D7.4

R4.4 Market Analysis

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EXECUTIVE SUMMARY

This report aims to present a market analysis of different energy forecasting models. For this purpose, first, a review of different models, including energy demand forecasting in general and electricity demand forecasting, has been carried out. Next, an analysis of the models has been carried out considering a series of benchmarks or parameters that, according to the literature, are relevant when describing and classifying demand forecasting models. Then an analysis of the positioning of the WHY tool has been carried out, considering the strengths, weaknesses, opportunities and threats.

There is a wide field of research around energy demand modelling.

Energy modelling dates back to the 1970s, the result of successive oil crises that significantly impacted the world economy. Since then and over the last fifty years, many models have been developed. During the last decade, numerous energy models have emerged, most of them open access. The dramatic need to move towards a zero net emissions energy model makes modelling relevant again.

Main characteristics of energy models

For this research, 118 energy models were selected, which at some point estimate the energy demand, specifically for electricity. The most numerous are Energy System Models (ESM), many of which are also integrated into broader models that cover the economy of many countries (e.g., NEMS, ENTICE-BR or TIAM-UCL). In second place are those models whose focus is on the projection of energy demand and, in particular, electricity demand. The third group of models covers the electricity sector in a broad sense. The fourth group is models that focus on the future development of the electricity system. The fifth group projects energy consumption in buildings, especially in residential buildings and finally, the last group analyses (domestic) consumers' behaviour.

Only four models (3.4% of the sample) represent household energy consumption (the main objective of the WHY project): Demod, IDA ICE, SEEM energy model and Social Practices Agent-Based Model.

The European Union and North America are among the leaders in developing energy models. Of the 118 models in the sample, only 22 originated outside Europe (17 from the USA, three from Australia, one from Canada and one from China). Eight have their origin in international collaborative projects and the rest in Europe (53 from the EU-27, 24 from the U.K., seven from Switzerland and four from Norway).

Academic institutions and research centres are currently the leading promoters and executors of this type of tool. Some institutions (e.g., Fraunhofer ISI, University College London) have a wide range of models, which can sometimes interact as interdependent modules. The number of consulting firms engaged in this activity seems to be lower.

Problems regarding the transparency or replicability of energy models led, in 2014, the Open Energy Modelling Initiative. Therefore, there has been an increase in the number of open access models, whose characteristics open the door to their improvement over time. Consulting companies do not follow this trend and develop marketable models.

Numerous demand forecasting models developed in research do not continuously evolve. Approximately 20% of the models do not appear to be updated or improved over time (e.g., Markal model is not updated, although maintained because it has many users/countries).

Python (open source) and GAMS are the main mathematical programming languages and optimisation instruments. VEDA and CPLEX are, in this sample, the leading solvers used.

Increasing temporal and spatial resolution could, in principle, improve the accuracy of the model's results, whether in a simulation, optimisation or projection model. In this regard, the geographical scope of the models can vary from analyzing individual buildings, municipalities, regions, countries, world regions, or the whole world. The most common time scopes are annual and hour. However, there are many different options such as minutes, year's seasons or times of the day. A large part of the models is long term, and the most common time framework refers to 2030, 2040 and 2050.

In the case of models for commercial or presumed commercial purposes, there is a tendency for them to have an annual temporal resolution (72%). Likewise, 46% of the OAMs have an hourly resolution.

For the development of the models, the most frequently objective is the reduction of the costs followed by the assessment of policy interventions and technological shifts. With different mathematical approaches, developing scenarios is the principal methodology applied. 80.5% of the models include several scenarios for the analysis.

Most of the models refer to optimisation, simulation and, to a lesser extent, projection. The academic institutions mainly develop models of optimisation, simulation, and a combination of them. The consulting companies, instead, have created most of the projection models. Research centres, consultancy firms and cooperation projects have a more diversified portfolio in terms of the type of models.

A large share of the sample develops a scheme to reproduce the energy reality or use linear programming (especially for optimisation) and dynamic programming. In the case of electricity-related models, there are no tools of particular relevance.

SWOT analysis of the WHY toolkit

A SWOT analysis has been made considering the main characteristics of the WHY toolkit and the market analysis. It shows that the WHY toolkit and the consortium must still face substantial challenges.

The WHY toolkit has its versatility and modularity among its strengths. It includes financing and governance-related issues. It results from international cooperation with different developers (consulting companies, academia, research centres, energy-related company and public institutional partner). However, it also has weaknesses, such as the lack of a business model and reflection about the future collaboration of a diverse group of partners with different interests.

As mentioned, there is a high quantity of energy demand forecasting models, some of which have a long track record than the WHY consortium. The lack of a recognized brand and the maintenance cost over time are also threats to the WHY toolkit.

Nevertheless, the energy transition process brings opportunities for a tool that can offer accurate data for the development of energy communities, assess the impact of a blackout, energy-related policies, the increase of environmental awareness, and other changes in human behaviour, among others.

Strengths	Weaknesses
The versatility of the tool (different use cases) The modularity of the tool It includes issues related to financing and governance mechanisms and social variables. Robustness of the consortium	Need to reflect on the tool's business model Collaboration of actors of different nature with sometimes conflicting interests
Opportunities	**Threats**
Accurate data for the current energy transition process for the development of energy communities, integrated energy system models, energy consumption behaviour, etc. Increasing social and environmental awareness of different actors The more active role of consumers Estimate of the impact of different interventions Dealing with a blackout	High quantity of energy demand forecasting models Long track record of many competitors Lack of a recognized brand Cost of maintenance over time

Table 1. WHY toolkit SWOT analysis
Source: own elaboration.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Long text
Aladin	ALternative Automobiles Diffusion and INfrastructure
ASTRA	ASsessment of TRAnsport
CCUS	Carbon Capture, Utilisation and Storage
CDR	Carbon Dioxide Removal
DOE	US Department of Energy
DSO	Distribution system operator
E3	Energy-environment-economy
E3M	Energy-Economy-Environment Modelling Laboratory
EFM	Energy forecasting model
EIA	Energy Information Administration
ENVI	Energy environmental impact model
ERI	Energy Research Institute
ESD	Energy for Sustainable Development Ltd
ESMs	Energy System Models
ETM	Energy technology model
ETSAP	Energy Technology System Analysis Program
EU	European Union
Fraunhofer ISI	Fraunhofer Institute for Systems and Innovation Research
GEA	Global Energy Assessment
GHG	Greenhouse gas
GINFORS-E	Global Interindustry FORecasting System – Energy
GWS	Gesellschaft für Wirtschaftliche Strukturforschung mbH (Institute of Economic Structures Research)
IAEA	International Atomic Energy Agency
IAM	Integrated assessment model
ICT tool	Information Communication Technology tool
IEA	International Energy Agency

IIASA	International Institute for Applied Systems Analysis
IPAC	Integrated energy and environment Policy Assessment model for China
LEAP	Long-range Energy Alternatives Planning
MAED-2	Model for Analysis of Energy Demand
MAGICC	Model for Greenhouse gas Induced Climate Change
n.a.	Not available
NEMS	National Energy Modelling System
NUTS	Nomenclature of territorial units
OAM	Open Access Model
OSM	Open Source Model
PACE	Policy Analysis based on Computable Equilibrium
POLES	Prospective Outlook on Long-term Energy Systems
PRIMES	Price-Induced Market Equilibrium System
ROI	Return on Investment
SAFIRE	Strategic Assessment Framework for the Implementation of Rational Energy
SGM	Second Generation Model
SWOT	Strengths, Weaknesses, Opportunities, and Threats
UCL	University College London
VLEEM	Very long term energy environment model
WBGU	German Advisory Council on Global Change
WEC	World Energy Council
WEM	World Energy Model

1. Introduction

The need to transform the global economy into a "net-zero" greenhouse gas (GHG) economy requires profound changes across value chains and all economic sectors. The goal of this transformation is environmental sustainability, one of the dimensions of sustainable development as described in the U.N. Sustainable Development Agenda. "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs [...] It is essential to harmonise three basic elements: economic growth, social inclusion and environmental protection, to achieve sustainable development. These elements are interrelated and are all essential for the well-being of people and societies..." (U.N., 2020).

Decarbonizing the economy implies, to a large extent, changing the entire energy value chain, from energy production to distribution and consumption, in such a way as to achieve "net zero emissions", the objective of the European Union according to its Climate Law by 2050 (European Parliament, Council of the European Union, 2021). Decarbonizing the energy system requires different technologies and strategies, which are very varied and range from the use of renewable energies (e.g., wind, solar or hydro), the deployment of smart grids to greater energy efficiency, enhanced electrification of energy and mobility uses, and the uptake of novel zero-emission options (e.g. green hydrogen, Carbon Capture, Utilisation and Storage (CCUS), clean synthetic fuels) and the use of Carbon Dioxide Removal (CDR) options to compensate for residual emissions from hard-to-abate sectors and processes. Energy System Models (ESMs) are extensively used to analyse the impacts, challenges and benefits of low-emission pathways and strategies at national, regional and global levels.

Until now, the focus of ESMs has been mainly on the supply side (e.g., optimisation of investments in generation, renewable energies deployment, optimisation of transmission and distribution networks). However, the energy transition process is making energy demand projections increasingly important, given the growing social awareness on decarbonization and the more active role consumers will play in the energy system. Energy-saving and energy efficiency measures, the uptake of more efficient fuels and technologies (e.g., heat pumps, electric vehicles), the development of distributed renewable resources, including demand response measures, are becoming increasingly important and will eventually impact the behaviour of energy consumers. This will impact, for instance, on system operators who play a vital role in matching electricity supply and demand and who will be forced to adapt to the new circumstances.

As an example of how a shift in human behaviour impacts electricity demand, due to the COVID-19 crisis, the growth of teleworking has led to considerable changes in domestic electricity demand, with people shaking up their routines and using energy at different times of the day. For instance, in the United Kingdom, *data from more than a million smart metre customers show that people are waking up later, and there is now a surge in electricity usage at 8 am, compared to 7 am pre-lockdown. Dinner time has been brought forward, with an energy spike at 6 pm compared to between 7 pm and 8 pm previously* (Burford, 2022). Further information could be found in Deliverable D2.1 where an extensive assessment on the changes due to COVID-19 on the electrical energy consumption has been made.

In this regard, one of the critical goals of the WHY project, according to Deliverable 1.1[1], is the development of the WHY Toolkit, *a software that will allow users to make better forecasts for electricity consumption in households; analyse, evaluate, and validate policy decisions or other interventions such as changes in regulation, policy measures or funding, and examine how today's world would look like if certain energy policy decisions had or had not been taken. By simulating how people might have reacted to specific policy decisions, the WHY model will analyse the effects of these decisions on the system's development.*

Since there are different tools that, to a certain extent, might appear to address the exact needs that the tool developed in the WHY project cover, the present deliverable contains a comprehensive analysis of demand forecasting and prediction models carrying out a benchmarking analysis and a SWOT analysis. The goal of this market analysis is to help in Task T7.3 to: a) identify the market's potential size for the main results of the project, b) the assessment of the competitors and c) the potential value of the results for all potential market opportunities towards commercialization, which will be evaluated in the exploitation strategies phase.

The deliverable contains the following chapters:

1. A short description of the methodology.
2. **An analysis of references (academic or otherwise) and documentation relative to demand forecasting and prediction models for small consumers**, and review of other sources of information about demand models, including the analysis of the potential uses and applications of the models. Analysis of the coherence and complementarity of the model with other European energy system models such as

[1] (Nacht, Borges, Bolintineanu, Merveille, & Fragkos, 2020).

PRIMES, TIMES, PROMETHEUS or other European models to assess the consistency and complementarity of the proposed models with these larger models.

3. Based on the information collected, **a benchmarking and comparative analysis of the developed model against the modelling solutions identified** in the previous chapter will be presented. This benchmarking includes a comparative assessment of the model's main characteristics, the developer, its geographic scope, the main causal variables included in the model, target public and users. The objective of this exercise will be to identify the advantages and potential future improvements of the proposed model. This benchmark is completed with a **SWOT analysis of the WHY toolkit.**

This deliverable lays the foundation for future work in the WHY project, especially for the exploitation strategies phase. The results complement the state-of-the-art research for models, legislation, and initiatives, described in Deliverable D1.2 and will consider the requirement for the WHY Toolkit presented in Deliverable D1.3.

2. Methodology

The chosen methodology has been a non-systematic literature review on the different references (both academic or otherwise) and documentation relative to demand projection models for small consumers to undertake this analysis. This methodology will allow having a description of the state/nature of existing evidence. It is widely used in reports by governments and international institutions (Eklipse, 2020).

Among its main strengths, it can cover a broad subject area. Although systematic review can be considered the optimal approach, a non-systematic literature review may be considered a good approach if it is supported by experts' engagement (Lilley, Payne, Fox, Brown, & Fountain, 2020). In this regard, several interviews were also held with the experts on the WHY project involved in developing or applying demand forecasting and prediction models.

The goal has been to identify a representative base of models that will account for the most relevant theoretical (and practical) perspectives and approaches, although not intended to be comprehensive.

One of the main characteristics of a systematic review is that it must *follow a well-defined protocol introduced to bring more clarity, rigour and repeatability* (Kuster, Yacine Rezgui, & Mourshed, 2017). This research was accompanied by a process of reflection on the search elements. The focus of the search was set not only on peer-reviewed articles but also on sectoral publications. In this sense, the ResearchGate, Science Direct, and Google Scholar engines have been used to survey the literature by searching the terms in the following figure (Figure 1), but there has also been a search for research centres, universities and companies that are involved in modelling.

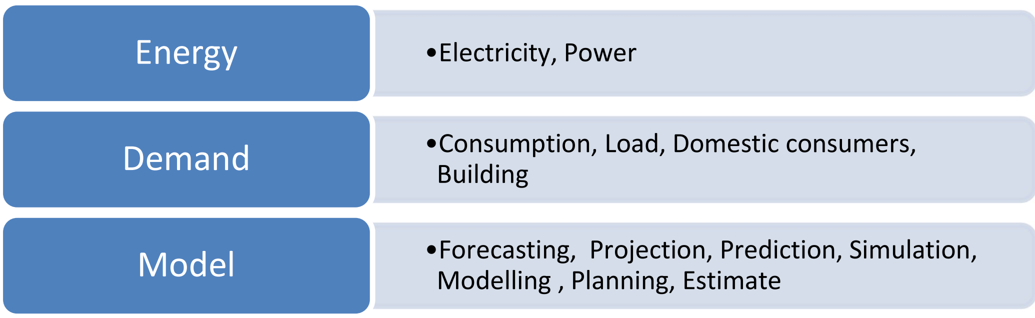


Figure 1. Keywords
Source: own elaboration.
Note: The search was conducted in the English language.

To characterise the different models among the primary sources of information that have been consulted are (Verwiebe, Seim, Burges, Schulz, & Müller-Kirchenbauer, 2021), (Oberle & Elsland, 2019), (Ringkjøb, HauganIda, & Solbrekke, 2018), (Kuster et al., 2017), (Joint

Global Change Research Institute. Pacific Northwest National Laboratory & University of Maryland, 2018), (Bhattacharyya & Timilsina, 2009), (de Blas, Miguel, & de Castro, 2021), (Fraunhofer Institute for Systems and Innovation Research ISI, 2022), (UNFCCC, 2022), (Energypedia, 2022), (IAMC, 2021), (UCL, 2022) and (IAEA, 2022). However, they are not the only ones. In addition, the manuals of the models, where it was possible to access them, were reviewed together with academic references describing them. The web pages of the models themselves or institutions that have created or used them over time or compiled examples of models for different reasons have also been surveyed (e.g., AFRY, Enerdata). However, not all references have been included in this report[2].

A small database has been constructed to collect information from the different energy system models in the sample. Among the main characteristics included is a brief summary of the object of the model, the developer's name, type of developer and its origin. It also contains information on their availability, whether the models are updated over time, energy sectors covered, type of mathematical modelling and other associated parameters. Considerations related to the software required, the model's geographical and temporal resolution and coverage are also incorporated. Finally, it has been considered appropriate to include some economic parameters, such as price. However, there has been no "success" in searching for this type of information. As will be discussed later, this may be due to different reasons, among which is the great variety of open access models considered, such as the need or adaptability of the models to the needs of the clients/users.

[2] A list of the models with the leading websites consulted is given in Annex 1.

3. Analysis of references and documentation relative to demand forecasting and prediction models for small consumers

This chapter provides an analysis of the different energy models analysed[3]. Although the energy models chosen and reviewed had to be preferably European, some references to non-European models are also included.

When trying to identify key insights and trends in demand forecasting around the world, it has been observed that there is a wide field of research around energy demand modelling (Verwiebe et al., 2021). This market analysis results indicate a high demand for this type of product.

For this research, finally, 185 models were selected, from which 67 were later rejected because of different reasons: lack of information on the model itself (e.g., Backbone or Ficus), focuses on specific issues such as optimising supply and demand matching (e.g., Gridcal, NEMO), designing electricity distribution networks (e.g., GridLAB-D or Mosaik) or finding the optimal technological options for electricity supply in isolated areas (e.g., OnSSET).

From the 118 models finally included in the analysis, there is information that could not be accessed in some cases. However, this has not been considered relevant given that a sufficiently representative group of models is available. As can be seen in Figure 2, the models have been classified into six groups.

[3] Annex 2 includes a table with the models selected and the name of the leading developer of the tool.

Energy models	• AnyMOD, Calliope, Demand for Energy Services, DESSTinEE , DynEMo, E3ME, E3MG, EnerFuture, Energy Policy Simulator, ETM, EnergyPlan, EnerNEO model, ENTICE-BR, ESME, ETEM , ETM-UCL, Euro-Calliope, GEM-E3, GINFORS, IMAGE, IPAC, LEAP, MARKAL, MDM-E3, MEDEAS, MESSAGE, NEMESIS, NEMS, NIEIR Multi-purpose model, Oemof , OMEGAlpes, OSeMOSYS, PACE, PANTA-RHEI, POLES -JCR, PRIMES, PROMETHEUS, ReMIND , SAFIRE, SAGE, SGM, SNOW, STEMES, TEMPEST, TIAM-ECN, TIAM-UCL, TIMES, TIMES UK, TIMES-Norway, UK MARKAL, VLEEM, WEM
Energy demand models	• Aladin, ASTRA Transport, Country Energy Demand Forecast, Demod, eLoad, EnerMED, FORECAST, Invert/EE-Lab - Invert-Agents, MAED, Temoa, Timer Energy Demand Model, UK Foreseer
Electricity/ infrastructure models	• AFRY BID3, AMIRIS, DEAM, DIETER, EleServe, ELMOD, GRIMSEL-FLEX, HOMER, LIBEMOD, RAPSim, ReEDS, Region4FLEX, renpass GIS, SHIPMod, SimSES, Switch, TransiEnt, WeSIM
Renewable energies/electricity system development	• Balmorel, Breakthrough Energy Model, CAPOW, EnergyNumbers-Balancing, EnergyPro, EnergyScope, FlexiGIS, GREEN-X, LOADMATCH, LUSYM Invest, MESAP, PLEXOS, PowerGAMA, REMix , Renpass, Reopt, RETScreen, SIREN, SMS++, urbs , USENSYS
Building environment models	• CaRB2, CESAR-P, DER-CAM, DREEM, Enertile, ETM (EUROfusion Times Model), HEB, IDA ICE (IDA Indoor Climate and Energy), OpenTUMFlex, PyLESA, SEEM Energy Model, SmartCED
Behavioural models	• BLUE, LoadProfileGenerator, Social Practices Agent Based Model

Figure 2. Selected energy models
Source: own elaboration.

