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Systematic mapping of power system models

Expert survey

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Abstract

The power system is one of the main subsystems of larger energy systems. It is a complex system in itself, consisting of an ever-changing infrastructure used by a large number of actors of very different sizes. The boundaries of the power system are characterised by ever-evolving interfaces with equally complex subsystems such as gas transport and distribution, heating and cooling, and, increasingly, transport. The situation is further complicated by the fact that electricity is only a carrier, able to fulfil demand for such things as lighting, heat or mobility.

One specific and fundamental feature of the electricity system is that demand and generation must match at any time, while satisfying technical and economic constraints. In most of the world's power systems, only relatively small quantities of electricity can be stored, and only for limited periods of time. A detailed analysis of supply and demand is thus needed for short time intervals.

Mathematical models facilitate power system planning, operation, transmission and distribution, demonstrating problems that need to be solved over different timescales and horizons. The use of modelling to understand these processes is not only vital for the system's direct actors, i.e. the companies involved in the generation, trade, transmission, distribution and use of electricity, but also for policy-makers and regulators. Power system models can provide evidence to support policy-making at European Union, Member State and Regional level.

As a consequence of the growth in computing power, mathematical models for power systems have become more accessible. The number of models available worldwide, and the degree of detail they provide, is growing fast. A proper mapping of power system models is therefore essential in order to:

- **provide an overview of power system models and their applications available in, or used by, European organisations;**
- **analyse their modelling features;**
- **identify modelling gaps.**

Few reviews have been conducted to date of the power system modelling landscape. The mission of the *Knowledge for the Energy Union* Unit of the Joint Research Centre (JRC) is to support policies related to the Energy Union by anticipating, mapping, collating, analysing, quality checking and communicating all relevant data/knowledge, including knowledge gaps, in a systematic and digestible way. This report therefore constitutes:

- From the **energy modelling perspective**, a useful mapping exercise that could help promote knowledge-sharing and thus increase efficiency and transparency in the modelling community. It could trigger new, unexplored avenues of research. It also represents an ideal starting point for systematic review activities in the context of the power system.
- From the **knowledge management perspective**, a useful blueprint to be adopted for similar mapping exercises in other thematic areas.

Finally, this report is aligned with the objectives of the **European Commission's Competence Centre on Modelling**, ([1]) launched on 26 October 2017 and hosted by the JRC, which aims to promote a responsible, coherent and transparent use of modelling to support the evidence base for European Union policies.

In order to meet the objectives of this report, an online survey was used to collect detailed and relevant information about power system models. The participants' answers were processed to categorise and describe the modelling tools identified. The survey, conducted by the *Knowledge for the Energy Union* Unit of the JRC, comprised a set of

([1]) https://ec.europa.eu/jrc/en/news/launch-commission-competence-centre-modelling questions for each model to ascertain its basic information, its users, software characteristics, modelling properties, mathematical description, policy-making applications, selected references, and more.

The survey campaign was organised in two rounds between April and July 2017. 228 surveys were sent to power system experts and organisations, and 82 questionnaires were completed. The answers were processed to map the knowledge objectively. ([2])

The main results of the survey can be summarised as follows:

- **Software-related features**: about two thirds of the models require third-party software such as commercial optimisation solvers or off-the-shelf software. Only 14% of the models are open source, while 11% are free to download.
- **Modelling-related features**: models are mostly defined as optimisation problems (78%) rather than simulation (33%) or equilibrium problems (13%). 71% of the models solve a deterministic problem while 41% solve probabilistic or stochastic problems.
- **Modelled power system problems**: the economic dispatch problem is the most commonly modelled problem with a share of approximately 70%, followed by generation expansion planning, unit commitment, and transmission expansion planning, with around 40–43% each. Most of the models (57%) have non-public input data while 31% of models use open input data.
- **Modelled technologies**: hydro, wind, thermal, storage and nuclear technologies are widely taken into account, featuring in around 83–94% of models. However, HVDC, wave tidal, PSTs, and FACTS ([3]) are not often found unless the analysis is specifically performed for those technologies.
- **Applicability in the context of European energy policy**: more than half of the mapped models (56%) were used to answer a specific policy question. Of the five Energy Union strategic dimensions, integration of the European Union internal energy market was addressed the most often (27%), followed by climate action (23%), research, innovation and competitiveness (21%), and energy efficiency (15%).

