
</tr>
<tr>
<td>16th - 17th December 2020</td>
<td>Online</td>
<td>Winter 2020 - Semi-annual ETSAP meeting</td>
<td>82</td>
</tr>
<tr>
<td>7-9 June 2021</td>
<td>Online</td>
<td>Summer 2021 - Semi-annual ETSAP meeting</td>
<td>77</td>
</tr>
<tr>
<td>Dates: 29th - 30th November 2021</td>
<td>Hybrid (in person and online)</td>
<td>Winter 2021 - Semi-annual ETSAP meeting</td>
<td>120 (30 in-person, 90 online)</td>
</tr>
</tbody>
</table>

A.4 BUDGET

The ExCo agreed previously to transfer €150 k to the next year budget to cover core ETSAP activities ensuring the OA can enter into necessary contracts before the membership fee for 2022 is paid. Thus, €150 000 will be transferred to 2022.

According to the economic overview done in November 2021, €195 281 is available for projects and other activities.
### Table – ETSAP Budget for 2020 and 2021

<table>
<thead>
<tr>
<th>BALANCE (BUDGET)</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income Membership</td>
<td>Actual 440 000</td>
<td>Actual 300 000</td>
</tr>
<tr>
<td>Income (training, change OA)</td>
<td>Actual 674 509</td>
<td>Actual 8 087</td>
</tr>
<tr>
<td>Income (transferred from previous year)</td>
<td>Actual –</td>
<td>Actual 665 049</td>
</tr>
<tr>
<td>Base activities</td>
<td>Actual - 302 960</td>
<td>Contracted - 133 700</td>
</tr>
<tr>
<td>Coordinated projects</td>
<td>Approved - 159 100</td>
<td>Application –</td>
</tr>
<tr>
<td>Commitments from previous year</td>
<td>Actual -311 555</td>
<td>Actual -494 155</td>
</tr>
<tr>
<td>Transfer Income (savings)</td>
<td>Budget - 170 000</td>
<td>Budget - 150 000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BALANCE</th>
<th>170 894</th>
<th>195 281</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commitments transferred to next year</td>
<td>Budget 494 155</td>
<td>Budget –</td>
</tr>
<tr>
<td>Transfered Income to next year</td>
<td>Budget - 665 049</td>
<td>Budget - 195 281</td>
</tr>
</tbody>
</table>

| NEW BALANCE                              | –             | –             |
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 over the years 2020 – 2021 delivered during Annex XIV: 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.


Kannan R. et al. (2022). *A netzero Swiss energy system by 2050: Technological and policy options for the transition of the transportation sector*. Futures & Foresight Science (February).


Petrović S. Colangelo A. Balyk O. Delmastro C. Gargiulo M. Simonsen MB. (2020). The role of data centres in the future Danish energy system. Energy, 116928.


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