The most numerous are those that model the energy system as a whole (ESMs). Many of them are also integrated into broader models that try to cover the economy of many countries (e.g., NEMS, an integrated model of the U.S. energy system linked to a macroeconomic model; ENTICE-BR a dynamic growth model of the global economy that includes links between economic activity, carbon emissions and the climate or TIAM-UCL a global optimisation model that investigates decarbonization of the global energy-environment-economy system).

Secondly, there are those models whose focus is on the projection of energy demand and, in particular, electricity demand. Their number is smaller, but they might have similarities with the WHY toolkit. Another group is models that study the electricity sector in a broad sense. In this case, there are models that have been discarded because they did not include the electricity demand. The next group is that of models that focus on the future development of the electricity system, considering, among other factors, the need to adapt the demand to the variable supply generated by renewables.

Other models project energy consumption in buildings, especially in residential buildings. These models also serve as a reference for the WHY toolkit since it focuses on these types of agents. Finally, and to a lesser extent, some models analyse (domestic) consumers' behaviour, which is also related to the WHY toolkit.

All the above models have in common that at some point, with greater or lesser accuracy, they estimate the energy demand, specifically for electricity in all of them.

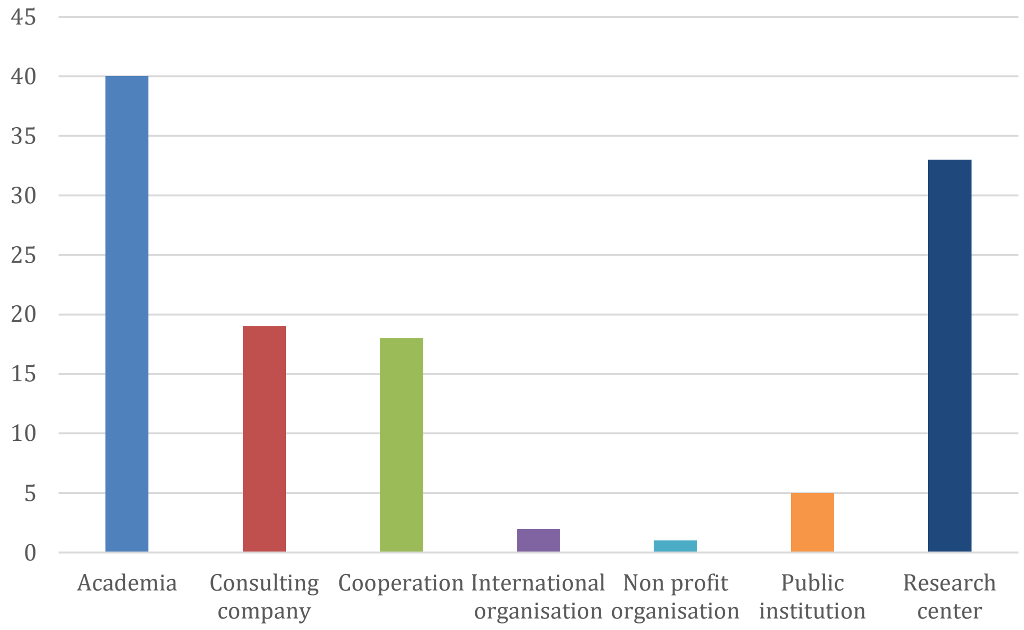
3.1. Type of developer

According to (Oberle & Elsland, 2019), the first macroeconomic models date from the late 1950s. The beginning of energy modelling can be found in the 1970s, after the first oil crisis of 1973. Specifically, in 1976, the newly created (1974) International Energy Agency (IEA) launched the Energy Technology System Analysis Program (ETSAP), intending to develop a detailed model of the energy system from both a technical and economic perspective, focusing its analysis mainly on the role of crude oil and energy efficiency.

In subsequent years, new similar initiatives were developed at the European level (e.g., Price-Induced Market Equilibrium System-PRIMES and Long-range Energy Alternatives Planning system-LEAP) by public institutions, consulting companies, research centres and universities. The growing demand for projections has led academic institutions to devote efforts to their development to access funding sources that apply the results to decision making (e.g., policymakers, utilities).

Considering the sample analysed, it can be seen in Graph 1 that academic institutions and research centres are currently the leading promoters and executors of this type of tool. There are institutions such as the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI)[4] or the University College London (UCL) that have a wide range of models, which can sometimes interact as interdependent modules.

[4] (Fraunhofer ISI, 2022).



Graph 1. Number of energy models by type of developer
Source: own elaboration.

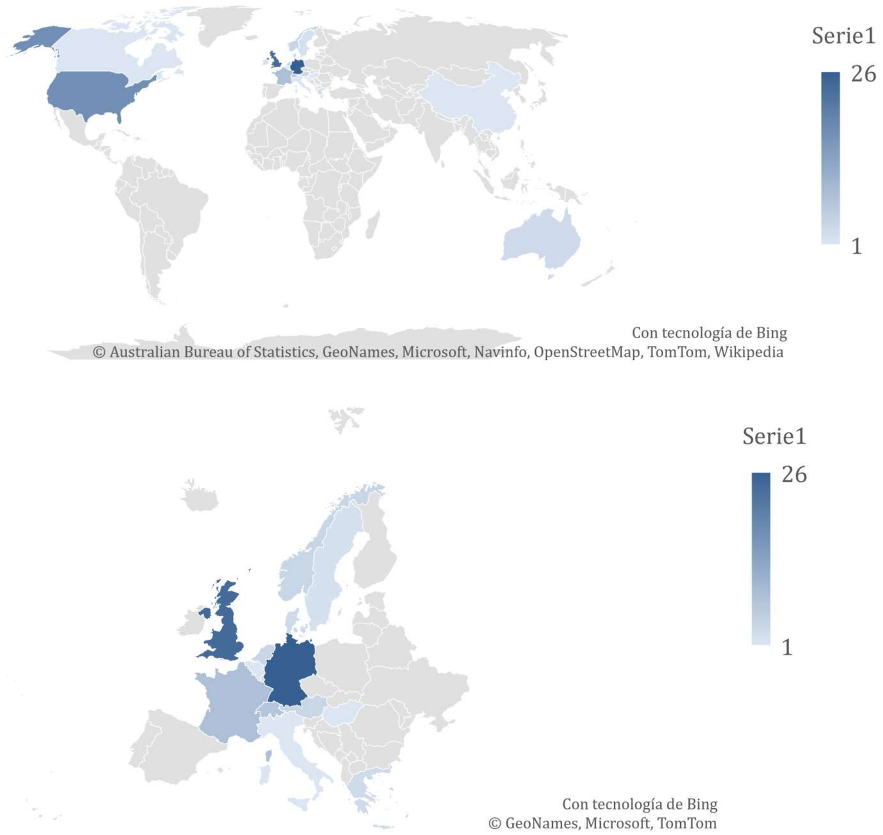
There is also a trend towards the cooperative development of energy models, many of them due to joint participation in projects financed by third parties, in many cases of an international nature and with different participant profiles (companies, universities, R&D centres) (e.g., Second Generation Model (Pacific Northwest National Laboratory and Joint Global Change Research Institute at the University of Maryland); TIMES UK (UCL+UK Department of Business, Energy and Industrial Strategy) or Medeas (ICM-CSIC, AEA, ARU, B4Y, BSERC, CIRCE, CRES, DUHA, IIASA, INSTM, M.U., UVA)). It can also be seen from the sample analysed that most of the international cooperation projects take place between European partners.

Of the models included in this analysis, only a small part (around 15%) are developed by companies that offer consulting or advisory services: Enerdata Intelligence Consulting, E3Modelling, EQUA simulation AB, GWS ZEWGmbH or Quintel Intelligence. As with research centres and academic institutions, in some cases, some of the companies offer several types of models (e.g., E3Modelling with the PRIMES-PROMETHEUS-GEM-E3 modelling suite or Enerdata). This could be because the search for information was conducted in English, so it was impossible to locate companies offering this type of product/service at a more local (country) level.

Related to the collaboration in the development of models, in this sector, competitors become collaborators in research projects on numerous occasions. This situation happens, for example, in the WHY project itself (TNO vs E3Modelling)[5] or the POLES model (where Enerdata participates, a company that sells its services independently of its project partners).

3.2. Country of origin

The WHY project is primarily focused on the European context (it is a European funded project with European partners) and electricity markets are more regional in scope than other types of energy commodities such as natural gas or crude oil. However, this analysis has not sought to set a spatial limit since, in many cases, the models have the overall energy system, for example. Moreover, one of the possibilities of using the WHY toolkit would be to integrate it as an additional module to large Integrated Assessment Models (IAMs) or ESMs. Next, *Map 1* shows the main origins of the models in the sample, with a special focus on EU developers, particularly the country of origin of the company, university or institution leading the development of the model.



Map 1. Geographic distribution of the models by country of origin
Source: own elaboration.

[5] TNO and E3Modelling cooperate in the WHY project, however, in other cases they are competitors.

Of the 118 models analysed, only 22 originated outside Europe (17 from the USA, three from Australia, one from Canada and one from China). Eight have their origin in international collaborative projects and the rest in Europe (53 from the EU-27, 24 from the U.K., seven from Switzerland and four from Norway).

3.3. Open access and software

Problems regarding their transparency or replicability have accompanied the development of energy system models. As a result, less than a decade ago, in 2014, the Open Energy Modelling Initiative launched the Open Access Models (OAM) movement[6]. In this regard (Oberle & Elsland, 2019) distinguish among four groups of OAM models depending on the software or type of software needed (Figure 3).

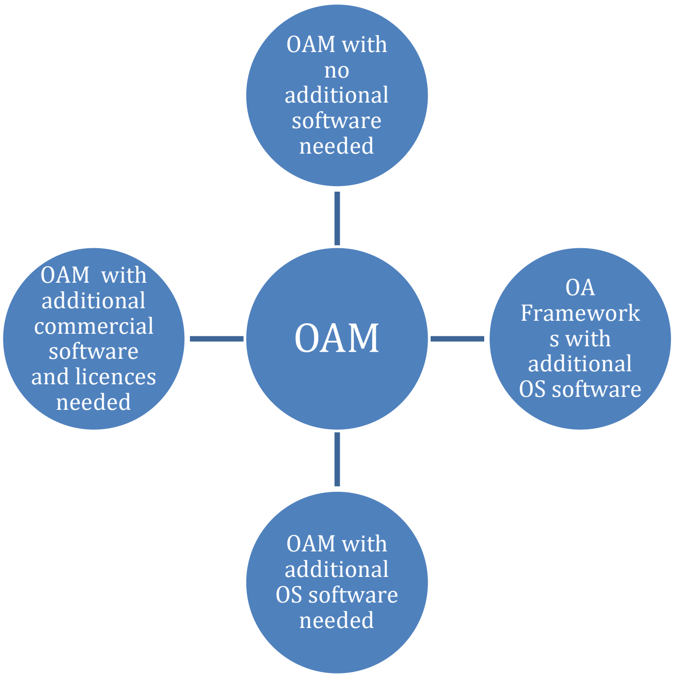


Figure 3. OAM types
Source: own elaboration based on (Oberle & Elsland, 2019).

As seen first, those models are freely downloadable and do not require additional software (such as DESSTinEE or RETScreen). Next, there are those so-called Open Access frameworks, which serve as tools from which individual code parts can be selected and implemented to create a model, which is then used to analyse a system (Oemof, Calliope, or TEMOA are examples). Thirdly, are identified those OAM that require additional open-source software[7]

[6] Not all OAM are Open Source Models (OSM), whose source code is always publicly available as well.
[7] Such as GLPK (GNU Linear Programming Kit) O.S. solver.

for their execution (e.g., OSeMOSYS, renpass or Switch) and finally, the group of OAM that requires additional licensed software[8] for their use (Markal, TIMES) or a license (e.g., LEAP).

About half of the sample of models that include electricity demand projections are open access models[9]. 20% are commercially available models or are suspected to be commercially available. The remaining 29% could be used by developers who could use them to help support their studies or to offer consulting or advisory services to third parties.

As might be expected, consultancy companies commonly develop their models to commercialise them, while academia and research centres use them for their use or society's availability by making them OAM (see Table 1). Despite the above, some models have a commercial purpose but offer open access versions for students (e.g., Leap).

However, some cases change this picture. Thus, there are for-profit companies that develop OAM models (e.g., Balmorel by Ram-Iose; Energy Policy Simulator by Energy Innovation LLC and ETM by Quintel Intelligence) or academic institutions and research centres that sell their models (e.g., HOMER from NREL, or MESAP from the Institute for Energy Economics and the Rational Use of Energy). These are minor cases, but they should be noted.

	Academia	Consulting company	Cooperation	International organisation	Non-profit organisation	Public institution	Research centre
Commercial use	1	10	1				2
OAM	22	3	8		1	4	18
Own use	6		2			1	4
Supposed commercial use	1	5	2				2
Supposed own use	10		5	2			8

Table 1. Availability of the model vs software
Source: own elaboration.

As shown in Table 2, more information on the necessary software is available for OAM models (around 65% of the software information is for this model type). Python, an open-source licensed software, is used in many models, closely followed by GAMS for mathematical programming and optimisation[10]. VEDA and CPLEX are, in this sample, the leading solvers used[11].

[8] Such as GAMS (General Algebraic Modelling System).
[9] This study cannot determine whether the lower number of models for commercial purposes is due to the promotion of open access models, or the methodology used in the selection of the models.
[10] GAMS and especially the solvers used in GAMS are not open-source.
[11] A table listing all the software compiled for the models analysed is included in Annex 3.

	Commercial use	OAM	Own use	Supposed commercial use	Supposed own use	Total
Python		24	2	1	2	29
GAMS	1	11	6		2	20
Excel	3	9	2		2	16
VEDA	1	2	2		3	8
CPLEX		3	1		2	6
Java		4		1		5
Matlab		4			1	5
Stand-alone	3	2				5
R		3	1			4
AIMMS		1	1		1	3
Julia		3				3
JuMP		3				3
Fortran		2		1		2
Pyomo		3				3
VBA		3				3
Vensim		1			2	3
Subtotal	8	78	15	3	15	119

Table 2. Availability of the model vs software
Source: own elaboration.

For example, ETM, Markal and TIMES use GAMS and VEDA. LUSYM uses GAMS and Matlab. PRIMES uses GAMS. DESSTinNÉE employs Excel and VBA; LEAP, Excel. Examples of models using Python are urbs, CAPOW, Calliope, Medeas, OseMOSYS, Pylesa and Simses.

Table 3 shows that GAMS is used more in the models that aim at optimisation, followed by Python. In the rest of the cases, Python is the leading software used, especially in the case of models aimed at simulation of the energy system.

	Optimisation		Projection		Projection/ Simulation		Simulation		Simulation/ Optimisation
GAMS	16	Python	2	C#	1	Python	10	Python	6
Python	11	DOS	1	EXCEL	1	Java	4	EXCEL	3
EXCEL	7	EVIEWS	1	GAMS	1	Fortran	3	S.A.	1
VEDA	7	Fortran	1	Vensim	1	VBA	3	Coin-OR	1
CPLEX	4	GTAP	1	SA		Dymola	2	CPLEX	1

Table 3. Main software by programming language / modelling libraries used
Source: own elaboration.

While the advantages of using such a tool are apparent, the tool itself will need to satisfy the requirements of future users. The issue at hand is that the bandwidth of possible users is broad; it ranges from Modelling experts who know how to adapt the underlying models to fit their requirements to policymakers, who will most likely only use the results of the models without using the tool itself.

	Commercial use	OAM	Own use	Supposed commercial use	Supposed own use
In process			1		
No	1	1			1
Seems not		7	5	3	6
Supposed yes		20	3	1	9
Yes	13	28	4	6	9

Table 3. Availability of the model vs updated or not
Source: own elaboration.

As will be seen on Section 4.1, the WHY project has five use cases, two of which concern the connection of WHY results to other widely used European models, such as PRIMES or TIMES. This will probably allow the improvement of energy demand projections, including the behaviour of domestic consumers, and the assessment of linkages with energy supply. In this sense, it is essential that the tool to be developed is robust and quickly upgraded to be helpful over a long time. Consequently, the updating or not of the different models has been included as a parameter of this market study.

Numerous demand forecasting models developed in research do not continuously evolve. Approximately 20% of the models do not appear to be updated or improved over time. A case in point is the Markal model, which is not updated, although maintained because it has many users/countries.

3.4. Scenario's analysis

To analyse alternative future developments of energy systems in general and project electricity demand, one of the principal methodologies applied is the development of energy scenarios (Oberle & Elsland, 2019), which can be quantitatively assessed with ESMs. With the scenarios, the models can map essential parameters (e.g., the size and technology of the power plants, the development of smart grids or the evolution of policy signals). Scenarios are particularly interesting for policymakers in designing policies and strategies in the field of energy economics. In this regard, 80% of the models in this market analysis allow different scenarios to be developed, as seen in Table 3.

	Academia	Consulting company	Cooperation	International organisation	Non-profit organisation	Public institution	Research center
False	4	2	3			1	8
n.a.	2						3
True	34	16	15	2	1	4	23

Table 4. Type of developer vs scenarios
Source: own elaboration.

3.5. Time and spatial resolution of the models

Spatial and temporal resolution of models sets limitations to which processes can be modelled. It can be looked at from a double perspective. On the one hand, it is an issue that can improve the model's accuracy. Increasing temporal and spatial resolution could, in principle, improve the accuracy of the model's results, whether in a simulation, optimisation or projection model. This is especially true in the case of electricity system models, where technological development and digitization are making it possible to handle increasing information and thus to manipulate data with increasing spatial (e.g., different buildings, specific power plants) and temporal (e.g., seconds and minutes) resolution. In the WHY toolkit, there is a quarter-hour resolution for a household.

On the other hand, there is the question of the model's scope (e.g., modelling electricity demand in the domestic sector has a different scope than modelling the global energy system, and both do not have to reach the building-minute level).

The geographical scope can vary from analysing individual buildings, municipalities, regions, countries, world regions, or the whole world (Ringkjøb, HauganIda, & Solbrekke, 2018). In addition, an energy model has three time-dimensions. First is the planning time horizon, which refers to how far in the future the specific planning analysis is relevant (short vs long term). Next, the timeframe refers to the overall period modelled (e.g., 2030, 2040, 2050, five-year period). Finally, the time resolution is related to the level of detail of the analysis (e.g., second, minutes, hours, intraday) (IRENA, 2017).

Most of the models in the sample are long term models periodically reviewed. Moreover, a large part of this, especially the models representing the energy system, global, world region or national, are set at the nearest (today's) horizon of 2030, while most models cover the period at least to 2050, while most IAMs extend to at least 2100, as longer time frames are required to analyse climate scenarios. However, projections are also made to 2040 and 2050 (date for decarbonisation) and even beyond (e.g., Remind model with projections until 2110 and 2150).