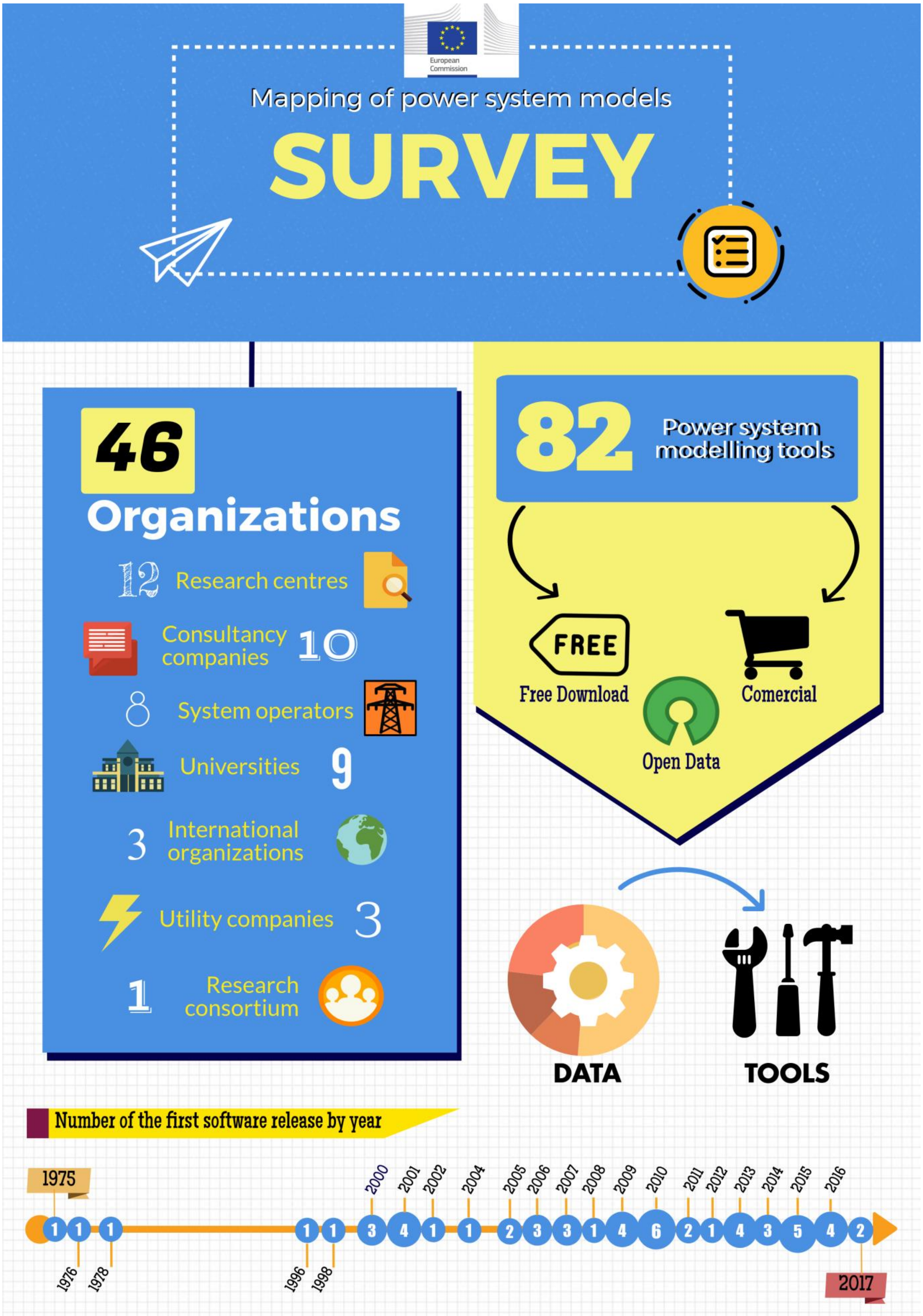
This report includes JRC recommendations based on the results of the survey, on future research avenues for power system modelling and its applicability within the Energy Union strategic dimensions. More attention should be paid, for example, to model uncertainty features, and collaboration among researchers and practitioners should be promoted to intensify research into specific power system problems such as AC ([4]) optimal power flow. The report includes factsheets for each model analysed, summarising relevant characteristics based on the participants' answers.

While this report represents a scientific result *per se*, one of the expected (and welcomed) outcomes of this mapping exercise is to **raise awareness of power system modelling activities among European policy makers**.

([2]) Knowledge of models included in this report is based exclusively on information provided by survey participants. The suitability of any given modelling tool to answer specific research or policy questions should not be based on the contents of this report alone, although it offers a useful starting point.