Table 6 shows the temporal resolution of the models analysed. As can be seen, 29% of the models have an annual resolution (e.g., CarB2, E3MG, Energy Transition Model), 25% have an hourly resolution (e.g., AnyMOD, BLUE, Calliope), and 7.6% have a minute resolution (e.g., FlexiGis, OpenTUMFlex). 3.4% of the models, which represent the TIMES family models and MARKAL, have a resolution that considers the year's seasons (differentiating between three or four) and two times of the day (day and night).

Time resolution	Number of models
Seconds	2
Minutes	9
Hours	30
Days	2
Years	34
Five-year periods	3
Multi year	2
Minutes, years	3
Hours, years	4
Intraday, seasons	7
Intraday, seasons, years	2
User dependent	3

Table 6. Time resolution of the models in the sample
Source: own elaboration.

Concerning the geographical resolution of the models (Table 7), 18% are only country level (e.g., Astra, Dieter, Energy Scope, EnergyMED). Users can choose the resolution in 15% of the models (e.g., Plexos, Siren, Wesim, urbs, PRIMES). In 11%, the resolution is both at the country and region level (NUTS[12] 2, e.g., Ginfors and Shipmod). In 7% of the cases, it goes down only to building level (e.g., SmartCED; Social Practices Agent Based model), and in total 11% may reach the level of buildings. In 6% (e.g., Temoa, TransiEnt), it is sub-national (regional).

[12] Nomenclature of territorial units.

Geographic resolution	Number of models
Buildings	8
Nodes	6
Municipalities	4
Sub-national (regions)	7
Countries, sub-national (regions), municipalities	5
Countries, sub-national (regions)	11
Countries	21
World regions, countries	4
World regions	6
World	3
World, world regions	5
World, world regions, countries	3
World, countries, sub-national (regions), municipalities	2
User dependent	15

Table 7. Geographic resolution of the models in the sample
Source: own elaboration.

In the other cases, the geographical resolution is varied (e.g., the Switch model offers different levels of geo resolution "Buildings, microgrids, cities, states, countries, continents"). 14% of the models can reach a geo resolution of municipalities (e.g., Usensys, Region4Flex, Pylesa).

Next table shows (Table 8) that most common in the selected sample are models that combine country-year and country-time resolution.

	Countries	User dependent	Countries, sub-national (regions)	Buildings	Sub-national (regions)	Nodes	World regions	Countries, sub-national (regions), municipalities	World, world regions	Municipalities	World regions, countries	World	World, world regions, countries	World, countries, sub-national (regions), municipalities
Years	8	1	4	1	2		2	3	2		1	1	3	
Hours	7	8	2	1	1	4				2	1			2
Minutes		2		2		1				1		1		
Intraday, seasons	1		1		2		1		1			1		
Hours, years			2					1	1					
Five-year periods			1				1				1			
Minutes, years		1												
User dependent	1								1					
Days	1													
Intraday, seasons, years	1		1											
Multi year		1			1									
Seconds					1						1			

Table 8. Geographic resolution vs. time resolution
Source: own elaboration.

Research centres, academia and models developed through cooperative projects have the most remarkable diversity of time scales (e.g., years, hours, minutes, intraday-seasons, hours-years, minutes-years, days, multi-years, seconds). Table 9 shows the temporal resolution of the analysed models, considering the developer type. In the case of the geographical scope, however, there is a greater diversity of scopes, and it is independent of the type of developer.

	Academia	Consulting company	Cooperation	International organisation	Non-profit organisation	Public institution	Research centre
Years	3	13	9			2	7
Hours	13	1	4		1	1	10
Minutes	6						3
Intraday, seasons	4		2				1
Hours, years				2			2
Five-year periods	1					1	1
Minutes, years	1	1					1
User dependent							3
Days			1				1
Intraday, seasons, years			1				1
Multi year	2						
Seconds	2						

Table 9. Time resolution vs. type of developer
Source: own elaboration.

Regarding the models' availability types (e.g., commercial use, OAM), there is no noticeable trend related to the geographic resolution. There are models with different availability for different geographical scopes. However, it can be observed (Table 10) that in the case of models for commercial or presumed commercial purposes, there is a tendency for them to have an annual temporal resolution (72%). Likewise, 46% of the OAMs have an hourly resolution.

	Commercial use	OAM	Own use	Supposed commercial use	Supposed own use	Total
Years	8	8	3	10	5	34
Hours		26	1		3	30
Minutes		6	1		2	9
Intraday, seasons		1	1		5	7
Hours, years		1	1		2	4
Minutes, years	3					3
Five year periods		1			2	3
User dependent		1			2	3
Seconds		1	1			2
Multi year		2				2
Intraday, seasons, years			2			2
Days		2				2
Subtotal	11	49	10	10	21	101

Table 10. Time resolution vs. availability of the model
Source: own elaboration.

3.6. Model methodologies[13]

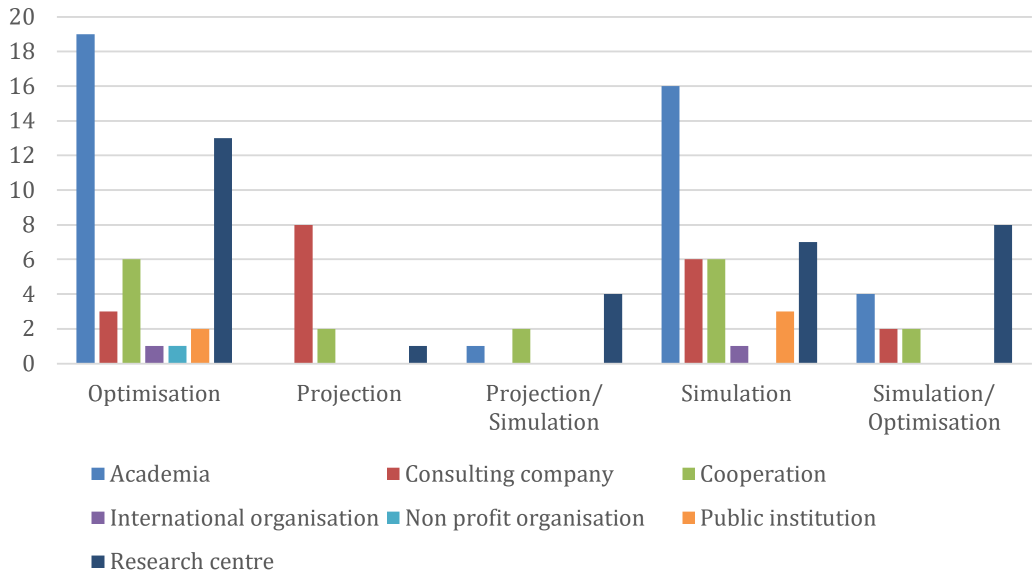
For this exercise, models have been classified into the next five categories[14]:

- Optimisation: Optimisation models try to determine the optimal maximin or minimum value of a complex equation. They can use linear programming, integer linear programming or non-linear programming among others.
- Simulation: A simulation model tries to emulate a real-life system by using the software. They can develop different scenarios or develop the strategies of the different agents (e.g., agent-based models).
- Projection: This categorization is applied when it is only specified that the model is intended to make projections.
- Projection-simulation: This category is used when the information on the model indicates that it performs both projections and simulations.
- Simulation-optimisation: This category is used when the information on the model indicates that it performs both simulations and optimisations.

Most of the models from the sample are optimisation and simulation models and a mixture of these (see Graph 2).

[13] Although the references consulted usually refer to the approach of the model (bottom-up or engineering approach and top-down or economic approach), not enough information has been obtained to include it as a variable in the analysis.

[14] From the underlying mathematics, there is a lack of a homogeneous categorisation for the classification of models. Sometimes elements such as the mathematical objective and the instruments used are mixed up in the studies. Thus, (Kuster et al., 2017) indicate as model type both the approach (e.g., bottom-up) and the econometric tool to solve the model (e.g., regression analysis, time series). This is probably due to an absence of precision in the terms used to define what models do and how they do it.



Graph 2. Type of developer vs. Model type
Source: Own elaboration

The academia and research community mainly develop optimisation, simulation, and combination models. The consulting companies have created the most significant number of projection models. Research centres, consultancy firms and cooperation projects are more diversified in the type of models they develop (and methodologies they use), and they are also the ones that make prediction models.

51% of the models in the sample represent either the entire energy system (including or not all-consuming sectors (tertiary, residential, industry and transport) or can represent all energy sources. 41% represent in more detail the electricity sector (sometimes with, e.g., renewables, natural gas, co-generation, distribution networks). Only 4 models (3.4% of the sample) represent household energy consumption as their main objective (the principal objective of the WHY project): Demod, IDA ICE, SEEM energy model and Social Practices Agent Based Model.

The models representing the energy system are divided between optimisation (23), simulation (13) and projection (10) models. In the case of electricity, mainly optimisation and simulation models are used. The electricity models do not usually employ projections (Table 11).

	Optimisation	Projection	Projection/ Simulation	Simulation	Simulation/ Optimisation
All energy	23	10	5	13	2
Electricity	6		1	8	7
Electricity, heat	4			2	2
All energy, all sectors	1			4	
Domestic energy consumption				4	

Table 11. Energy sectors vs. Math model type.
Source: own elaboration.

A large part of the models (31%) can be categorised as framework models, which develop a scheme to reproduce the energy reality. Many of these models have as their background Computable General Equilibrium modelling that combines economic theory with actual economic data to derive the impacts of policies or shocks in the economy computationally (Table 12) and analyses the complex interactions between the energy system and the overall economy.

Model class	Number of models	Percentage from the total sample
Framework	40	33,9%
Linear programming	26	22,0%
Dynamic programming	19	16,1%
Iterative mixed-integer program	6	5,1%
Agent-based simulation	5	4,2%
Others not defined	5	4,2%

Table 12. Main mathematics model class
Source: own elaboration.

25% use linear programming (e.g., Energyscope, Enertile, Powergama, ReEDs) and 22% use dynamic programming (e.g., AFRY BID3, Astra, Dynemo, Energy policy simulator) and 5.1% use mixed integer programming (this is very relevant e.g., for electricity dispatching models).

The most frequently stated objective in the models is the reduction of the total system costs (35%) (e.g., HBE, Elmod, ESME, PRIMES), followed by the analysis of the impact of specific measures (14.4%) (e.g., Enerneo, Dreem, MAED, Nemesis) and the implementation of certain policies (14%) (e.g., PACE, Panta Rhei, Poles, Snow, PROMETHEUS). The maximisation of the profit of the agents (e.g., Entice-BR, Green-X, Aladin) and the evaluation of technological shift (e.g., IPAC, Simses, SmartCEO) are also objectives behind mathematical modelling of the energy systems (Table 13).

Final objective	Number of models	Percentage from the total sample
Cost minimization	41	34,7%
Impact assessment	17	14,4%
Policy Implementation	16	13,6%
Maximising the utility	4	3,4%
Technological shift	4	3,4%
Cost and emissions minimization	3	2,5%
Dispatch	3	2,5%
Impact assessment. Investment	3	2,5%
Optimisation	3	2,5%
Policy and technology implementation	3	2,5%
Forecasting	2	1,7%
Non-domestic building stock and its energy consumption	2	1,7%

Table 13. Main mathematics objectives
Source: own elaboration.

The sample includes social assessment, like the one described in (Cuesta, Castillo-Calzadilla, & Borges, 2020), in at least six cases. These include terms such as welfare (DESStinEE), the impact of other socioeconomic factors on energy demand (eLoad), social benefit (Green-X), changes resulting from the interaction of socioeconomic and environmental factors (IMAGE), socioeconomic developments (MAED) and effect of changing appliances and heating controls (SmartCED).

In the specific case of projection models, the main objectives are the assessment of policy implementation (55%) and the evaluation of technological changes (27%) (Table 14).

Projection models	Number of models
Impact assessment	2
Policy and technology implementation	2
Policy Implementation	6
Technology and decarbonization impact	1
Total	11

Table 14. Mathematics objectives of projection models
Source: own elaboration.

4. Benchmarking and comparative analysis of the developed model against the modelling solutions identified

The following is an analysis of the weaknesses, threats, strengths, and opportunities (SWOT analysis) of the WHY toolkit, considering the study carried out on the sample of models selected and analysed in the previous section[15]. This analysis serves as a basis for assessing the competitive position of the WHY toolkit and as a first step to developing the future strategic plan.

According to (Kenton, 2021), a SWOT analysis assesses *the performance, competition, risk, and potential of a business, a product line or division, an industry, or other entity*. In this case, the SWOT analysis refers to a product, the WHY toolkit.

The strengths and weaknesses will then be internal to the toolkit, and the consortium will have some control over it and may be able to change (e.g., the team, patents or intellectual property). On the contrary, opportunities and threats are external issues, outside the consortium, in the larger market. The WHY toolkit could take advantage of opportunities and protect against threats; however, it is impossible to change them (e.g., competitors, raw materials prices, and customer shopping trends) (Parsons, 2021).

(Kenton, 2021) describes a product's strengths as *what an organisation excels at and what separates it from the competition* (e.g., a strong brand, loyal customer base, a strong balance sheet or unique technology). On the other hand, weaknesses may prevent the product from operating at its optimal level, and product improvements may be necessary to remain competitive (e.g., a weak brand or lack of capital). Opportunities are favourable external factors that can give the tool a competitive advantage (e.g., increasing sales and market share). Finally, threats are factors that could harm the product's competitiveness (e.g., increasing competition).

4.1. WHY toolkit

In Table 5, the WHY project tool is presented in more detail to contextualise where and how the tool is located in the market analysis sample framework.

[15] Annex 4 contains a more detailed sample of some of the models analysed in the study to show the type of information that could be accessed.

MODEL	WHY toolkit
MAIN CHARACTERISTIC/ BASIC DESCRIPTION	The WHY project develops innovative methodologies and a toolkit for short and long-term household energy consumption modelling, including human behaviour. Use cases benchmark these models ranging from local to European-wide energy grids and global mitigation strategies. The WHY Toolkit builds on the causality chain to model the energy demand, building on associations between measurable variables.
NAME AND TYPE OF DEVELOPER	University of Deusto (Academia), 4ward Energy Research (Research centre), E3Modelling (Consulting company), TNO (Research centre), Goiener (non-profit citizen cooperative dealing with electric energy commercialisation), Renewables Grid Initiative e.V (NGOs and TSOs alliance), Klima-Bündnis (Public Institution), Forschungszentrum Jülich (Research centre)
COUNTRY OF ORIGIN	International cooperation
AVAILABILITY	OAM with components of commercial use (to be specified)
UPDATED OR NOT UPDATED	To be specified
SECTORS	Electricity demand of households
MODEL CLASS	Projection / simulation / optimisation
MATH MODEL TYPE	Time series, bottom-up
MATHS OBJECTIVE	Projections
TIME RESOLUTION	15 minutes
COUNTRY COVERAGE	EU member states
GEO RESOLUTION	Buildings, energy communities, cities, regions, nations
IS SUITED FOR MANY SCENARIOS?	True. 5 different use cases: • World: linking the bottom-up information of energy consumption in the world energy models. • E.U.: linking the bottom-up information of energy consumption in the PRIMES European energy model to reassess EU strategies for energy efficiency and climate neutrality. • Blackout: anticipate domestic energy consumers' behaviour in the event of a blackout. • Energy trading company: choose the best type of public interventions on prices. • Energy communities: planning facilities, governance, impact.
SOFTWARE	Components are developed in different programming languages / tools: Python, C#, R and GAMS.
OTHERS	WHY builds a Causal Model to improve the understanding of human decision processes behind these demand patterns, accurately forecasting how different policies impact household energy consumption. Five use cases will be used to assess different policy scenarios, focusing on the E.U. Green Deal, energy efficiency directives, and the Renovation Wave policies.
MAIN WEBPAGE	WHY H2020 Project (why-h2020.eu)

Table 15. WHY toolkit characterization
Source: own elaboration.

4.2. WHY toolkit SWOT Analysis

As mentioned above, the different energy models presented have been classified in different ways, mainly according to their scope. This section considers the SWOT analysis of the tool developed in the WHY project framework with references to all the use cases.

4.2.1. Strengths

As has just been shown, the WHY toolkit is a tool that can be applied to different use cases ranging from micro-grid up to national, European and global levels. Consequently, it can be said that it will be a highly versatile tool, easy to use, to understand and to test different scenarios. It is flexible and transparent as all its components including data and source code will be openly accessible. In this regard, the tool can be adapted to different countries, technologies, and behaviour of end consumers, for instance, in the implementation of energy communities. The WHY toolkit may also update the models of the technologies and behaviours to the new devices/solutions put into the market and size according to different criteria (maximise self-consumption or the Return on Investment (ROI), among others.

This tool is modular and operational and has a couple of elements that make it stand out from other energy models: it includes issues related to financing and governance mechanisms as well as behavioural elements, it focuses on the citizens and uses millions of data points to represent different categories of consumers in each country. The tool will be validated in different scenarios and five different Use Cases ranging from micro-grid to European analysis.

In addition, it allows moving from social variables to load curves and detecting whether an external intervention on prices, for example, affects the level of energy consumption. In this way, it is possible to understand which incentives significantly influence rationalising electricity consumption. It will also be used to better project the behaviour of consumers in the event of a blackout.

Finally, the variety of agents involved in its development and the different nature of these agents is an element that gives it particular relevance. The consortium of the WHY project includes agents from the academic world (U.D.), R&D (TNO, 4ward Energy Research, Forschungszentrum Jülich), a consultancy with a long tradition in the field of energy and economy modelling (E3Modelling), public institutions (Klima-Bündnis), as well as the collaboration of agents especially interested in this kind of tool (Renewables Grid Initiative and Goiener) that will use it for their business. Therefore, it can be concluded that this is an integrated and robust group, with knowledge and experience in all areas of electricity demand modelling, from design and development to the use of these tools in practice, beyond the research itself.

4.2.2. Weaknesses

At the current stage of development of the tool, one of the weaknesses could be the simulation time, which will be higher than in other more specialised models since we are aiming for a very holistic approach.

It is also necessary to think over and debate the business model of the tool and its strategic plan. It is necessary to determine how it will be distributed, which channels, or under what conditions. Considering the variety of use cases, the different target audiences that may demand it, and the great variety of existing models is even more relevant, even though it is a tool that focuses on predicting household electricity demand.

This consortium brings together agents of different nature and with sometimes conflicting interests. Therefore, there is a risk that someone may decide to drop out of the project at a certain point, which could mean a loss of knowledge, for example. For this reason, it is necessary to achieve a close-knit and integrated team with a shared vision of the business model(s) to be developed once the tool is entirely available.

4.2.3. Opportunities

The current energy transition process opens a window of opportunity that the WHY toolkit should seize. While energy transition processes have been occurring naturally throughout history, in the current stage of Information Communication Technology tools (ICT tools), the need for a streamlined process against the decarbonization of the economy makes it more than ever a priority to get the proper steps.

Having tools that are as accurate as possible becomes an essential element for the success of this transition. Currently, there are some gaps or deficiencies, for instance: the lack of data from end-users, the lack of tools to size energy communities, the lack of tools to help planners to define and simulate different financing schemes, the lack of standardised verification and validation methodologies to assess the performance of the systems and a lack of tools to present the benefits of the solutions to all stakeholders (e.g., citizens, financial entities or public authorities). In this regard, the WHY toolkit will face these gaps and help this energy transition process, energy communities and cooperatives, among others.