([3]) HVDC, PST and FACTS stand for High Voltage Direct Current, Phase-Shifting Transformer, and Flexible AC Transmission Systems, respectively.

([4]) AC stands for Alternate Current.



Source: JRC, 2017.

1 Introduction

1.1 Motivation and purpose

Plenty of tools (5) for modelling real-life problems related to power planning, operation, distribution, and transmission activities are available worldwide. Each tool models a complex mathematical problem and provides a unique view of a particular situation within this extensive sector, allowing for diverse techno-economic analyses at different time scales and horizons. Due to the growing number of power system models, a mapping of knowledge among the available models is needed in order to answer to the following research questions:

(a) What models exist.

(b) Which organisations (6) are using such models.

(c) What problem(s) they can model.

(d) Why/how they are useful to provide evidence for policy-making support.

The mission of the *Knowledge for the Energy Union* Unit of the Joint Research Centre (JRC) is to support policies related to the Energy Union by anticipating, mapping, collating, analysing, quality checking and communicating all relevant data/knowledge, including knowledge gaps in a systematic and digestible way. Within this framework, this report constitutes a mapping exercise that could help promoting knowledge sharing and thus increase efficiency and transparency in the modelling community. Moreover, this work can also trigger new avenues of research that have not been explored yet.

In order to achieve those goals, detailed and relevant information about power system models has been collected through a survey and the participants' answers have been processed to categorise and describe the identified modelling tools. Therefore, the specific contributions of this report are twofold:

- A comprehensive mapping of power system models available in or used by European organisations and their applications. This mapping is related to the aforementioned research questions (a) and (b).
- An analysis of modelling features as well as a preliminary identification of modelling gaps. This analysis is related to the aforementioned research question (c).

Mapping power system models could be useful for policy-making support at the European and Member State levels, which is itemised above as research question (d). However, this report does not intend to answer such question. Since the power system models' knowledge described and analysed in this report is exclusively based on the answers of a survey distributed to relevant power-system-related organisations and experts, the results themselves cannot be used as decision-making criteria to link models (or family of models) with specific policy questions. Indeed, the report includes relevant information to perform such linkage, but the authors recognize that assessing the suitability of a modelling tool for policy making support is a complex decision itself which should rely on more information (which might be collected through a systematic review) apart from the one reported in this manuscript. Therefore, further efforts are needed on answering research question (d).

(5) The terms *tool* and *model* are used indistinguishably throughout this report.
(6) The term organisation encompasses universities, agencies, institutions, companies, research centres, or individuals throughout this report.

1.2 Approach

The goal of the proposed survey was to collect detailed and relevant information about power system models available in or used by European organisations. The *Knowledge for the Energy Union* Unit of the JRC has conducted this survey in the form of an online questionnaire between 15 May and 20 July 2017. A broad range of power system experts from different organisations have been surveyed. The DIGIT-EUSURVEY (7) platform – the European Commission's official survey management tool – has been used to gather their inputs (8).

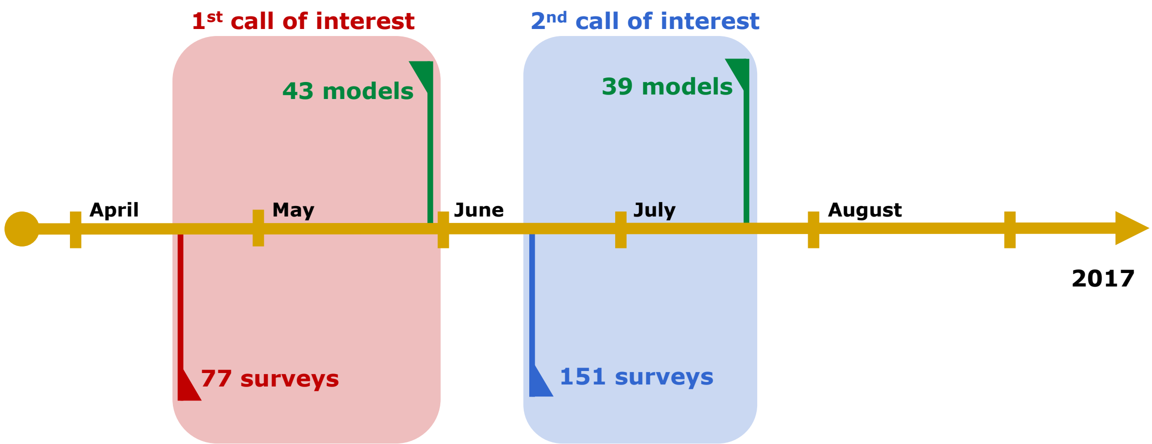
The design of the questionnaire has been inspired by those in literature (see Section 2 and references [1], [2]). For the sake of completeness, the template of this survey is provided in Annex 1. Most of it is organised in multiple choice questions and it is divided in 8 sections:

- Section A: Basic information – Organisation.
- Section B: Basic information – Tool.
- Section C: Users and uses.
- Section D: Software characteristics.
- Section E: Modelling properties and mathematical description.
- Section F: Applications.
- Section G: References.
- Section H: Further information.