While a large number of energy system models can be seen as a threat, having a tool that is adaptable to different use cases, which provides more accurate electricity demand forecasts than the competing models, becomes an opportunity. In this sense, the WHY tool can be used to improve demand forecasting in the case of integrated assessment energy models (IAM) and energy-environment-economy models (E3), which focus heavily on socio-economic aspects (large traditional models, most of those presented in the previous section, are oriented to generation and the demand data had temporal series as a starting point). The details of the WHY data will help to develop more accurate demand projections integrated into the large-scale models, which will allow a more profound analysis of the impact of new energy efficiency measures, implementation of demand response measures or new taxes, among others. This process is facilitated by the development of model plug-ins in WHY WP4 to link the WHY Toolkit with the large-scale ESMs included in the consortium (PRIMES, TIAM-ECN, PROMETHEUS).

Another feature of this transition process is the more active role that energy consumers, particularly domestic consumers, are expected to play. Increasing social and environmental awareness of the different actors is another opportunity for the WHY toolkit, especially in the use case of energy communities, and better knowing the best tool to induce changes in consumers behaviour, for instance.

In this regard, the WHY toolkit opens the door to analysing and estimating the impact of different interventions (like tariff changes or consumer engagement campaigns) on the load profile considering different socio-economic and geographic conditions. In particular, the WHY Toolkit can be used to generate realistic synthetic data of end users, validate the tool in different scenarios to size energy communities and simulate different financial schemes like crowdfunding, pay-performance or cooperative shares, which are elements that add value to the tool.

Moreover, this tool also seeks to predict consumers' behaviour in the event of a blackout, a relevant issue in recent times. It is a valuable tool for small grid operators, municipalities, and large cities, where these may have stakes in electricity suppliers (e.g., in Germany). However, this does not seem to be the tool's primary use. The tool would need to enable them to be more resilient. Also, in a scenario in which the increased penetration of variable renewables may make the system less stable with higher volatility, this tool may become more relevant in the face of blackouts of less than 2 hours duration.

4.2.4. Threats

As mentioned above, there are many energy system models, which include demand forecasting in one way or another. Many of these models have a long track record, are well recognized and have been widely used to support policymakers or energy utilities.

Moreover, many competitors have comprehensive experience knowledge and know their market, needs and how to operate well. Another difficulty is not having a recognized brand name. In this sense, some of the consortium players could help overcome this threat.

An additional threat is the cost of the maintenance and calibration of the tool over time. Once again, the current lack of a long-term business model is an element that works against it.

Strengths	**Weaknesses**
The versatility of the tool (different use cases) The modularity of the tool It includes issues related to financing and governance mechanisms and social variables. Robustness of the consortium	Simulation time Need to reflect on the tool's business model Collaboration of actors of different nature with sometimes conflicting interests
Opportunities	**Threats**
Accurate data for the current energy transition process for the development of energy communities, integrated energy system models, energy consumption behaviour, etc. Increasing social and environmental awareness of different actors The more active role of consumers Estimate of the impact of different interventions Dealing with a blackout	High quantity of energy demand forecasting models Long track record of many competitors Lack of a recognized brand Cost of maintenance over time

Table 16. WHY toolkit SWOT analysis
Source: own elaboration.

4.3. Challenges

At the moment, of this SWOT analysis, the tool has not yet been completed, consequently we might some more information on how it will actually function. It is necessary to remember that many challenges need to be addressed and not be forgotten to draw up a strategic plan.

- It is essential to develop an easy-to-handle with a user-friendly interface tool. The tool must be adaptable to the reality of each country. Moreover, a fundamental requirement is to keep the tool up to date and in good condition.
- To ensure that the model considers enough variables to be robust for at least 5 to 10 years and that it can then be updated and recalibrated with little new data.
- The model should be shared during the development phase.
- In this regard, there is a need to address how to keep the models up to date, anticipate upcoming trends, enhance the model's capabilities, and improve specific features of the model related to running projects.
- It is desirable that the software is simple, and that the consortium develops sufficient training for its use (offering support mechanisms for its use, demos and tutorials is fundamental for the success and employability of the tool). For instance, an energy cooperative has technical and qualified personnel; however, in an energy community[16] there is less modelling expertise, and thus the WHY toolkit should be as simple as possible and accompanied with appropriate tutorials and demos.
- The WHY toolkit may have different customer segments such as engineering companies, energy trading companies, utilities, public institutions such as municipalities or regional governments (although consultancies would probably support these last[17]), making it a product that can have a large market but needs to orient its marketing strategy in an appropriate and well-targeted way.
- Specific uses of the tool have excluded some consumptions, such as vulnerable consumers (e.g., in the energy trading company use case, to choose the best type of public interventions on prices, vulnerable consumers have been excluded to focus on higher energy demand consumers). Including them would be a significant challenge that is not considered by current models (at least those included in this market study).
- Develop a marketing mix strategy, which considers the product, the price, the place and the promotion.

4.4. Questions about the price of the tool

The primary economic data that we have tried to collect throughout the market study has been the price of the different solutions and modelling tools. However, as can be seen in

[16] It is advantageous for energy communities to know how electricity is consumed.

[17] In the case of municipalities, the main problem is usually time, and therefore they prefer to outsource the services to a trading company or energy consultant.

the following table, of the models selected for comparison, information has only been found for two of them (see Table 7).

As can be seen, this is mainly due to how this intangible product is developed and marketed. Thus, on the one hand, the development of energy models is often carried out by researchers in the academic world or researchers in R&D centres. The former tend to design models to produce academic papers or get additional funding for research. Together with the latter, they participate in research projects put out to public tenders. Many consulting firms also participate in this type of process or sell the results of projections/simulations to third parties, but very often, they adapt the tool to meet their clients' needs. In addition, companies often spend time explaining the models and results to their clients, which has a high cost and is a labour-intensive process.

It should also be borne in mind that in many cases, the models that have been developed are open access, and there are even open-source models. Therefore it is even more challenging to obtain information on the right price, and as a consequence, there is little public information about it[18].

EnergyPro	One year licence	From € 400 to 1.680 per user depending on the product	Additional language: € 360 (D.E., D.K., U.K.)
	Standard licence	From € 1.000 to 4.200 per user depending on the product	Additional language: € 900 (D.E., D.K., U.K.)
Homer Pro	Students. All modules included	4 months: US$ 59,89	12 months: US$ 108,89
	Academic	US$/ 33 month + Packages: US$ 65-93 /month +Add-on modules: US$ 5-10 /month depending on the module per module	12 months: US$ 252 + Packages: US$ 500-750 +Add-on modules: US$ 3-7 /month depending on the module per module
	General	US$ 65 /month + Packages: US$ 130-185 /month +Add-on modules: US$ 10-20 /month depending on the module per module	US$ 42 /month + Packages: US$ 83-125 /month +Add-on modules: US$ 6-15 /month depending on the module per module
LEAP	It is free to qualified users in developing countries, but there is a cost for OECD based users.		
MESAP	€6,800	There is a 30% discount for research groups	

Table 17. Prices of the HomerPro and EnergyPro tools
Source: own elaboration based on (EMD International, 2022), (Energy Plan, n.a.b), (Energy Plan, n.a.a) *and* (UL, 2022).

[18] Additional information could be obtained by searching for tender offers where energy modelling is included. However, it has not been considered at first as an agile and practical way to find information on the subject.

When thinking about the price that the WHY tool could have, it would be necessary to consider the costs that its application could have. The tool should be updated and properly maintained, as mentioned above. To do so implies a cost mainly of qualified personnel (to operate and manipulate it and to offer demonstrations and handling classes, among others), although it also has a part of hardware and software equipment.

As we have seen, this tool has different utilities, as shown by the five use cases that have been designed and will be developed in the WHY project. Each use case has been proposed by a consortium member with a specific interest. At this stage of the project, it is difficult to determine a price for the tool. The WHY partners have not thought about how to distribute the WHY toolkit and what marketing mix should be used for. Box 1 includes some considerations about the price of the WHY toolkit.

It could be essential to segment the audience of the WHY toolkit to set the price. In the first phase, a distinction could be made between offering a tangible product (the tool, the results of running the tool) and an intangible service (the adaptation of the tool used by third parties).

Taking into consideration the uses cases of the WHY project, the market could also be segmented considering the final users: 1) integrated energy system models to accurate the energy demand projection, 2) public institutions for the analysis of possible price interventions or other energy policies related to housing; 3) small DSOs (distribution system operators) to better understand the behaviour of energy consumers when facing a blackout and 4) energy communities to the design of the facilities. In addition, the model could be offered in open access format for educational purposes (e.g., to universities) since it allows the dissemination of the tool, its improvement and greater recognition thanks to the academic papers that would use it.

The price might then depend on the size and need of each of the segments (e.g., energy cooperatives, energy communities, DSOs), the type of service/product (the model itself, the result of some projections), the period (one month vs annual licence), and the number of users (1 licence, vs multiple licences) among others.

Box 1. Market segmentation

5. Conclusions

Modelling of the energy sector also has a long history. The first models date back to the first global energy crisis in the 1970s, but they have not lost their importance, as other issues become increasingly important (e.g. the transition to clean energy and the linkages of energy-related emissions with climate change). New models continue to be developed, some of which incorporate elements such as consumer behaviour.

Energy is a field of great interest for modelling.

There are many energy models that can be organised under different criteria, generally considering the scope of application. In this way, this work has evaluated energy models, energy demand models, electricity models, renewable energy and electricity system development models, those that model the energy consumption of buildings, and models that take into account the behaviour of buildings and their energy consumption.

The scope of this study has been broad due to the characteristics and potential utilities of the WHY toolkit.

Although the WHY project is an EU funded project, references to models developed in non-EU Member States have also been included, as the usefulness of the WHY toolkit could also be integrated into them. A non-systematic search for models shows that North America and Europe are among the leading developers of this kind of model. Australia, China, Middle Eastern countries, and some Latin American countries have also developed models, but not as much information was found.

The European Union and North America are among the leaders in developing energy models.

Academia and research centres are among the leading developers of energy models. The number of consulting firms engaged in this activity seems to be lower. The increasing development over the last decade and a half of open access energy models could be the principal cause of a less relevant role of consulting companies.

The sample's reduced presence of energy modelling consulting companies could be related to the reduced number of models offered.

The abundance of open access models and the possibility of their improvement can be an essential tool for improving projections and evaluating the impact of energy transition processes in different scenarios. However, this can pose difficulties in maintaining and updating the tools over time.

Developing future scenarios to evaluate the current energy transition becomes an instrument of great value for energy system planning.

Python and GAMS are the main mathematical programming languages and optimisation used in ESMs. VEDA and CPLEX are, in this sample, the leading solvers used. Not only the energy models themselves can be open access. The software used in them can also be open source (e.g. Python), opening the door to further energy models or further refinement of existing ones.

Therefore, what will be the role of marketable models in the future?

The geographical scope of the models can vary from analysing individual buildings, municipalities, regions, countries, world regions, or the whole world. A large part of the models is long term, and the most common timeframe refers to 2030, 2040 and 2050. The most common time resolutions are annual and hour. However, there are many different options such as minutes, year's seasons or times of the day.

Increasing temporal and spatial resolution could, in principle, improve the accuracy of the model's results, whether in a simulation, optimisation or projection model.

From the mathematical point of view, most of the models refer to optimisation, simulation and, to a lesser extent, projection. Academia develops mainly optimisation models and consultancy firms projection models. Research centres and cooperation projects have a more diversified portfolio of models.

Most energy system models are framework models that develop a scheme to reproduce the energy reality or use linear programming (especially for optimisation) and dynamic programming. In the case of electricity-related models, there are no tools of relevance, and they are used interchangeably. For the development of the models, the most frequently objective is the reduction of the costs followed by the assessment of policy interventions and technological shifts.

The analysis shows a lack of a homogeneous categorization for the classification of models, probably because of the absence of precision in the terms used to define what models do and how they do it.

Considering the work done, the WHY toolkit has its versatility and modularity among its **strengths**. It includes financing, consumer behaviour, and governance-related issues. It results from international cooperation with different developers (consulting companies, academia, research centres, energy-related companies and public institutional partners).

However, **it also has weaknesses,** such as developing a business model and the future collaboration of such a diverse group of partners with potentially different interests.

As mentioned, there is a high quantity of energy demand forecasting models, some of which have a long track record compared to the WHY consortium. The lack of a recognized brand and the maintenance cost over time are also **threats** to the WHY toolkit.

Nevertheless, the energy transition process brings **opportunities** for a tool that can offer accurate data for the development of energy communities, assess the impact of a blackout, energy-related policies, the increase of environmental awareness, and other changes in human behaviour, among others.

The SWOT analysis of the WHY toolkit shows its main strengths, weaknesses, opportunities, and threats.

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ANNEX 1- List of modelling solutions and main webpages consulted

MODEL	MAIN WEBPAGE	MODEL	MAIN WEBPAGE
AFRY BID3	https://afry.com/en/service/bid3-power-market-modelling	MDM-E3	MDM-E3: UK Multisectoral Dynamic Model - E3 | Cambridge Econometrics (camecon.com)
Agent-based Market model for the Investigation of Renewable and Integrated energy Systems (AMIRIS)	AMIRIS (dlr-ve.gitlab.io)	MEDEAS	Medeas | Modeling the renewable energy transition in europe
Aladin (ALternative Automobiles Diffusion and Infrastructure)	Energy demand models - Fraunhofer ISI https://www.aladin-model.eu/aladin-en/	MESAP (Modular Energy System Analysis Planning)	https://www.energyplan.eu/othertools/national/mesap-planet/
AnyMOD	https://github.com/leonardgoeke/AnyMOD.jl	MESSAGE	MESSAGE - IIASA
ASTRA Transport (ASsessment of TRAnsport Strategies)	Energy demand models - Fraunhofer ISI http://www.astra-model.eu/index.htm	Model for Analysis of Energy Demand (MAED)	Model for Analysis of Energy Demand (MAED-2) | IAEA
Balmorel	The Balmorel Open Source Project - Home	NEMESIS	https://klimaat.be/doc/8.-nemesis.pdf
BLUE (Behaviour, Lifestyles and Uncertainty Energy model)	https://www.ucl.ac.uk/energy-models/models/blue	NEMS	The National Energy Modeling System: An Overview 2018 (eia.gov)
Breakthrough Energy Model	Facilitating the Energy Transition — documentation (breakthrough-energy.github.io)	NIEIR Multi-purpose model	Energy Markets and Policy – National Institute of Economic and industry Research (nieir.com.au)
California and West Coast Power Systems model (CAPOW)	n.a.	Oemof (Open Energy Modelling Framework)	oemof - Reiner Lemoine Institut (reiner-lemoine-institut.de)
Calliope	Calliope	OMEGAlpes	About OMEGAlpes — OMEGAlpes 0.0.1 documentation
CaRB2	https://www.ucl.ac.uk/energy-models/models/carb2	OpenDSS (Open Distribution System Simulator)	OpenDSS (epri.com)
CESAR-P	n.a.	OpenTUMFlex	https://wiki.openmod-initiative.org/wiki/OpenTUMFlex
Country Energy Demand Forecast	Country Energy Demand Forecast | Enerdata	OSeMOSYS	http://www.osemosys.org/about.html https://www.ucl.ac.uk/energy-models/models/osemosys
DEAM (Dynamic Energy Agents Model)	https://www.ucl.ac.uk/energy-models/models/deam	PACE	EU competitiveness and the 2030 framework - Publications Office of the EU (europa.eu)
Demand for Energy Services, Supply and Transmission in EuropE (DESSTinEE)	DESSTINEE Supply - Sentinel https://wiki.openmod-initiative.org/wiki/DESSTinEE	PANTA-RHEI	Detail - GWS (gws-os.com)
Demod	Overview — demod beta documentation	PLEXOS (PLEXOS Integrated Energy Model)	https://www.energyexemplar.com/plexos

DIETER (Dispatch and Investment Evaluation Tool with Endogenous Renewables)	https://www.diw.de/de/diw_01.c.511677.de/publikationen/sonstige_aufsaetze/2015_0000/a_dispatch_and_investment_evaluation_tool_with_endogenous_renewables__dieter.html	POLES (Prospective Outlook on Long-term Energy Systems)-JCR	Model | EU Science Hub (europa.eu)
Distributed Energy Resources Customer Adoption Model (DER-CAM)	DER-CAM | Grid Integration Group (lbl.gov)	PowerGAMA (Power Grid and Market Analysis)	https://www.sintef.no/en/software/power-grid-and-market-analysis-powergama/
DREEM (Dynamic high-Resolution dEmand-sidE Management)	https://teeslab.unipi.gr/we-have-the-dreem/ https://www.i2am-paris.eu/detailed_model_doc/teemsuite	PRIMES	PRIMES – E3 Modelling https://e3modelling.com/modelling-tools/primes/,
DynEMo	https://www.ucl.ac.uk/energy-models/models/dynemo	PROMETHEUS	PROMETHEUS – E3 Modelling, https://e3modelling.com/modelling-tools/prometheus/
E3ME	What | E3ME | Cambridge Econometrics	PyLESA (Python for Local Energy Systems Analysis)	https://wiki.openmod-initiative.org/wiki/PyLESA
E3MG	n.a.	RAPSim (Renewable Alternative Powersystems Simulation)	https://sourceforge.net/projects/rapsim/
EleServe	https://www.ucl.ac.uk/energy-models/models/eleserve	ReEDS (Regional Energy Deployment System)	Regional Energy Deployment System (ReEDS) | NREL
ELMOD	DIW Berlin: Models	Region4FLEX	Region4FLEX - wiki.openmod-initiative.org
eLoad	Energy demand models - Fraunhofer ISI https://www.forecast-model.eu/forecast-en/content/methodology.php	ReMIND (Regional Model of Investments and Development)	https://www.pik-potsdam.de/en/institute/departments/transformation-pathways/models/remind#:~:text=REMIND%20(REgional%20Model%20of%20Investment,implications%20for%20our%20world%20climate.
EnerFuture	https://www.enerdata.net/research/forecast-enerfuture.html	REMix (Renewable Energy Mix)	https://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/Modellbeschreibungen/DLR_Energy_System_Model_REMix_short_description_2016.pdf
Energy Policy Simulator	Energy Policy Solutions	Renpass (Renewable Energy Pathways Simulation System)	renpass - Renewable Energy Pathways Simulation System | Das ZNES | Zentrum für nachhaltige Energiesysteme (ZNES) Flensburg (znes-flensburg.de)
Energy Transition Model (ETM)	Energy Transition Model	renpass GIS (Renewable Energy Pathways Simulation System)	https://github.com/chrisflei/renpass_gis
EnergyNumbers-Balancing	https://energynumbers.info/balancing/	Reopt (Renewable Energy Integration and Optimisation)	REopt Energy Integration & Optimization Home | NREL
EnergyPlan (Advanced Analysis of Smart Energy Systems)	https://www.energyplan.eu/	RETScreen (RETScreen Clean Energy Project Analysis Software)	http://msessd.ioe.edu.np/wp-content/uploads/2017/04/Textbook-clean-energy-project-analysis.pdf
energyPro	https://www.emd-international.com/energypro/modules/	SAFIRE	http://en.opasnet.org/w/SAFIRE