The survey campaign has been organised in two rounds, as illustrated in Figure 1:

- On 26 April 2017, a first call of interest to fill out the survey was sent to a list of power system experts/organisations. The deadline to receive the replies was set in 31 May 2017. 77 questionnaires were sent during the first call of interest and 43 surveys were filled out by the deadline.

Figure 1. Timeline of the survey campaign.



Source: JRC, 2017.

(7) The link for the DIGIT-EUSURVEY platform is https://ec.europa.eu/eusurvey/home/about
(8) Regulation (EC) 45/2001 of the European Parliament and of the Council of 18 December 2000 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data, is applicable in this questionnaire.

- On 16 June 2017, a second call of interest to fill out the survey was sent to power system experts/organisations. 151 questionnaires were sent during the second call of interest. The list included the power system experts/organisations which had not replied during the first round of questionnaires yet (49) as well as new experts and organisations (102), also suggested by the answers obtained from the first round of questionnaires (see Sections B and H in Annex 1). The deadline to receive the replies was set on 16 July 2017. 39 surveys had been filled out by the deadline.

Therefore, the total number of models considered in this report amounts to 82, which were filled out by experts working on research centres, consultancy companies, system operators, universities, international organisations and utility companies.

1.3 Report layout

The rest of the report is outlined next. Section 2 presents a meta-review of reviews of models. Section 3 thoroughly analyses the participants' answers and maps the knowledge provided by each participant. The modelling tools are fairly and pragmatically compared based solely on the responses from the respondents. Section 4 concludes the report summarising the main findings as well as highlighting JRC recommendations on future research avenues for power system modelling.

Four annexes are also included at the end of the main report:

- Annex 1 includes the list of questions of the survey template.
- Annex 2 provides a complete list of modelling tools (energy and power) from the reviewed references.
- Annex 3 contains factsheets about the power system models participating in the questionnaire.
- Annex 4 provides figures comparing different characteristics of the power system models participating in the questionnaire.

2 Literature review

A suite of reviews concerning modelling tools for electricity systems [1], [3]–[6], energy systems [2], [7]–[13], transport [14], and water-energy nexus [15] can be found in the literature. These reviews can be considered as mapping exercises of modelling tools. In addition, the OpenEnergy platform [16] is working towards improving the transparency of energy modelling tools and analytics in order to promote reproducibility in energy system research. This is a complex and effort-consuming task because, similar to the work presented in this report, the platform intends to collect basic information and information about openness, software, references, coverage, mathematical properties and model integration ([9]).

Energy system modelling tools have been widely analysed, mainly by Connolly *et al.* [2] reviewing 37 tools and by Mahmud and Town [14], with 44 tools. However, other sectors, such as the electricity one, also need a comprehensive analysis of all available tools in order to be able to choose the suitable one for a specific analysis or for answering a specific policy-driven question.

Table 1 lists the main topic for each of the previous papers. For a quick comparison, Figure 2 shows the number of reviewed modelling tools for each sector (energy, electricity, transport, water-energy nexus, and wind power).

Bhattacharyya and Timilsina [7] performed a comparative analysis of 10 energy system models looking at their capability to reflect specific features of developing countries. Their report also gave a brief overview of two electricity system tools such as `WASP` (or the current version `WASP-IV`) and `EGEAS`, developed around the 80s by the International Atomic Energy Agency (IAEA) and by the Electric Power Research Institute, respectively. Their conclusion is that most of the modelling tools lack enough data (and thus may lead to inadequate policy recommendations) and they do not model specific features to better characterize the system.