EnergyScope	https://www.sciencedirect.com/science/article/pii/S0306261919314163	SAGE (System for Analysis of Global Energy Markets)	https://www.eia.gov/analysis/pdfpages/m072(2003)1index.php
EnerMED	EnerMED Model: Bottom-up energy demand forecasting model | Enerdata	Second Generation Model (SGM)	Second Generation Model (SGM) | Joint Global Change Research Institute (umd.edu)
EnerNEO model (National Energy Outlook)	EnerNEO model (National Energy Outlook) | Enerdata	SHIPMod (Spatial Hydrogen Infrastructure Planning Model)	SHIPMod | UCL ENERGY INSTITUTE MODELS - UCL – University College London
Enertile (previously called PowerACE)	Home| enertile	Simplified Energy Enthalpy Model (SEEM Energy Model)	https://rtf.nwcouncil.org/simplified-energy-enthalpy-model-seem https://nwcouncil.app.box.com/s/xlmqj6wcv1o715gzjv65hv28klv05aho
ENTICE-BR	n.a.	SimSES (Simulation of stationary energy storage systems)	SimSES - EES (tum.de)
ESME	https://www.ucl.ac.uk/energy-models/models/esme	SIREN (SEN Integrated Renewable Energy Network Toolkit simulation)	Modelling Overview SIREN Toolkit - Sustainable Energy Now WA (sen.asn.au)
ETEM (Energy Technology Environment Model)	https://www.energyplan.eu/othertools/local/etem/	SmartCED (Smart Consumers and Energy Demand Model)	https://www.ucl.ac.uk/energy-models/models/smartced
ETM (EUROfusion Times Model)	https://www.researchgate.net/publication/342963698_Analysis_of_the_Effects_of_Electrification_of_the_Road_Transport_Sector_on_the_Possible_Penetration_of_Nuclear_Fusion_in_the_Long-Term_European_Energy_Mix	SMS++	SMS++ - wiki.openmod-initiative.org
ETM-UCL (European TIMES Model)	https://www.ucl.ac.uk/energy-models/models/etm-ucl	SNOW (Statistics Norway's World model)	https://www.cree.uio.no/models/snow/
Euro-Calliope	Euro-Calliope - Sentinel	Social Practices Agent Based Model	Models (wholesem.ac.uk)
FlexiGIS	https://www.sciencedirect.com/science/article/pii/S1876610218306416	STEMES (Spatio Temporal Model of Energy Systems)	Models (wholesem.ac.uk)
FORECAST	https://www.forecast-model.eu/forecast-en/index.php	Switch	Switch Power System Planning Model (switch-model.org)
GEM-E3 (General Equilibrium Model for Economy-Energy-Environment)	E3-Modelling, https://e3modelling.com/modelling-tools/gem-e3/	Temoa (Tools for Energy Model Optimisation and Analysis)	Temoa – Tools for Energy Model Optimization and Analysis (temoacloud.com)
General Integrated Modeling environment for the Supply of Electricity and Low-temperature heat (GRIMSEL-FLEX)	n.a.	TEMPEST (Technological EconoMic Political Energy Systems Transition)	https://www.ucl.ac.uk/energy-models/models/tempest
GINFORS	model GINFORS-E - Global Interindustry FORecasting System - Energy | Modelling Inventory and Knowledge Management System of the European Commission (MIDAS) (europa.eu)	TIAM-ECN	http://www.transrisk-project.eu/virtual-library/transrisk-models/ecn-%E2%80%93-tiam

GREEN-X	https://green-x.at/	TIAM-UCL	TIAM-UCL | UCL ENERGY INSTITUTE MODELS - UCL – University College London
HEB (High Efficiency Buildings)	https://www.researchgate.net/publication/272238049_MONETARY_BENEFITS_OF_AMBITIOUS_BUILDING_ENERGY_POLICIES	Timer Energy Demand Model (The IMage Energy Regional model)	https://models.pbl.nl/image/index.php/TIMER_model https://models.pbl.nl/image/index.php/Energy_supply_and_demand
HOMER (Hybrid Optimisation of Multiple Energy Resources)	HOMER - Hybrid Renewable and Distributed Generation System Design Software (homerenergy.com)	TIMES	IEA-ETSAP | Acquiring ETSAP Tools
IDA-ICE (IDA Indoor Climate and Energy)	IDA ICE - Simulation Software | EQUA	TIMES UK	https://www.ucl.ac.uk/energy-models/models/uk-times
IMAGE (Integrated Model to Assess the Global Environment)	About | PBL Netherlands Environmental Assessment Agency	TIMES-Norway	https://www.ntnu.no/trykk/publikasjoner/PositionPaper_2015/HTML/files/assets/common/downloads/page0010.pdf
Invert/EE-Lab - Invert-Agents	Energy demand models - Fraunhofer ISI https://invert.at/ https://www.invert.at/overview.php	TransiEnt	TransiEnt - wiki.openmod-initiative.org
IPAC	Welcome to IPAC (ipac-model.org.cn)	UK Foreseer	Foreseer of future resources | University of Cambridge https://www.geog.cam.ac.uk/research/projects/foreseer/
LEAP (Long-range Energy Alternatives Planning)	https://unfccc.int/resource/cd_roms/na1/mitigation/Module_5/Module_5_1/b_tools/LEAP/Manuals/Leap_Use_Guide_English.pdf	UK MARKAL	https://www.ucl.ac.uk/energy-models/models/uk-markal
LIBEMOD (LIBEralization MODel for the European Energy Markets)	https://www.frisch.uio.no/ressurser/LIBEMOD/	urbs	urbs: A linear optimisation model for distributed energy systems — urbs 1.0.0 documentation
LOADMATCH (LOADMATCH Grid Integration Model)	https://www.pnas.org/content/pnas/112/49/15060.full.pdf https://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/WorldGridIntegration.pdf	USENSYS	usensys
LoadProfileGenerator	LoadProfileGenerator	VLEEM	https://unfccc.int/topics/mitigation/workstreams/response-measures/progress-in-the-implementation-of-articles-48-and-49-of-the-convention-modelling-tools-to-assess-the/response-measures-models-vleem
LUSYM Invest (Leuven University System Modelling)	https://www.mech.kuleuven.be/en/tme/research/energy_environment/Pdf/WP-en2018-07	WeSIM (Whole-electricity System Investment Model)	icl-model-summary (wholesem.ac.uk)
MARKAL	IEA-ETSAP | Markal	World Energy Model (WEM)	World Energy Model – Analysis - IEA

Source: own elaboration.

ANNEX 2- List of modelling solutions identified with the developer

MODEL	NAME OF DEVELOPER	MODEL	NAME OF DEVELOPER
Energy Models		**Energy demand models**	
AnyMOD	TU Berlin	Aladin (ALternative Automobiles Diffusion and Infrastructure)	Fraunhofer ISI
Calliope	ETH Zürich	ASTRA Transport (ASsessment of TRAnsport Strategies)	Fraunhofer ISI in cooperation with MFIVE and TRT
Demand for Energy Services, Supply and Transmission in EuropE (DESSTinEE)	Imperial College London	Country Energy Demand Forecast	Enerdata. Intelligence + Consulting
DynEMo	University College London (UCL)	Demod	EPFL
E3ME	Cambridge Econometrics	eLoad	Fraunhofer ISI
E3 MG	Cambridge Centre for Climate Change Mitigation Research (4CMR)	EnerMED	Enerdata. Intelligence + Consulting
EnerFuture	Enerdata. Intelligence + Consulting	FORECAST	Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI)
Energy Policy Simulator	Energy Innovation, LLC	Invert/EE-Lab - Invert-Agents	EEG - Vienna University of Technology (in the framework of an Altener project) with Fraunhofer ISI in the frame of the Altener project Invert
Energy Transition Model (ETM)	Quintel Intelligence	Model for Analysis of Energy Demand (MAED)	IAEA
EnergyPlan (Advanced Analysis of Smart Energy Systems)	Sustainable Energy Planning Research Group - Aalborg University	Temoa (Tools for Energy Model Optimisation and Analysis)	NC State University
EnerNEO model (National Energy Outlook)	Enerdata. Intelligence + Consulting	Timer Energy Demand Model (The IMage Energy Regional model)	PBL Netherlands Environmental Assessment Agency
ENTICE-BR	Department of public Administration, Center for Environmental Policy Administration. The Maxwell School, Syracuse University.	UK Foreseer	University of Cambridge
ESME	Energy Technologies Institute	**Electricity/infrastructure models**	
ETEM (Energy Technology Environment Model)	ORDECSYS	AFRY BID3	AFRY
ETM-UCL (European TIMES Model)	University College London (UCL)	Agent-based Market model for the Investigation of Renewable and Integrated energy Systems (AMIRIS)	German Aerospace Center
Euro-Calliope	Tim Tröndle; Bryn Pickering; Stefan Pfenninger	DEAM (Dynamic Energy Agents Model)	University College London (UCL)
GEM-E3 (General Equilibrium Model for Economy-	European Commission Funded Multinational Collaboration	DIETER (Dispatch and Investment Evaluation Tool with Endogenous Renewables)	DIW Berlin

Energy-Environment)			
GINFORS	Gesellschaft für Wirtschaftliche Strukturforschung (GWS) mbH	EleServe	University College London (UCL)
IMAGE (Integrated Model to Assess the Global Environment)	Netherlands Environmental Assessment Agency	ELMOD	DIW Berlin
IPAC	Energy Research Institute (ERI)	General Integrated Modeling environment for the Supply of Electricity and Low-temperature heat (GRIMSEL-FLEX)	University of Geneva
LEAP (Long-range Energy Alternatives Planning)	Stockholm Environment Institute	HOMER (Hybrid Optimisation of Multiple Energy Resources)	Originally NREL
MARKAL	Cooperative multinational project	LIBEMOD (LIBEralization MODel for the European Energy Markets)	Frisch Centre & the Research Department at Statistics Norway
MDM-E3	Cambridge Econometrics	RAPSim (Renewable Alternative Powersystems Simulation)	Nuclear Engineering Seibersdorf (NES)
MEDEAS	ICM-CSIC	ReEDS (Regional Energy Deployment System)	NREL
MESSAGE	International Institute for Applied Systems Analysis (IIASA)	Region4FLEX	DLR Institute of Networked Energy Systems
NEMESIS	Cooperative project	renpass GIS (Renewable Energy Pathways Simulation System)	Zentrum für nachhaltige Energysysteme (ZNES)
NEMS	Energy Information Administration (EIA), US Department of Energy (DOE)	SHIPMod (Spatial Hydrogen Infrastructure Planning Model)	University College London (UCL)
NIEIR Multi-purpose model	National Institute of Economics and Industry Research	SimSES (Simulation of stationary energy storage systems)	Technical University of Munich
Oemof (Open Energy Modelling Framework)	Reiner Lemoine Institut / ZNES Flensburg	Switch	University of Hawaii
OMEGAlpes	G2Elab	TransiEnt	Hamburg University of Technology
OSeMOSYS	KTH Royal Institute of Technology, University College London (UCL)	WeSIM (Whole-electricity System Investment Model)	Imperial College of London
PACE	ZEW GmbH	**Renewable energies/electricity system development**	
PANTA-RHEI	GWS	Balmorel	RAM-lose
POLES (Prospective Outlook on Long-term Energy Systems)-JCR	European Commission, DG Joint Research Centre; EDDEN Lab, University Grenoble Alpes, France; Enerdata	Breakthrough Energy Model	Breakthrough Energy Foundation
PRIMES	E3Modelling, National Technical University of Athens	California and West Coast Power Systems model (CAPOW)	North Carolina State University
PROMETHEUS	E3Modelling, National Technical University of Athens	EnergyNumbers-Balancing	UCL Energy Institute
ReMIND (Regional Model of Investments and Development)	Potsdam Institute for Climate Impact Research	EnergyPro	EMD International A/S

SAFIRE	Energy for Sustainable Development Ltd (ESD)	EnergyScope	EPFL, UCLouvain
SAGE (System for Analysis of Global Energy Markets)	EIA (Energy Information Administration)	FlexiGIS	DLR Institute of Networked Energy Systems
Second Generation Model (SGM)	Pacific Northwest National Laboratory/Joint Global Change Research Institute at the University of Maryland	GREEN-X	Coordinator: Vienna University of Technology, Energy Economics Group (EEG)
SNOW (Statistics Norway's World model)	Research Department Statistics Norway	IDA ICE (IDA Indoor Climate and Energy)	
STEMES (Spatio Temporal Model of Energy Systems)	Imperial College of London	LOADMATCH (LOADMATCH Grid Integration Model)	Stanford University
TEMPEST (Technological EconoMic Political Energy Systems Transition)	University College London (UCL) with the Science Policy Research Unit at the University of Sussex (SPRU) and the Energy Systems Catapult	LUSYM Invest (Leuven University System Modelling)	University of Leuven
TIAM-ECN	Energy research Centre of the Netherlands (ECN)	MESAP (Modular Energy System Analysis Planning)	Institute for Energy Economics and the Rational Use of Energy (IER) at the University of Stuttgart
TIAM-UCL	UK Energy Research Centre from the ETSAP-TIAM model	OpenDSS (Open Distribution System Simulator)	Electric Power Research Institute (EPRI)
TIMES	Cooperative multinational project.	PLEXOS (PLEXOS Integrated Energy Model)	Energy Exemplar
TIMES UK	University College London (UCL) and the UK Department of Business, Energy, and Industrial Strategy	PowerGAMA (Power Grid and Market Analysis)	SINTEF Energy Research
TIMES-Norway	Institute for Energy Technology (IFE)	REMix (Renewable Energy Mix)	DLR Institute of Engineering Thermodynamics
UK MARKAL	University College London (UCL)	Renpass (Renewable Energy Pathways Simulation System)	ZNES Flensburg
VLEEM	Cooperation project coordinated by Enerdata	Reopt (Renewable Energy Integration and Optimisation)	The National Renewable Energy Laboratory
World Energy Model (WEM)	International Energy Agency (IEA)		
Building environment models		RETScreen (RETSCreen Clean Energy Project Analysis Software)	Natural Resources Canada
CaRB2	University College London (UCL)	SIREN (SEN Integrated Renewable Energy Network Toolkit simulation)	Sustainable Energy Now Inc.
CESAR-P	Urban Energy Systems Lab, Empa	SMS++	Dipartimento di Informatica, Università di Pisa
Distributed Energy Resources Customer Adoption Model (DER-CAM)	Lawrence Berkeley National Laboratory (Berkeley Lab)	urbs	Chair of Renewable and Sustainable Energy Systems, Technical University of Munich
DREEM (Dynamic high-Resolution dEmand-sidE Management)	TEESlab	USENSYS	Environmental Defense Fund

Enertile (previously called PowerACE)	Fraunhofer ISI	**Behavioural models**	
ETM (EUROfusion Times Model)	EUROfusion	BLUE (Behaviour, Lifestyles and Uncertainty Energy model)	University College London (UCL)
HEB (High Efficiency Buildings)	Center for Climate Change and Sustainable Energy Policy (3CSEP)	LoadProfileGenerator	FZ Jülich
IDA-ICE (IDA Indoor Climate and Energy)	EQUA Simulation AB	Social Practices Agent Based Model	University of Surrey
OpenTUMFlex	Technical University of Munich		
PyLESA (Python for Local Energy Systems Analysis)	University of Strathclyde		
Simplified Energy Enthalpy Model (SEEM Energy Model)	Council and NEEA (Northwest Energy Efficiency Alliance)		
SmartCED (Smart Consumers and Energy Demand Model)	University College London (UCL)		

Source: own elaboration.

ANNEX 3- Software employed by availability of the models

	Commercial use	OAM	Own use	Supposed commercial use	Supposed own use	Total general
Python		24	2	1	2	29
GAMS	1	11	6		2	20
Excel	3	9	2		2	16
VEDA	1	2	2		3	8
CPLEX		3	1		2	6
Java		4		1		5
Matlab		4			1	5
Stand-alone	3	2				5
R		3	1			4
AIMMS		1	1		1	3
Julia		3				3
JuMP		3				3
Fortran		3		1		4
Pyomo		3				3
VBA		3				3
Vensim		1			2	3
ANSWER		1	1			2
C++		2				2
Dymola		1	1			2
GLPK		1	1			2
GTAP			1	1		2
Modelica		1	1			2
PostgreSQL		2				2
Windows		2				2
AMPL		1				1
Analytica					1	1
ArcGIS			1			1
C#		1				1
CAD software	1					1
Coin-OR		1				1
CONOPT		1				1
CSS		1				1
Developed in-house		1				1
DOS				1		1
EnergyPlus		1				1
energyRt		1				1
EnerMED model	1					1
EVIEWS	1					1
Flow-based market coupling and Nodal (LMP)	1					1
GLPSOL		1				1

GMPL			1			1
GNU MathProg		1				1
HTML		1				1
IDIOM				1		1
LibreOffice Calc		1				1
Linux		1				1
MacOs		1				1
Microsoft Access		1				1
Microsoft Visual Basic		1				1
Microsoft Visual Studio				1		1
MPSGE		1				1
MySQL		1				1
NREL SAM		1				1
NTCs	1					1
OMEGAlpes		1				1
Optimisation and Modeling Library (OML)		1				1
ORACLE		1				1
Ox				1		1
PATH			1			1
PHP		1				1
PostGIS		1				1
Power Point	1					1
PuLP		1				1
Resource-Technology Network (RTN) representation			1			1
Risk Solver					1	1
RMySQL		1				1
Ruby (on Rails)		1				1
SA	1					1
SAGE		1				1
SMS++		1				1
SQLite		1				1
Word	1					1
XPRESS		2				1

Source: own elaboration.

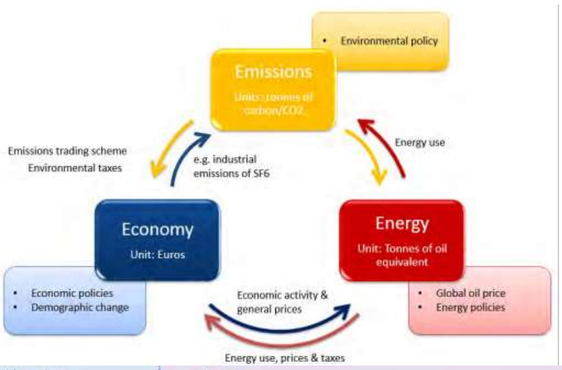
ANNEX 4- Details of some energy models

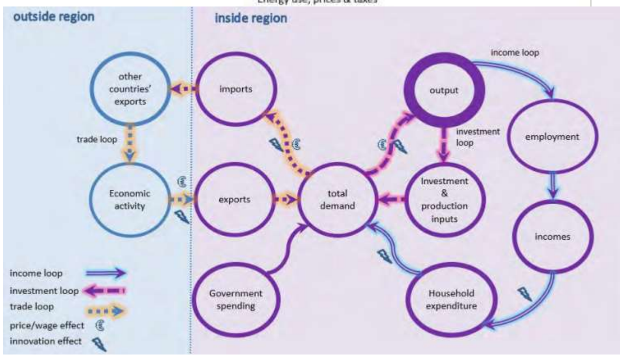
1 AFRY BID3

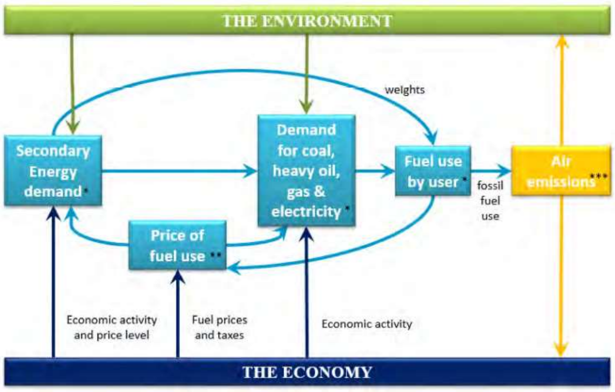
Model name	AFRY BID3
Name of the developer	AFRY
Organisation details	Engineering, design, and advisory services company
Country of origin	Sweden
Basic description	AFRY's power market dispatch model uses mathematical techniques to model the dispatch of power stations, market prices, capacity evolution, and all other important features of power markets. BID3 is used in many power markets worldwide, including the European network along with South America, Asia-Pacific, and the Middle East.
Main area of application	Used to simulate the dispatch of all supply and demand in electricity markets. Equally capable of covering both short-term analysis for trading and long-term scenarios
Other	Updated
Cost	n.a.