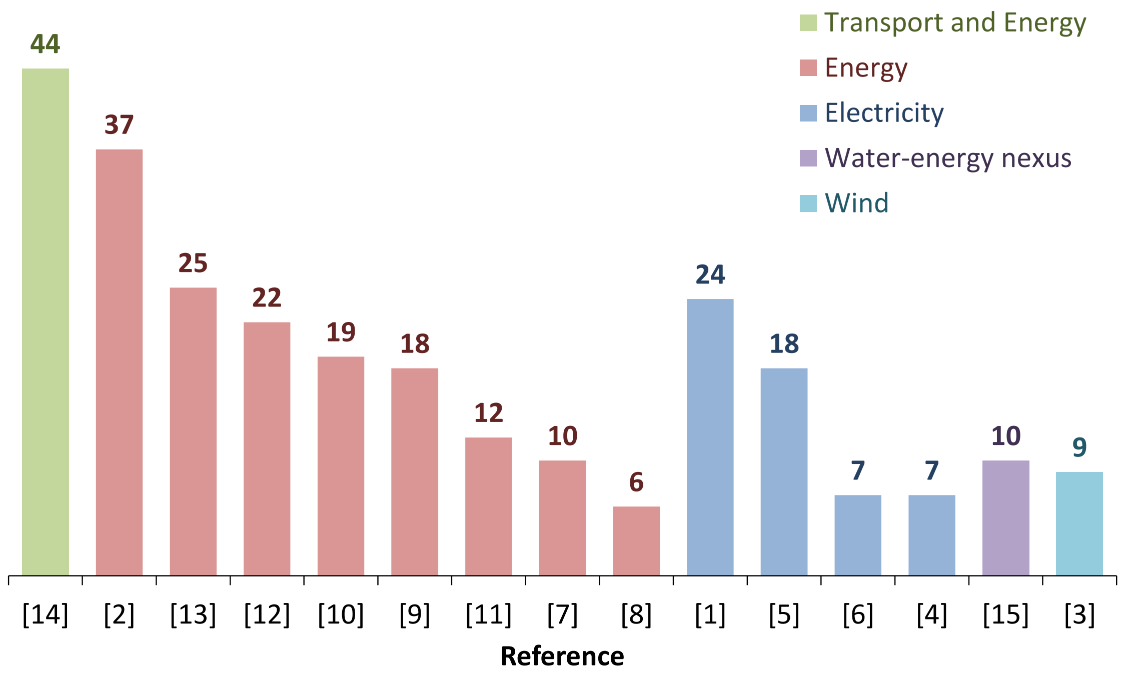
Table 1. Topic for the selected reviews.

Reference	Topic
[1]	EERA Smart Grids members' tools
[2]	Integration of renewable energy
[3]	Short-term wind power prediction
[4]	Review of electricity system models
[5]	Power system software packages
[6]	Policy analysis purpose and capabilities
[7]	Pure review of energy system models
[8]	Planning and analysis of Integrated Community Energy Systems
[9]	China's future energy system
[10]	Hybrid renewable energy systems
[11]	Sustainable urban development
[12]	Review of energy system models in UK
[13]	Open energy system models
[14]	Electric vehicle and integration in power distribution grid
[15]	Policy-driven applications

Source: JRC, 2017.

([9]) An example of how this information is displayed can be found in https://oep.iks.cs.ovgu.de/factsheets/models/40/.

Figure 2. Number of reviewed models per type.



Source: JRC, 2017.

Connolly *et al.* [2] compared 37 modelling tools related to energy systems. The aim was to understand which tool is suitable to analyse the integration of renewable energy. The comparison was based on their availability, type, details of the corresponding analyses that can be performed, and the energy sectors considered among electricity, heat, and transport. The study was conducted through a survey for the developers of each tool.

Mendes *et al.* [8] surveyed and reviewed 6 bottom-up ([10]) energy tools putting an emphasis on the incorporation of the environmental, economic, and social aspects of sustainability.

Mischke and Karlsson [9] focused their analysis on the review of 18 energy modelling tools developed in Chinese institutions (universities and other entities). The study emphasised the usefulness of the tools to evaluate research questions and policy recommendations of high relevance for the future Chinese energy system.

Similar to [2], Sinha and Chandel [10] reviewed 19 tools for hybrid renewable energy systems. The authors highlighted the current status, capabilities, strengths, and limitations of each tool. Also, a review of case studies carried out by these tools was also performed.

In [11], van Beuzekom *et al.* analysed a group of models for the purpose of choosing the right tool for sustainable urban development.

Hall and Buckley [12] focused on the review of energy system models in the United Kingdom. They first analysed a qualitative indicator based on the mean number of citations as well as the number of appearance of about 100 papers since 2008. Later, the authors also raised the need for a unified categorisation and classified 22 energy system models currently used in UK. Three different classifications are proposed:

- Options of the models including purpose and structure of the model, geographical coverage, sectorial coverage, time horizon and time step.

([10]) According to [2], a bottom-up tool '*identifies and analyses specific energy technologies, finding investment options and alternatives*'.

- Technological description.
- Mathematical description.

A description and comparison of open source tools is provided in the Open Energy Model Initiative (Openmod) [13]. As of August 2017, 25 tools comprise the range of models which are to some degree open or available. In line with information openness, the OpenEnergy Platform [16] has collected 35 energy modelling tools so far, which are organised in factsheets.

Although the review of energy systems models has been extensively addressed by several authors, little attention has been paid to specifically review models used in power systems or related to the electricity sector [1], [3]–[6]. Needless to say, some of the above references include also power system tools that have applications in energy systems as well.

Giebel *et al.* [3] paid attention to the short-term prediction tools for wind power forecasting in the electricity sector.

Foley *et al.* [4] provided the description of several tools used in the USA and Europe in the context of the electricity sector. Also the authors pointed out the need for more information on available tools in the electricity sector so that the electricity analysts can take better decisions on the choice of the suitable tool for specific assessments.

Bindner and Marinelli [1] comprehensively compared modelling tools suitable for smart grids. Similar to [2], the authors gathered information through a survey to the developers of the tools within the European Energy Research Alliance (EERA) [17] smart grid members.

In [5], Hay and Ferguson listed some software packages for specific power system modelling capabilities such as steady state power system analysis, dynamic power system analysis, real time simulation, economic, operational, and planning models, among others.

Koppelaar *et al.* [6] aimed to analyse the ability of modelling tools to support policy making; however, the degree of comparison among the tools is not as high as, for instance, in [2] or [5].

The water-energy nexus is gaining more and more attention for practitioners and academics. Recently, Khan *et al.* [15] collected several modelling tools related to this issue to analyse their policy-driven applications. These tools are not only related to energy systems but also to the water sector or even to the food sector.

For the sake of completeness, the reader is referred to Annex 2 for the list of models reviewed in the papers mentioned above.

3 Mapping of power system modelling tools

The total number of completed questionnaires is 82, as stated in Section 1. This section is then devoted to mapping the modelling tools with their characteristics while analysing aggregated results based on the responses from the participants. For the sake of clarity, the reader is referred to the list of abbreviations at the end of the main report since the next subsections include acronyms for software licenses or modelled problems, among others.

As already mentioned in Section 1, given the adopted investigation workflow, the authors would like to emphasize that the suitability of a modelling tool to answer specific research or policy questions cannot be merely based on the rankings provided in the following subsections.

3.1 Models and organisations

Table 2 lists the name of the models and organisations participating in the survey as well as the responsible organisation(s) for the power system modelling tool. Several remarks should be made about this table:

- Models precluded in the analysed literature [1]–[15] are highlighted in red. 74% of models (61 out of 82) analysed through the questionnaire has not been considered in the reviews provided in the literature.
- Some organisations asked not to be explicitly mentioned in the results (see Annex 1, question H.5). Therefore, their names have been anonymised while keeping the information about the type of organisation (*e.g.* "Utility company 1", "Research centre 2", "System operator 3", etc.).
- More than one organisation could use the same models (*e.g.* `Balmorel`, `MESSAGE`, `Plexos`, `PSS/E` or `SDDP`) for their applications. However, throughout this report, identical models given by different organisations have been deemed different modelling tools since they may have been used for different applications or with different features.

Factsheets of the models can be found in Annex 3 following a compact format, as similarly done in the OpenEnergy Platform [16], *i.e.*, they provide several information about of the models as given by the participants in the survey such as software-related features (availability, first and last release, number of users, platform, third party software, I/O structure and I/O compatibility), model-related characteristics (horizon, time step, geographical coverage, analytical approach, underlying methodology, mathematical approach and form), and the European Union strategic dimensions in which the models are best suited for.

Table 2. Organisation related to each model.