2 E3ME

Model name	E3ME
Name of the developer	Cambridge Econometrics
Organisation details	Independent organisation that specialises in data, we provide you with credible and robust evidence that allows you to make decisions.
Country of origin	United Kingdom
Geographical coverage	Europe at Member State level (incl. Croatia), three other EU candidate countries, Norway, and Switzerland, 11 other major economies explicitly and the rest of the world grouped into political regions.
Basic description	E3ME is a dynamic, computer-based, global macroeconomic model which represents the three pillars of sustainability: economy, society and environment. E3ME's detailed sectoral disaggregation is important for assessing interactions between the pillars. The model is highly empirical in its approach. Several specific national models (including some with sub-national disaggregation) have been developed from E3ME and share the same underlying properties. The econometric E3ME model has been built as a framework for assessing energy-environment-economy issues and policies. Its close links between energy demand and economic indicators make it well-suited to assessing the social and economic impacts of response measures.
Type of users	Policy makers
Main area of application	In the past the model has mainly been used for: general macro and sectoral economic analysis; more focused analysis of policies relating to greenhouse gas mitigation; assessing incentives for industrial energy efficiency; analysing sustainable household consumption, for example to assess impacts of raw material taxation on household consumption patterns and other economic variables. It is now used throughout the world, especially for the assessment of climate and energy policy. International trade is an important part of the analysis. It is designed to assess both national and global policy challenges and give increased certainty to decision makers. Recently the model has been used to contribute to several official policy assessments in Europe, including the Energy Taxation Directive, the Energy Efficiency Directive and the 2030 environmental targets. It is also frequently being applied at national level, both within and outside Europe.
Other	Supported and maintained
Cost	n.a.
Model overview	







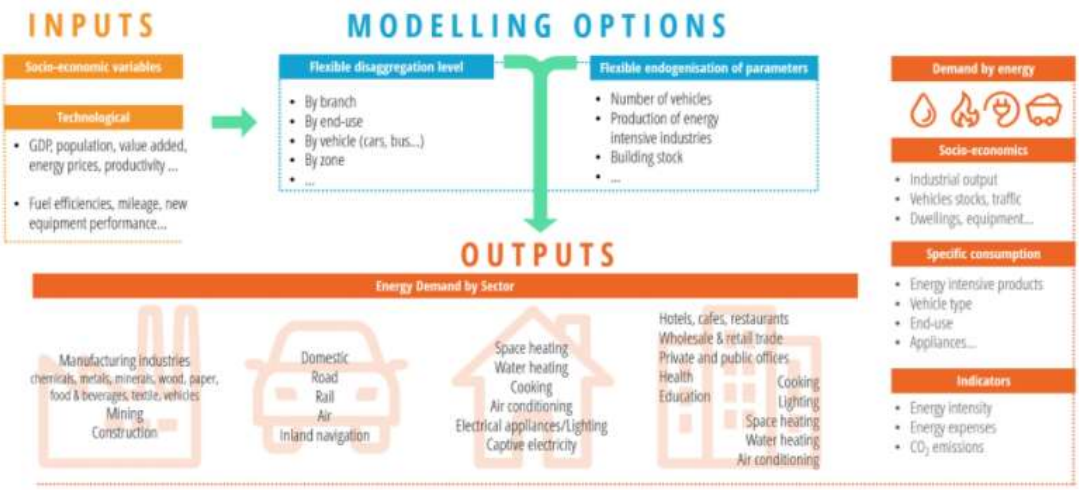
* thousand toe ** € per thousand toe *** thousand tonnes

3 E3MG

Model name	**E3MG**
Name of the developer	Cambridge Centre for Climate Change Mitigation Research (4CMR)
Organisation details	A multi-disciplinary research centre dedicated to finding strategies to reduce climate change risks while preserving a vibrant global economy, so environmental, economic and energy security aims are achieved.
Country of origin	United Kingdom
Geographical coverage	World, split in 20 regions
Basic description	E3MG is a sectoral econometric model that has been developed with the intention of analysing long-term energy and environment interactions within the global economy and assessing short and long-term impacts of climate-change policy. It is very similar to E3ME in structure and closely links economic outcomes with energy policy. It has a particular focus on taxes and subsidies, making it highly relevant to analysis of these response measures. Its global nature also makes it a useful tool for assessing the deployment of new technologies in developing countries.
Main area	E3MG is relevant in assessing the socio-economic impact of climate change mitigation policies on a global level. It is particularly useful in analysing the effects of changes in tax and subsidy policies, as well as analysing technological diffusion in developing countries.
Type of users	Researchers
Cost	n.a.

4 Enerdata energy models

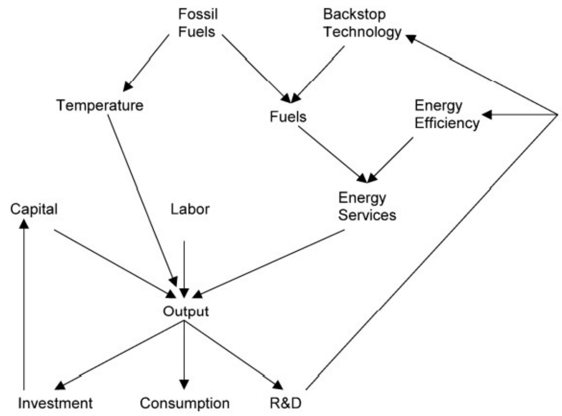
Model name	**Global Energy Forecasts: EnerFuture**
Name of the developer	Enerdata
Organisation details	Enerdata is an independent research and consulting firm specialising in the analysis and modelling of the global energy markets and its drivers.
Country of origin	France
Geographical coverage	Global coverage of 65 countries and aggregates
Basic description	EnerFuture provides energy projections to 2050. It offers clear insight into the future of energy demand, electricity generation, prices and GHG emissions by energy source and sector at both country and regional levels.
Type of users	
Main area of application	A useful tool to assess the evolution and drivers of energy markets worldwide, EnerFuture will help you define your business' strategic decisions.
Other	Supported and updated. Latest version 2021
Cost	n.a.
Model name	**EnerMED**
Basic description	EnerMED is a bottom-up model for long-term energy demand, and GHG forecasts at national and regional level. It analyses energy demand at a detailed level, by subsector and end-use / appliances / types of vehicles. The user can configure the energy consumption structure to adapt its equations to the available data and to the national context. Then EnerMED simulates the energy demand in detail. For each end-use, a useful energy demand is calculated. The market share and efficiency of each technology are modelled to obtain the final energy consumption and GHG emissions.
Main area of application	Simulation of energy demand by type and end-use according to various energy efficiency scenarios. Calculation of future energy demand and related CO_2, and GHG emissions. Calculation of energy indicators (sectoral energy intensities, unit consumption, etc.)
Other	Updated
Cost	n.a.
Model overview	



Model name	**EnerNEO**
Basic description	EnerNEO is used and developed to assess the possible long-term evolution (up to 2050) of national energy demand and power supply under various conditions for climate and energy policies, including agreement on INDCs at the COP21. It gives a detailed quantitative assessment of energy demand by fuel, sector and sub-sectors as well as the development of power generation and capacities. EnerNEO is a partial equilibrium simulation model of the energy sector. The simulation process uses dynamic year-by-year recursive modelling, which gives full development outcomes to various long-term horizons.
Main area of application	The purpose of this tool is to provide a stand-alone Excel model allowing users to create their own customised scenarios and to assess the long-term impacts of climate and energy constraints on energy demand and power production. Besides its standard module, this Excel tool offers great flexibility through an advanced mode enabling users to define their own variables and parameters as inputs, creating customised scenarios.
Other	Updated
Cost	n.a.

5 ENTICE-BR

Model name	ENTICE-BR
Name of the developer	Department of Public Administration, Centre for Environmental Policy Administration (CEPA). The Maxwell School, Syracuse University.
Organisation details	An interdisciplinary centre that focuses on environmental issues, economics of technological change, public finance.
Country of origin	USA
Geographical coverage	World
Basic description	It is a top-down model providing explicit links between economic activity and environmental damages. ENTICE-BR is a modified version of the DICE model that includes links between climate policy and energy innovation. ENTICE-BR is a dynamic growth model of the global economy that includes links between economic activity, carbon emissions and the climate. The model includes fossil fuels as an input to production. However, ENTICE-BR retains the global framework of the DICE model, rather than dividing the world in separate regions. It calculates the costs and benefits of each policy. ENTICE-BR extends the ENTICE model to include policy-induced R&D on both energy efficiency and a carbon-free backstop energy technology source. The model is calibrated to a base year of 1995 and is solved in 10-year increments for a period of 350 years. In both the DICE and ENTICE models, the goal of the model is to maximise the present value of per capita utility, which increases along with increased per capita consumption, subject to various economic and environmental constraints.
Type of users	Mainly academia
Main area of application	ENTICE-BR is mainly used for: analysing the impacts of R&D spending in the energy sector (in particular climate-friendly); and studying the effects of various climate stabilisation policies. ENTICE-BR is highly relevant to assessing methods for improving energy efficiency and the development and diffusion of new technologies. The model can also be used for assessing the economic effects of such a policy. It is useful to make simulations and can be used to calculate an optimal climate policy in which marginal benefits equal marginal costs.
Other	Seems not updated
Cost	n.a.
Model overview	



6 Fraunhofer ISI´s energy models

Fraunhofer ISI develops and deploys detailed bottom-up models to map the diffusion of innovations throughout the entire energy system, from energy demand to energy supply. These energy system models are linked to macro-economic models. All models cover at least the individual countries of the European Union and the timeframe until 2050.

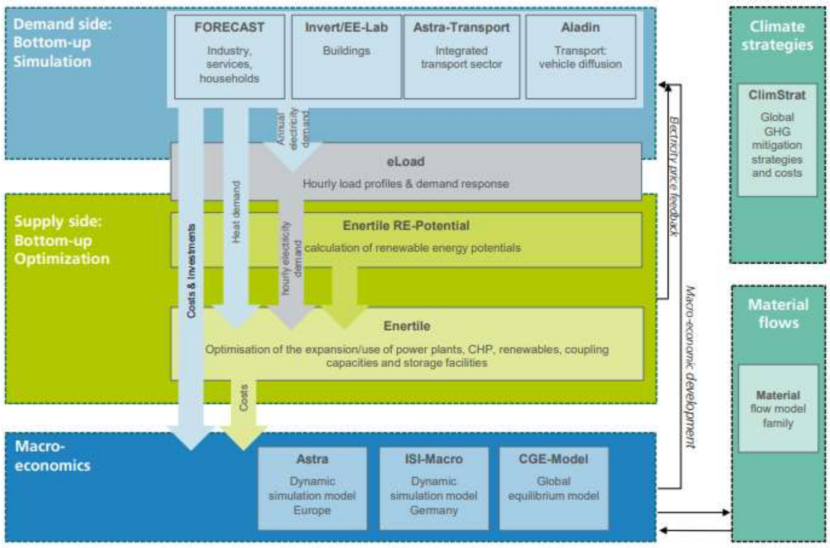


Figure 4 Fraunhofer ISI energy system models

Source: (Fraunhofer Institute for Systems and Innovation Research ISI, 2022).

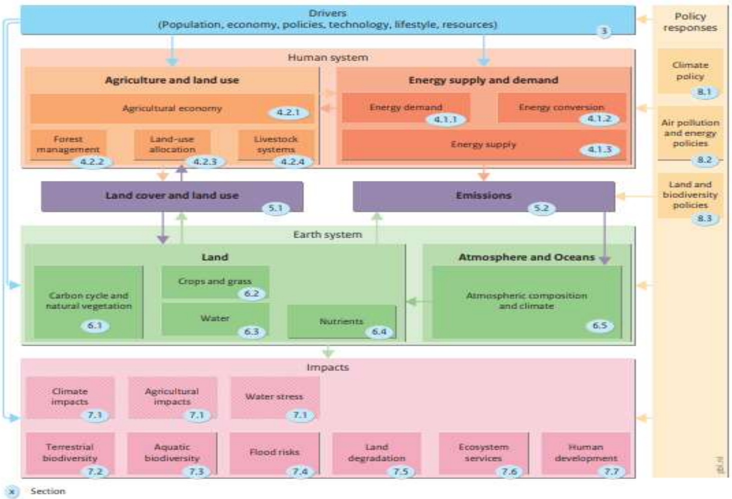
Forecast/eLOAD
FORECAST has been applied to a number of research projects analysing different aspects of the future development of energy demand. This includes the impact of policy-measures, technology dynamics, prices and other socio-economic factors on energy demand and greenhouse gas emissions until 2030 or 2050. ELOAD allows disaggregating the annual electricity demand of a country into hourly load curves and simulates the impact of demand side management options on the load curve. The model has typically been used in combination with FORECAST but can also be applied separately.
Invert/EE-Lab
A dynamic bottom-up techno-socio-economic simulation tool that evaluates the effects of different policy packages on the total energy demand, energy carrier mix, CO_2 reductions and costs for space heating, cooling, hot water preparation and lighting in buildings. The model is based on highly disaggregated data of the building stock. Each building segment is described by geometry data, U-values of building components, construction period, age and type of installed heating and hot water system etc.
ASsessment of TRAnsport Strategies (Astra model)
An integrated assessment model applied for more than 20 years for strategic policy assessment in the transport and energy field. It covers EU27 Countries plus Great Britain, Norway and Switzerland, and integrates nine modules linked together in manifold ways: a vehicle fleet model, transport model, emission and accident models, population model, foreign trade and economic model with input-output tables, government, employment and investment models. The model is based on the System Dynamics approach and built in Vensim®; it runs until the year 2050 and provides sophisticated tools for sensitivity analyses.
ALternative Automobiles Diffusion and INfrastructure (Aladin)
An agent-based simulation of alternative fuel vehicles purchase decisions. It uses driving data from several thousand individual vehicles. The core of the model is to calculate the total cost of ownership for different drivetrains (e. g. gasoline, diesel, BEV, PHEV for passenger cars) based on large data sets for individual user driving behaviour and to determine the utility maximising driving option under various restrictions including infrastructure or the limited model availability of new drivetrain technologies.

7 GINFORS-E

Model name	**Global Interindustry FORecasting System – Energy (GINFORS-E)**
Name of the developer	Gesellschaft für Wirtschaftliche Strukturforschung (GWS) mbH
Organisation details	The Institute of Economic Structures Research (GWS) is a private, independent economic research and business and policy consultancy organisation. Its goal is to provide objective, impartial, factual consultancy to aid social transformation and development processes.
Country of origin	Germany
Geographical coverage	GINFORS-E is a global model with country and sector (National Sub-national (NUTS2)) details for 64 countries and one rest of world region mainly based on OECD and IEA data. Explicitly included are all EU countries, all OECD countries, and their major trading partners.
Basic description	It is designed for assessments of economic, energy, climate and environmental policies up to the year 2050. The parameters used in the model equations are econometrically estimated based on time-series data. Agents have myopic expectations and follow behavioural routines of the past. Markets are not assumed to be cleared. The model solves annually.
Main area of application	GINFORS-E can be used to analyse the macroeconomic effects of a variety of price changes and policies in individual countries in the global context. It is designed for assessments of economic, energy, climate, and environmental policies up to the year 2050. The model can be applied for formulation, implementation, and evaluation. It is mainly used for ex ante simulations. This can include the effect of changed framework data (international oil prices), policy measures (carbon prices), technological changes (renewable energy deployment) or structural change (e-mobility).
Other	Supported and updated. In recent years, the way the model deals with the energy sector has been further refined to take account of global developments in renewable energy technologies. The model has also started to be used to examine future changes in consumption-based greenhouse gas emissions, which is why the name has been extended to GINFORS-E.
Cost	Non-Free Software licence

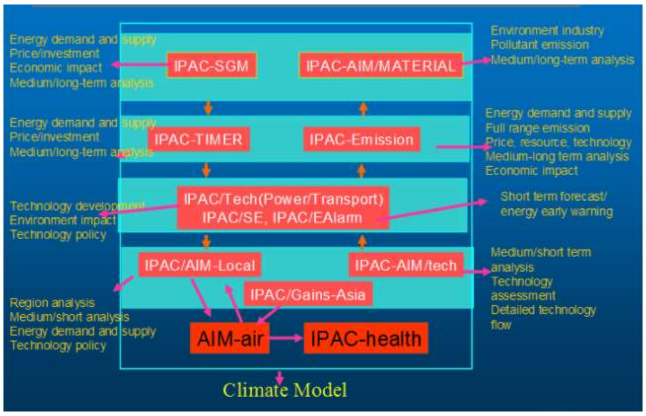
8 IMAGE

Model name	**Integrated Model to Assess the Global Environment (IMAGE)**
Name of the developer	Netherlands Environmental Assessment Agency, IAMC
Organisation details	An organisation of scientific research that pursues scientific understanding of issues associated with integrated assessment modelling and analysis.
Country of origin	Netherlands
Geographical coverage	World, split in 26 regions. Some tools have been developed to downscale information on population, income, energy use and emissions to a 0.5x0.5 grid level
Basic description	IMAGE is a computer model that simulates environmental consequences of human activities by integrating land, energy, climate, and policy models in one framework.
Main area of application	Its main goal is to provide insight in the most important interactions between these systems.
Other	Supported and updated.
Cost	n.a.
Model overview	



9 IPAC

Model name	Integrated energy and environment Policy Assessment model for China (IPAC)
Name of the developer	Energy Research Institute (ERI)
Organisation details	The ERI is a national research organisation conducting comprehensive studies on China's energy issues. The scope of research covers the fields of energy production, distribution, and consumption. The focus is on soft scientific studies in the fields of energy economy, energy efficiency, energy and the environment, and renewable energy.
Country of origin	China
Geographical coverage	IPAC includes the global model, national model and regional models.
Basic description	IPAC is a multi-model framework, which covers different modelling methodologies by focusing on various policy questions. The model consists of: 1. General energy supply and demand models (society, economy and energy activities module), which mainly analyse the demand and supply in the condition of social and economic development, and determines the energy prices; 2. An emissions model (land use module), which analyses the emissions from land use (agricultural food supplies, conditions and rest management and biomass energy production); 3. A disaggregated set of energy supply models that focus on technologies and regions of China (energy technology module analyses the short and mid-term energy utilisation technologies under different conditions and determines the energy demand under different technology compositions); 4. Air and health impact models (industrial process emission module). Modules in IPAC are currently linked.
Type of users	ERI: For research
Main area of application	Policy simulation Analysis
Other	The society, economy and energy activities module is built based on the ERB model developed by Pacific Northwest National Laboratory (PNNL) in the US. Energy technology module is the IPAC-AIM/technology module developed collaboratively by Climate Change Strategies Assessment Research Team in ERI and National Institute of Environmental Studies in Japan. Land use module is modified and extended based on the AGLU model developed by PNNL.
Cost	Supposed own use
Model overview	

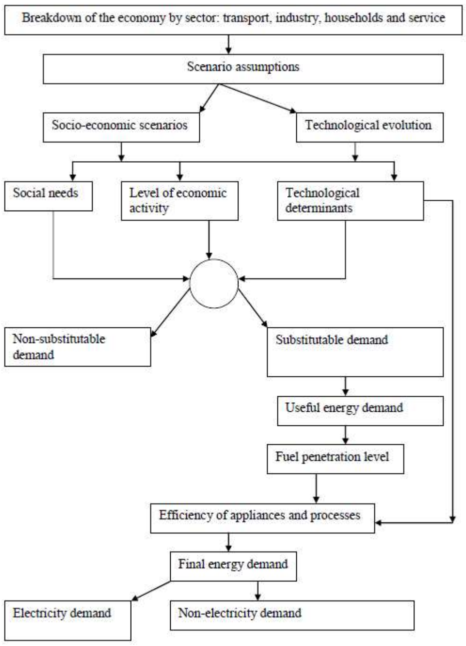


10 LEAP

Model name	Long-range Energy Alternatives Planning (LEAP)
Name of the developer	Stockholm Environment Institute
Organisation details	International non-profit research and policy organisation that tackles environment and development challenges.
Country of origin	Sweden
Geographical coverage	190 countries worldwide
Basic description	LEAP is a flexible modelling environment that allows building specific applications suited to particular problems at various geographical levels (cities, state, country, region or global). As an integrated energy planning model LEAP covers both the demand and supply sides of the energy system. LEAP is intended as a medium- to long-term modelling tool. Most of its calculations occur on an annual time-step, and the time horizon can extend for an unlimited number of years
Main area of application	LEAP is designed around the concept of scenario analysis.
Other	Updated
Cost	n.a.