(*Editor's note*: Models precluded in the analysed literature [1]–[15] are highlighted in red)

Model	Organisation	Responsible organisation of the power system modelling tool
1-node model [18]	Chalmers University of Technology	Chalmers University of Technology
AMaCha	RSE S.p.A.	RSE S.p.A.
AMIRIS [19]	German Aerospace Center, Department of Systems Analysis and Technology Assessment	German Aerospace Center, Department of Systems Analysis and Technology Assessment
ANTARES [20]	Réseau de transport d'électricité (RTE)	RTE
Artelys Crystal City	Artelys	Artelys
Artelys Crystal Super Grid [21]	Artelys	Artelys
Balmorel – SO2 [22]	System Operator 2	Open source model
Balmorel – RAM-lose [22]	RAM-lose edb	RAM-lose, Systems Analysis Group at Department of Management Engineering at the Technical University of Denmark, Ea Energy Analyses
BEM [23]	Paul Scherrer Institute (PSI)	PSI
BETSEE	Electricity Coordinating Center (EKC)	EKC
CAPE	Elering AS	Electrocon Inc.
CONTINENTAL MODEL	Electricité de France Research and Development (EDF R&D)	EDF R&D
CONVERGENCE	RTE	RTE
DIMENSION	ewi Energy Research and Scenarios (ewi ER&S)	ewi ER&S
Dispa-SET [24]	European Commission - DG JRC - Knowledge for the Energy Union	European Commission - DG JRC - Knowledge for the Energy Union
Dome [25]	School of Electrical and Electronic Engineering, University College Dublin	Federico Milano
eGo [26]	Reiner Lemoine Institut gGmbH	Reiner Lemoine Institut, Next Energy, ZNES
ELFO++ [27]	REF-E srl	REF-E srl
ELMOD [28]	Technische Universität Dresden (TU Dresden)	TU Dresden
ELTRAMOD [29]	TU Dresden	TU Dresden
EMMA [30]	Neon Neue Energieökonomik GmbH	Neon
EMPS	SINTEF Energy Research	SINTEF Energy Research
EnEkon	Lithuanian Energy Institute	Lithuanian Energy Institute
EnerPol [31]	Laboratory for Energy Conversion, ETH Zürich	Laboratory for Energy Conversion, ETH Zürich
ENTIGRIS	Fraunhofer-Institut für Solare Energiesysteme (Fraunhofer ISE)	Fraunhofer ISE
EPOD [32]	Chalmers University of Technology	Chalmers University of Technology
ESPAUT [33]	Ricerca sul Sistema Energetico (RSE)	RSE
ETP-TIMES [34]	Energy Technology Policy Division, IEA	Energy Technology Policy Division, IEA (TIMES methodology developed by IEA-ETSAP)
EUCAD [35]	Université Grenoble-Alpes, Grenoble Applied Economics Laboratory, Energy team (EDDEN)	GAEL, Univ. Grenoble Alpes
EUSTEM [36]	PSI	PSI
FLOP [37]	Institute for Research in Technology (IIT)	IIT
GE PSLF	GE Energy Consulting	GE Energy Consulting
GOESTO	EDF R&D OSIRIS	EDF R&D OSIRIS
GRARE [38]	CESI S.p.A	Property: Terna. Development: CESI S.p.A
Green islands	Université de Nantes, France	Laboratory of Economics and Management Loire-Atlantic (LEMNA)
iTesla Power System Tools [39]	RTE, Research and Development department	iPST consortium: AIA, Artelys, Imperial College, INESCTEC, KTH, Pepite, RSE, RTE, TechRain, Tractebel Engie
LEI – MESA [40]	Lithuanian Energy Institute	Lithuanian Energy Institute
LIMES [41]	Potsdam Institute for Climate Impact Research (PIK)	PIK
LUSYM [42]	Katholieke Universiteit Leuven (KU Leuven)	KU Leuven
MaCSIM	EKC	EKC
Merlin	EKC	EKC
MESSAGE – IAEA [43]	Planning and Economic Studies Section (PESS), International Atomic	IAEA