11 MAED-2

Model name	Model for Analysis of Energy Demand (MAED-2)
Name of the developer	International Atomic Energy Agency (IAEA)
Organisation details	The Agency assists Member States with practical solutions for their energy planning. It offers different types of energy modelling tools that enable States to make smart energy choices.
Geographical coverage	World, national
Basic description	MAED evaluates future energy demands based on medium- to long-term scenarios of socioeconomic, technological, and demographic development. Energy demand is disaggregated into many end-use categories corresponding to different goods and services. The influences of social, economic, and technological driving factors from a given scenario are estimated. These are combined for an overall picture of future energy demand growth (IAEA, 2006). MAED includes some additional modules which may be used to convert first, the total annual electricity demand into the hourly electricity consumption expressed in terms of the load imposed on the electric power generating system in each hour of the year, and then into the so-called load duration curve of the power system, which is only a convenient representation of the load for the purpose of analyzing the expansion of the system.
Other	Updated
Cost	Provides training on the use of this model to local professionals upon request from interested Member States
Model overview	

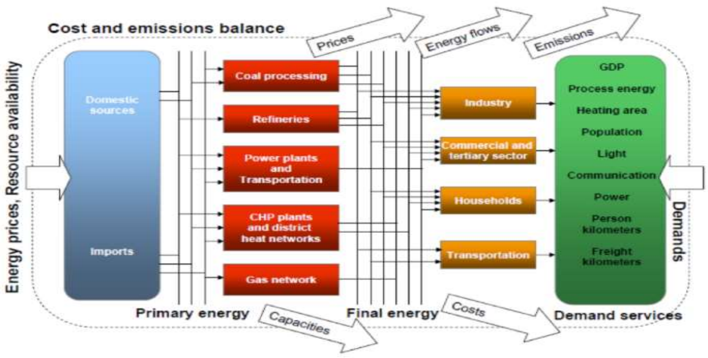


12 MARKAL/TIMES family models

Both models have been developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA).

Model name	MARKAL
Country of origin	Cooperative multinational project.
Geographical coverage	The scope can be national, regional, state or province, or community level. It covers 38 countries and regions including the EU27, USA, China, and Japan.
Basic description	MARKAL is a generic model tailored by the input data to represent the evolution over a period of usually 40 to 50 years of a specific energy system at the national, regional, state or province, or community level. This model offers: 1) A proven process of multinational cooperation, 2) An international network of analysts, 3) A methodology for energy and environmental policy analysis, 4) A basic standard model that finds least-cost solutions for directly comparable national results, 5) A set of national energy technology databases that are current and consistent, and 6) A track record of transferring its soft technology to new users. The basic components in a MARKAL model are specific types of energy or emission control technology. Each is represented quantitatively by a set of performance and cost characteristics. Both the supply and demand sides are integrated, so that one side responds automatically to changes in the other. The model selects that combination of technologies that minimises total energy system cost. The model requires input projections of energy service demands -- room space to be heated or vehicle-miles to be travelled, for example -- and projected resource costs. Then, a reference case is defined in which, for example, no measures are required to reduce carbon dioxide emissions. A series of runs is then made with successive reductions in emissions: emissions stabilised at present levels, for example, then reduced by 10 percent, 20 percent, etc., by some future date before being stabilised. In each case, the model will find the least expensive combination of technologies to meet that requirement -- up to the limits of feasibility -- but with each further restriction the total energy system cost will increase.
Type of users	77 institutions in 37 countries, many with developing economies.
Main area of application	1) To identify least-cost energy systems, 2) to identify cost-effective responses to restrictions on emissions, 3) to perform prospective analysis of long-term energy balances under different scenarios, 4) to evaluate new technologies and priorities for R&D, 5) to evaluate the effects of regulations, taxes, and subsidies, 6) to project inventories of greenhouse gas emissions and 7) to estimate the value of regional cooperation.
Other	Supported but not updated. The ETSAP decided to promote TIMES for new users in winter 2008.
Cost	Free of charge. IEA-ETSAP | Acquiring ETSAP Tools

Model name	TIMES (The Integrated MARKAL-EFOM System)
Country of origin	Cooperative multinational project
Geographical coverage	National, multi-regional and global
Basic description	The TIMES model generator was developed for energy scenarios to conduct in-depth energy and environmental analyses. It combines two different, and complementary, approaches to modelling energy: a technical engineering approach and an economic approach. TIMES models encompass all the steps from primary resources through the chain of processes that transform, transport, distribute and convert energy into the supply of energy services demanded by energy consumers. On the energy supply-side, it comprises fuel mining, primary and secondary production, and exogenous import and export. The "agents" of the energy supply-side are the "producers". The "agents" of the energy demand-side are the "consumers". All TIMES models have a reference energy system, which is a basic model of the energy system before it is substantially changed either for a particular region or for a particular scenario. The model outputs are energy flows, energy commodity prices, GHG emissions, capacities of technologies, energy costs and marginal emissions abatement costs. The principal insights generated from TIMES are achieved through scenario analysis. TIMES optimises the energy systems providing a least cost solution.
Type of users	Employed by modelling experts and policy makers. It is used by researchers at universities, research centres, Energy Policy and Planning Offices, Companies (e.g. Noblesoft), Public Institutions (e.g. Austrian Energy Agency).
Main area of application	TIMES is used for the exploration of possible energy futures based on contrasted scenarios. Once all the inputs, constraints and scenarios have been put in place, the model will attempt to solve and determine the energy system that meets the energy service demands over the entire time horizon at least cost. First it addresses the question: is the target feasible? If it is possible. Then it examines: at what cost?
Other	Supported and updated
Cost	Free of charge. IEA-ETSAP | Acquiring ETSAP Tools
Model overview	



13 MDM-E3

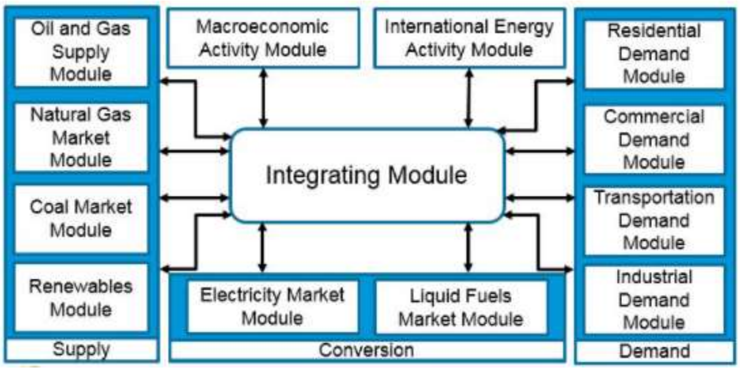
Model name	MDM-E3
Name of the developer	Cambridge Econometrics
Organisation details	Independent organisation that specialises in data, we provide you with credible and robust evidence that allows you to make decisions.
Country of origin	UK
Geographical coverage	UK
Basic description	Multisectoral Dynamic Model of the UK economy analyses changes in economic structure and assesses energy-environment-economy (E3) issues and other policies. It disaggregates the UK into twelve regions. In MDM-E3, the key indicators are modelled separately for each industry sector and region, yielding results for the UK.
Type of users	Own use
Main area of application	It is very similar to E3ME in structure, and its close links between energy demand and economic indicators make it well-suited to assessing the economic impacts of response measures. Additionally, taxes or the removal of subsidies can be assessed with the model in the UK. MDM-E3 can also be used to examine the impacts of efficiency measures, including rebound effects.
Other	Supported and updated
Cost	n.a.

14 MESSAGE

Model name	MESSAGE
Name of the developer	International Institute for Applied Systems Analysis (IIASA)
Organisation details	IIASA advances systems analysis and applies its research methods to identify policy solutions to reduce human footprints, enhance the resilience of natural and socioeconomic systems, and help achieve the sustainable development goals. The results of IIASA research are available to policymakers.
Country of origin	Austria
Geographical coverage	World, split in 11 regions
Basic description	The model provides a framework for representing an energy system with all its inter-dependencies from resource extraction, imports and exports, conversion, transport and distribution, to the provision of energy end-use services such as light, space conditioning, industrial production processes, and transportation. The model also covers all six Kyoto GHGs, their drivers and mitigation technologies. MESSAGE is relevant in analysing the development of 'greener' technologies, as well as looking at the diffusion of technology across countries. The model can also be used to analyse the trade flows of different energy products. MESSAGE is used in conjunction with MAGICC (Model for Greenhouse gas Induced Climate Change) for calculating internally consistent (probabilistic) scenarios for climate change. Through linkages with the MACRO model economic feedback on energy demand are assessed, and further linkages with the GLOBIOM (agricultural) model allows the assessment of land, forest, and water implications of energy systems. An explicit linkage to the GAINS air pollution framework allows the assessment of health impacts of energy systems.
Type of users	MESSAGE is used in applied projects and scientific studies around the world: IPCC, World Energy Council (WEC), German Advisory Council on Global Change (WBGU), European Commission and Global Energy Assessment (GEA)
Main area of application	Optimisation model used for medium- to long-term energy system planning, energy policy analysis, and scenario development.
Other	Supported and updated: models, tools, and data. MESSAGE-Access: used to assess future transitions in household energy use and the costs of alternative policies to accelerate universal transition to modern energy sources and technologies. The outputs of the model are also used to estimate the health, environmental and economic consequences of alternative transition pathways. implemented for the regions of South Asia, Pacific Asia, Central America, and sub-Saharan Africa. MESSAGE-MACRO: Assessing the economic impact of policies on energy costs, GDP, and energy demand. It is a linked model that reflects the influence of energy supply costs on the wider economy and vice versa. MESSAGE-MAGICC: A model to estimate the effects of greenhouse gas emissions on the global climate system. It estimates net carbon flows and atmospheric CO_2 concentrations, changes in radiative forcing, temperature, and sea level.
Cost	Free but has prerequisites

15 NEMS

Model name	NEMS (National Energy Modelling System)
Name of the developer	Energy Information Administration (EIA), US Department of Energy (DOE)
Organisation details	Forecasts and analyses to promote policy making, efficient markets, and public understanding regarding energy and its interaction with the economy and the environment. EIA began developing NEMS in the early 1990s.
Country of origin	USA
Geographical coverage	USA
Basic description	NEMS is an integrated model of the U.S. energy system linked to a macroeconomic model. It is a computer-based, energy-economy modelling system of U.S. energy markets. NEMS forecasts the production, imports, conversion, consumption, and prices of energy. NEMS consists of 13 modules: Four supply modules (oil and gas supply, natural gas market, coal market, and renewable fuels), Two conversion modules (electricity market and liquid fuels market), Four end-use demand modules (residential, commercial, industrial, and transportation, One module to simulate energy/economy interactions (macroeconomic activity), One module to simulate international oil markets (international), One module that provides the mechanism to achieve a general market equilibrium among all the other modules (integrating).
Type of users	EIA/DOE
Main area of application	EIA uses NEMS to produce the AEO and other projections of the U.S. energy sector, for example policy scenarios requested by Congress
Other	Supported and updated
Cost	Supposed own use

Model overview


16 NEMESIS

Model name	NEMESIS
Name of the developer	Multiple
Organisation details	Erasme Team
Country of origin	France, National Technical University of Athens, Greece, Federal Planning Bureau, Belgium.
Geographical coverage	EU27, USA, Japan
Basic description	NEMESIS is a multi-country macro-sectoral econometric model which can be used for assessment of structural policies, mainly environmental and R&D policies. It closely links energy and environmental policy to economic outcomes, making it a suitable tool for analysis of the response measures. It can be used to model the impacts of additional taxes on emissions or energy use. NEMESIS Energy Environment Module (NEEM) gives detailed results on energy supply and demand by fuel type and technology, and on various pollutants emissions: CO_2, SO_2, NO_X, HFC, PFC and CF_6; it also computes a carbon price (Taxation or tradable permit price associated to a carbon constraint).
Main area of application	The model has mainly been used for the assessment of short- and medium-term consequences of energy and environmental (air pollution) policies, R&D, technology-related and economic policies on EU economies and on the state of the environment; forecasting baseline scenarios for 30 years' time, including sustainable development scenarios. NEMESIS is relevant in analysing the socio-economic impacts of climate change mitigation policies, and in particular technology related policies and taxation schemes. NEMESIS can be used for many purposes as short and medium-term economic and industrial “forecasts” for business, government and local authorities; analysing Business As Usual (BAU) scenarios and economy long-term structural change, energy supply and demand, environment, land-use and more generally sustainable development, etc.
Other	Supported and updated
Cost	Non-Free Software licence

17 NIEIR Multi-purpose model

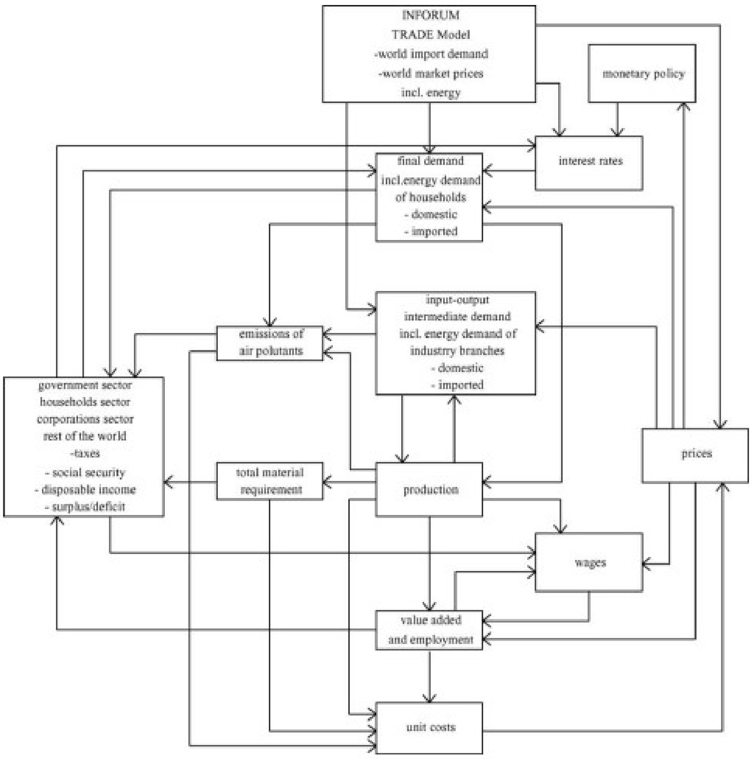
Model name	**NIEIR Multi-purpose model**
Name of the developer	National Institute of Economics and Industry Research
Organisation details	Founded in 1984 as a private economic research and consulting group. The Institute is not supported by separate corporate sponsorship or government grants. The Institute is independent of all party-political interests. The Energy Division undertakes a range of services including Energy modelling and forecasting, Analysis of public policy and government programs, Forensic data analysis, Energy markets and technology research, Critical reviews and Demand Forecasting. NIEIR uses its data sets and modelling systems to help clients analyse and update their policy. Econometric forecasts use mathematical techniques which rely on projecting past data trends, adjusted for estimates of future economic growth, incomes, energy prices, household formation and business structural trends.
Country of origin	Australia
Geographical coverage	Australia
Basic description	NIEIR Multipurpose model is an energy modelling system comprised of macroeconomic and industry activity models for the whole country and Australia's states; an energy forecasting model (EFM); an energy technology model (ETM); an energy environmental impact model (ENVI); an energy production and pricing model.
Type of users	Private economic research, consulting, and training. Its clients also include organisations responsible for network/generation planning and energy markets management.
Main area of application	The model is mainly used for: analysing impact of removal of cross-subsidies in electricity prices; forecasting of electricity demand and load growth; projecting of greenhouse gas emissions; evaluating alternative power station options; assessing the impact of increased penetration of energy-efficient technologies and renewable energies on energy demand and supply and greenhouse gas emissions.
Other	It is updated on an annual basis (with quarterly breakdown for some characteristics). The impact of global, national, and local economic changes can be seen at the local level.
Cost	Services sale

18 PACE

Model name	**Policy Analysis based on Computable Equilibrium (PACE)**
Name of the developer	ZEW GmbH
Organisation details	Economic policy consulting.
Country of origin	Germany
Geographical coverage	12 World regions
Basic description	PACE is a flexible system of general equilibrium models, integrating the economy, energy, and environment dimensions. The model has a standard multi-sector, multi-region core made up of global trade and energy use, which was designated to assess major policy initiatives in a world that is increasingly integrated through trade. Its main strength is its ability to assess the long-term economic and social impacts of environmental policy, particularly policy relating to shifts in taxation or subsidies and energy efficiency. PACE makes exogenous assumptions about energy specific technological progress by decreasing the energy intensity of production and consumption as time progresses.
Main area of application	The model is mainly used for economic analysis of energy and environmental policy initiatives; problem-specific investigation of trade, tax, and labour market policies without a focus on energy or environmental markets.
Cost	n.a.

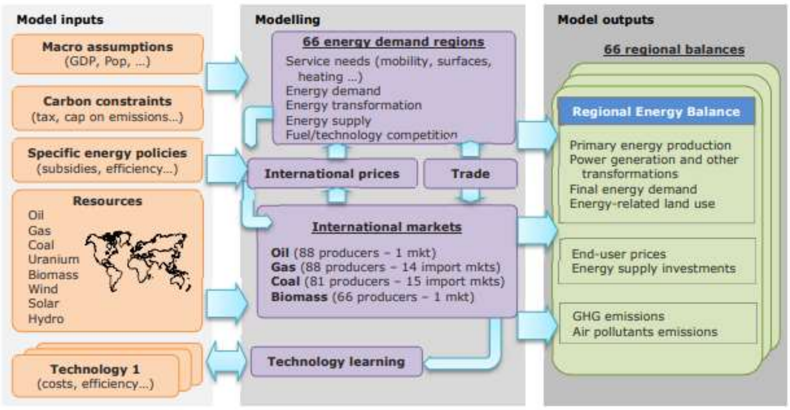
19 PANTA-RHEI

Model name	PANTA-RHEI
Name of the developer	Gesellschaft für Wirtschaftliche Strukturforschung mbH (Institute of Economic Structures Research, GWS)
Organisation details	It is a private, independent economic research and business and policy consultancy organisation.
Country of origin	Germany
Geographical coverage	Germany
Basic description	PANTA RHEI provides a detailed treatment of Germany's economy, linked to energy use and atmospheric emissions. The model is suitable for assessing changes in taxation policy and sectoral efficiency and has a detailed sectoral disaggregation. The foundations of the model lie in identifying predominantly demand-related factors (e.g. changes in purchasing power, economic growth, structural changes in specific sectors, demographics, including emigration and immigration) and price factors and linking them to expected macroeconomic and regional developments.
Main area of application	The model is mainly used for analysis of long-term changes in energy demand and supply and in an economy; estimating the impact of different climate policy instruments and forecasting energy emissions.
Other	Supported and updated
Cost	n.a.
Model Overview	



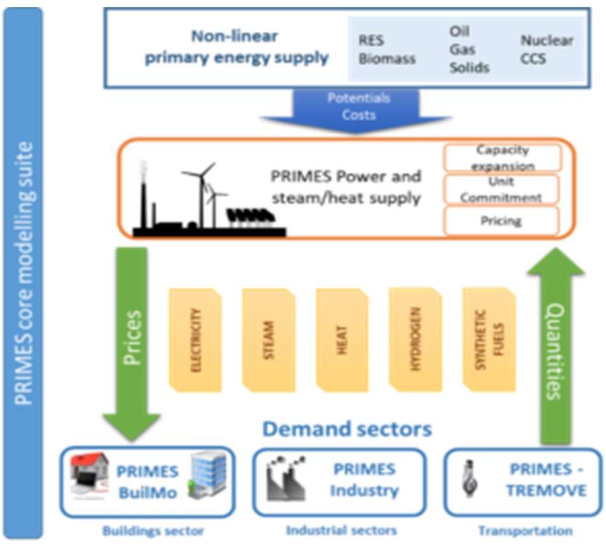
20 POLES-JRC

Model name	**Prospective Outlook on Long-term Energy Systems (POLES)**
Name of the developer	European Commission, DG Joint Research Centre, EDDEN Lab, University Grenoble Alpes, France, Enerdata
Organisation details	Energy systems analysis and economics, macroeconomics, and environmental economics.
Country of origin	France
Geographical coverage	World. The model is designed by connecting international, regional, and national submodels. The world energy consumption is decomposed into 66 geographical entities: the EU-28, 26 large economies (including detailed OECD countries, G20 and emerging Asian countries) and 12 country aggregates. International bunkers (air and maritime) are also considered. The geographical decompositions for oil, gas and coal production are different, to represent resource-rich countries in greater detail, with more than 80 individual producers.
Basic description	It is a world energy-economy partial equilibrium simulation model of the energy sector, with complete modelling from upstream production through to final user demand. The POLES model uses a dynamic partial equilibrium framework, specifically designed for the energy sector but also including other GHG emitting activities (e.g. the six GHGs of the "Kyoto basket"). The simulation process uses dynamic year-by-year recursive modelling, with endogenous international energy prices and lagged adjustments of supply and demand by world region, which allows for describing full development pathways to 2050.
Type of users	It is ideally suited to assessing the impacts of different pricing regimes, for example through taxation, but also of the development and diffusion of technology. The POLES model is useful for analysing the adoption and diffusion of new technologies, including low-carbon options, as well as looking at inter-technology substitution across time.
Main area of application	The model is mainly used for: running world energy scenarios (energy demand, supply, trade, prices) by world region; inter-technology substitution over time; simulation of CO_2 emission constraints and emissions trading; and analysing the impact of technological change on emissions.
Other	Supported and updated regularly. Latest version in 2017.
Cost	n.a.
Model overview	



21 PRIMES

Model name	**Price-Induced Market Equilibrium System (PRIMES)**
Name of **the** developer	E3Modelling (Energy-Economy-Environment Modelling Laboratory), National Technical University of Athens
Organisation details	Team of consultants, analysts and modellers specialised in providing consulting services based on advanced empirical modelling of the energy-economy-environment nexus. They support policy analysis and development of strategies and outlooks; develop and maintain large-scale energy, economy, and transport models, do Market analysis and system operation of the electricity and gas sectors, maintain large-scale energy and economic databases, develop new modelling tools, delivery to clients and capacity building and do research projects.
Country of origin	Greece
Geographical coverage	38 European countries (27 European Member States + UK + Energy Community countries)
Basic description	The PRIMES includes a combination of behavioural modelling following a micro-economic foundation with engineering and system aspects, covering all sectors and markets at a high level of detail. PRIMES focuses on prices as a means of balancing demand and supply simultaneously in several markets for energy and emissions. The model determines market equilibrium volumes by finding the prices of each energy form such that the quantity producers find best to supply matches the quantity consumers wish to use. The model handles dynamics under different anticipation assumptions and projects over a long-term horizon keeping track of technology vintages in all sectors. PRIMES model design is suitable for medium- and long-term energy system projections and system restructuring up to 2070, in both demand and supply sides. It simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system. The model provides projections of detailed energy balances, both for demand and supply, CO_2 emissions, investment in demand and supply, energy technology penetration, prices, and costs. The model produces projections over the period from 2015 to 2050 in 5-years intervals. The PRIMES model simulates a multi-market equilibrium solution for energy supply and demand and for ETS and other potential markets by explicitly calculating prices which balance demand and supply. PRIMES simulates demand and supply behaviour by agent (sector) under different assumptions regarding economic development, emission and other policy constraints, technology change and other drivers.
Type of users	The EC, Governments, companies, and other institutions including EURELECTRIC
Main area of application	PRIMES provides detailed projections of energy demand, supply, prices, and investment to the future, covering the entire energy system including emissions for each individual European country and for Europe-wide trade of energy commodities. The PRIMES model has served to quantify energy outlook scenarios, impact assessment studies. The model is mainly used for analysis of standard energy policy issues: security of supply, strategy, costs etc; analysis of environmental issues; looking at the impact of technology standards, new technologies and renewable resources; looking at energy efficiency, alternative fuels, trade, and EU energy provision; analysis of policy issues regarding electricity generation, gas distribution and refineries.
Other	Regularly extended and updated. Latest versions in 2018 and in 2021.
Cost	Services sale
Model overview	



The full suite comprises the following models: PRIMES-TREMOVE transport model (including synthetic fuels and hydrogen), PRIMES BuiMo residential and services model, PRIMES-Industry model, PRIMES Biomass supply model, PRIMES Electricity and Heat/Steam supply and market model, PRIMES Gas Supply and Market model: a stand-alone model representing in detail the gas infrastructure in the Eurasian and Middle-East area and the internal European market of gas within an oligopoly model embedding engineering gas flow modelling, PRIMES new Fuels and storage model covering Hydrogen, Synthetic fuels, Power-to-X, CO_2 capture from the air and biogenic, CCS/CCU and process-emissions modelling to enhance and perform sectoral integration aiming at simulating a zero-CO_2 system, PRIMES IEM model (for the internal energy market), and the CompactPRIMES model.

22 PROMETHEUS

Model name	PROMETHEUS
Name of the developer	E3Modelling, National Technical University of Athens
Organisation details	Team of consultants, analysts and modellers specialised in providing consulting services based on advanced empirical modelling of the energy-economy-environment nexus. They support policy analysis and development of strategies and outlooks; develop and maintain large-scale energy, economy, and transport models, do Market analysis and system operation of the electricity and gas sectors, maintain large-scale energy and economic databases, develop new modelling tools, delivery to clients and capacity building and do research projects.
Country of origin	Greece
Geographical coverage	World model that identifies ten countries/regions.
Basic description	It is a comprehensive world energy model that integrates stochastic relations, following explicit probability distributions, including covariance. Prometheus models the world energy system divided into 10 regions and produces yearly projections up to 2050. The model includes a set of long time series (IEA data mostly) on which econometric estimations are carried out. The model produces projections of energy demand by sector (industry, domestic, transport), power generation (representing about 25 technologies), Renewable Energy Sources, and hydrogen supply and use. Prometheus puts emphasis on oil and gas resources, while coal is assumed to have rather abundant supplies relative to production prospects in the projection time horizon. The model incorporates uncertainty surrounding the amount of oil and gas resources that are yet to be discovered. The model includes CO2 emissions and can simulate various emission reduction pathways at regional or global level. The PROMETHEUS model is organised in sub-models (modules), each one representing the behaviour of a representative agent, a demander and/or a supplier of energy.
Main area of application	The model produces projections of fossil fuel prices, which depend on demand, supply, technology and resources. As all outputs are probabilistic, fossil fuel price projections take the form of probability distributions. PROMETHEUS is designed to provide medium- and long-term energy system projections and system restructuring up to 2050, both in the demand and the supply sides. The model provides annual projections up to 2050 (model extension to 2100 is ongoing) for detailed energy balances, energy demand and supply by sector and product, power generation by fuel and technology, investment in power plants, prices and costs, carbon emissions and performance against goals of energy and climate policy.
Other	Supported and updated
Cost	Services sale

23 SAFIRE

Model name	Strategic Assessment Framework for the Implementation of Rational Energy (SAFIRE)
Name of the developer	Energy for Sustainable Development Ltd (ESD)
Organisation details	Identify and implement solutions that help businesses address their climate change risks and opportunities.
Country of origin	United Kingdom
Geographical coverage	34 European countries (25 EU Member States and 9 other countries across Europe), and 8 other major countries worldwide (Brazil, Canada, China, India, Indonesia, Japan, Mexico, USA). Local municipalities, government and regions in Austria, Bulgaria, Denmark, Germany, Ireland, Lithuania, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, United Kingdom.
Basic description	SAFIRE is an engineering-economic bottom-up supply and demand model for the assessment of the main impacts of (renewable and new non-renewable) energy technologies on a national, regional, or local level. SAFIRE can be applied to assess the impact of energy technology and associated policies on several economic indicators, such as market penetration, pollutant emissions, capital expenditure, external costs, net employment creation.
Type of users	Researchers
Main area of application	The SAFIRE model canused for assessing means of increasing the uptake of 'greener' technologies, as well as some of the economic impacts of their use. SAFIRE can be applied to assess the net impact of energy technology and associated policies on several economic aspects: market penetration, net employment creation, pollutant emissions (CO_2, SO_2, NO_X, CO, VOCs, particulates), value added, import dependency, capital expenditure, external costs and government expenditure (national version only).
Other	Seems not updated
Cost	n.a.

24 SAGE

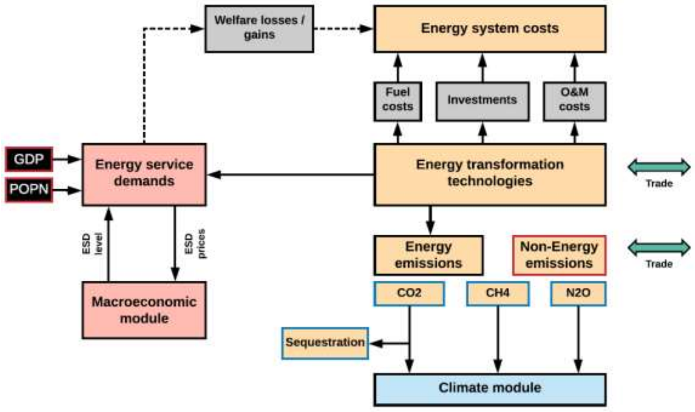
Model name	System for the Analysis of Global Energy Markets (SAGE)
Name of the developer	US Department of Energy
Organisation details	Ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.
Country of origin	USA
Basic description	Tool developed and used by the DOE for analysing global energy situations. It is an integrated regional energy model that captures the technological richness of the energy sector to determine the energy consumption
Main area of application	Analysing global energy situations
Other	Updated
Cost	n.a.

25 SGM

Model name	Second Generation Model (SGM)
Name of the developer	Pacific Northwest National Laboratory/Joint Global Change Research Institute at the University of Maryland
Organisation details	A Research Institute at the University. One of the United States Department of Energy national laboratories, managed by the Department of Energy's (DOE) Office of Science.
Country of origin	USA
Geographical coverage	14 regions (United States, Canada, Mexico, Western Europe, Eastern Europe, former Soviet Union, China, India, Brazil, Japan, South Korea, Australia/New Zealand, Middle East, Rest of World)
Basic description	SGM is a computable general equilibrium model with emphasis on demographics, resources, agriculture, energy supply and transformation, energy intense industries, household consumption, and government expenditure. The SGM approach starts with input-output tables and IEA energy balances. All energy quantities are preserved, but some adjustment to the input-output values is still required. Regional models may be run independently or as a system for international trade in emissions permits.
Main area of application	The model is used to project energy consumption and greenhouse gas emissions, but its main relevance is its use in evaluating the economic impacts of climate change policies and the use of technologies for emissions mitigation. The SGM model is relevant in assessing the socio-economic impacts of climate change mitigation policies, with a specific focus on resources, agriculture, and energy-intensive industries.
Other	Seems not updated
Cost	n.a.

26 TIAM-UCL

Model name	TIAM-UCL
Name of the developer	University College London (UCL)
Organisation details	Public research university located in London, United Kingdom.
Country of origin	UK
Geographical coverage	16 regions, global model
Basic description	It is a global optimisation model that investigates decarbonisation of the global E3 (energy-environment-economy) system. It also allows us to investigate international climate change policies, such as Kyoto, and international issues such as aviation and shipping, which are not possible with a UK model. Each region in the multi-region TIAM-UCL model has its own energy system and each region can trade fossil fuel and biomass resources with other regions. Energy flows and the demands for energy across the world are callibrating using measured data from the 2005 (the base year). The data is from the IEA Extended Energy Balances of OECD and non-OECD countries. It is built in the TIMES framework, a modelling framework that uses an optimisation approach to explore cost-optimal systems.
Main area of application	Examine energy and climate policies (carbon tax, cap-and-trade) for a single region, a group of regions or globally. Assess regional marginal greenhouse gas abatement costs, taking account of cap-and-trade policy and emission trading schemes. Generate regional specific resource prices for fossil fuels such as gas oil and coal. Understand how global endogenous technology learning could change the costs and benefits of key nascent technologies, such as fuel cells and batteries, in the future.
Cost	n.a.
Model overview	

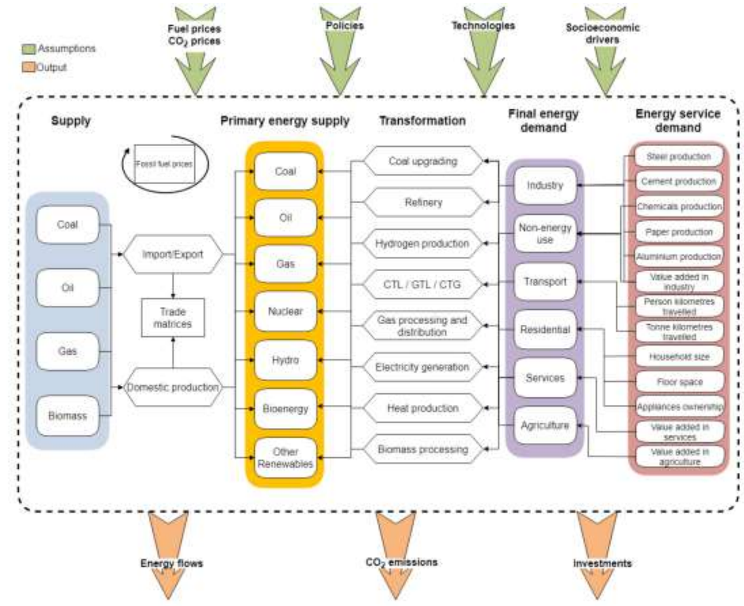


27 VLEEM

Model name	Very long term energy environment model (VLEEM)
Name of the developer	Cooperation project coordinated by Enerdata
Organisation details	Enerdata is an independent research and consulting firm specialising in the analysis and modelling of the global energy markets and its drivers.
Country of origin	France
Geographical coverage	World, split into 10 regions
Basic description	VLEEM has been designed under a EU research project to support R&D policy decisions in the field of energy, in relation with sustainability objectives in the very long term, making it a suitable tool for analysis of the response measures. VLEEM can be used for very-long-term analysis of possible technological solutions to climate change, with the main policy inputs being changes to energy-focused R&D.
Type of users	Industrial companies: oil and gas, power, equipment manufacturers, large industries, Policymakers: international organisations, ministries, National / international energy agencies, Investment banks and development agencies, Investors and private banks and Research centres, universities.
Other	Seems not updated
Cost	n.a.

28 WEM

Model name	World Energy Model (WEM)
Name of the developer	International Energy Agency (IEA)
Organisation details	The IEA was created in 1974 to help coordinate a collective response to major disruptions in the supply of oil. While oil security remains a key aspect of our work, the IEA has evolved and expanded significantly since its foundation. The IEA recommends policies that enhance the reliability, affordability and sustainability of energy. It examines the full spectrum issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, demand-side management, among others.
Country of origin	France
Geographical coverage	World, split in 21 regions
Basic description	The WEM is a large-scale simulation model designed to replicate how energy markets function. The WEM is the principal tool used to generate detailed sector-by-sector and region-by-region projections for the WEO scenarios. The model consists of three main modules: final energy consumption (covering residential, services, agriculture, industry, transport, and non-energy use); energy transformation including power generation and heat, refinery and other transformation – such as Coal to Liquids or hydrogen production; and energy supply (oil, natural gas and coal). Outputs from the model include energy flows by fuel, investment needs and costs, CO_2 emissions and end-user prices. The WEM is a very data-intensive model covering the whole global energy system. Much of the data on energy supply, transformation, and demand, as well as energy prices is obtained from the IEA's own databases of energy and economic statistics and through collaboration with other institutions.
Type of users	IEA
Main area of application	The model is mainly used for: analysing global energy prospects; estimating the environmental impact of energy use; analysing the effects of policy actions and technological changes and estimating investment in the energy sector.
Other	Updated every year and developed over many years. Latest version 2021
Cost	Seems not for sale. Internal Use
Model Overview	



Note: CTL = coal-to-liquids, GTL = gas-to-liquids, CTG = coal-to-liquids.