Model	Organisation	Responsible organisation of the power system modelling tool
	Energy Agency (IAEA)	
MESSAGE – LEI	Lithuanian Energy Institute	IAEA, IIASA
METIS [44]	Artelys.	Property: DG ENER. Development: Artelys.
MORGANE	EDF R&D	EDF R&D
NEMO [45]	Centre for Energy and Environmental Markets, University of New South Wales	Ben Elliston
NETPLAN [46]	PSR	PSR
Oemof [47]	Center for Sustainable Energy Systems (ZNES) Flensburg, Reiner Lemoine Institute (RLI) Berlin, Otto-von-Guericke-University of Magdeburg (OVGU)	ZNES Flensburg, RLI, OVGU
open_eGo	Research centre 2	Research centre 2
OPTGEN [48]	PSR	PSR
OWL [49]	IIT	IIT
Phoenix	Consultancy company 1	Consultancy company 1
Plexos – UCo2 [50]	Utility company 2	Internal model developed in Plexos
Plexos – CCo1 [50]	Consultancy company 1	Energy Exemplar
PLEXOS EU 2030 [51]	University College Cork (UCC)	UCC and Energy exemplar
Powel Optimal Multi Asset	Powel AS	Powel Smart Energy
PROMEDGRID [52]	CESI S.p.A	CESI S.p.A/TERNA
PSCAD	Elering AS	Manitoba Hydro International Ltd
PSS/E – SO3	System Operator 3	Siemens
PSS/E – SO5	System Operator 5	Siemens
PSS/E – SO1	System Operator 1	Siemens PTI
PSS/E – SO4	System Operator 4	Siemens
REMARK/REMARK+	Ricerca sul Sistema Energetico (RSE)	RSE
REMix [53]	DLR - German Aerospace Center, Institute of Engineering Thermodynamics, Department of Systems Analysis and Technology Assessment	DLR - German Aerospace Center, Institute of Engineering Thermodynamics, Department of Systems Analysis and Technology Assessment
RISK-BU	EDF R&D OSIRIS	EDF
ROM [54]	IIT	IIT
SciGRID [55]	NEXT ENERGY, EWE Research Centre for Energy Technology	NEXT ENERGY, EWE Research Centre for Energy Technology
SDDP – CCo1 [56]	Consultancy company 1	PSR
SDDP – PSR [56]	PSR	PSR
SHOP [57]	SINTEF Energy Research	SINTEF Energy Research
SICRE	CESI S.p.A	CESI S.p.A
sMTSIM	RSE S.p.A.	RSE S.p.A.
SPIRA	CESI S.p.A	CESI S.p.A
STARNET [58]	IIT	IIT
STEM	PSI	PSI
SynerGEE – UCo1	Utility company 1	Network Investments
TEPES [59]	IIT	IIT
TNA – EKC	EKC	Electricity Coordinating Center (EKC), SEDMS
TNA – PSS/E – ISOBH	Independent System Operator in Bosnia and Herzegovina	TNA: Electricity Coordinating Center (EKC) PSS/E: Siemens
Trimble	Sadales tīkls AS	Latvenergo AS
WASP [43]	PESS, IAEA	IAEA
WCM	EDF R&D OSIRIS	EDF R&D

Source: JRC, 2017.

3.2 Power system model characteristics

This section analyses the software-related (*e.g.* model availability, number of releases, etc.) and model-related (*e.g.* mathematical approach, underlying methodology, etc.) features of the participating models in subsections 3.2.1 and 3.2.2, respectively.

3.2.1 Software-related features

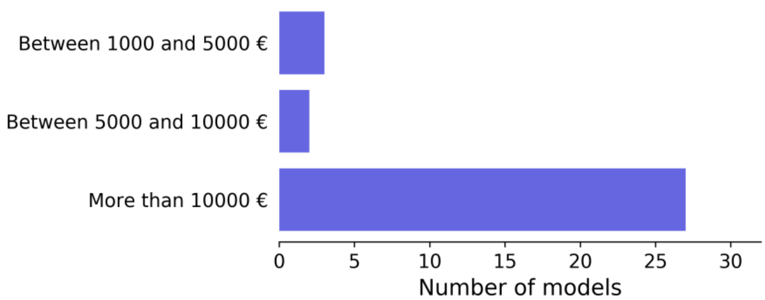
Regarding model availability, survey participants have been able to choose among *commercial*, *free to download*, *open source*, and *other*.

Half of the participants have indicated that their respective models are commercial and 76% of them have provided their cost range, as shown in Figure 3. It can be observed that the cost of 84.4% of the commercial models participating in the survey is greater than 10000 €. However, there are exceptions for some commercial models depending on the final user; for instance, some may have a discounted price policy for transmission system operators or academic research (*e.g.* `GRARE`).

Open source availability has been claimed by 14% of the participants (`1-nodel model`, `sMTSIM`, `EMMA`, `iTesla Power System Tools`, `Balmorel - RAM-lose`, `SciGRID`, `NEMO`, `Balmorel - SO2`, `Dispa-SET`, `eGo`, `oemof`, `open_eGo`), with different license types, *e.g.* GPL [60], AGPL [61], EUPL [62], Apache 2.0 [63], ISC [64], MPL [65], CC [66], etc. 11% of the models have been declared free to download (some of them upon request or whether there is interest in collaborating in a research project).

Some responses have claimed different types of availability for different components, *e.g*. `iTesla Power System Tools` is commercial for most computation modules, free to download for others, and open source for the framework.

Figure 3. Cost range of commercial models.



Source: JRC, 2017.

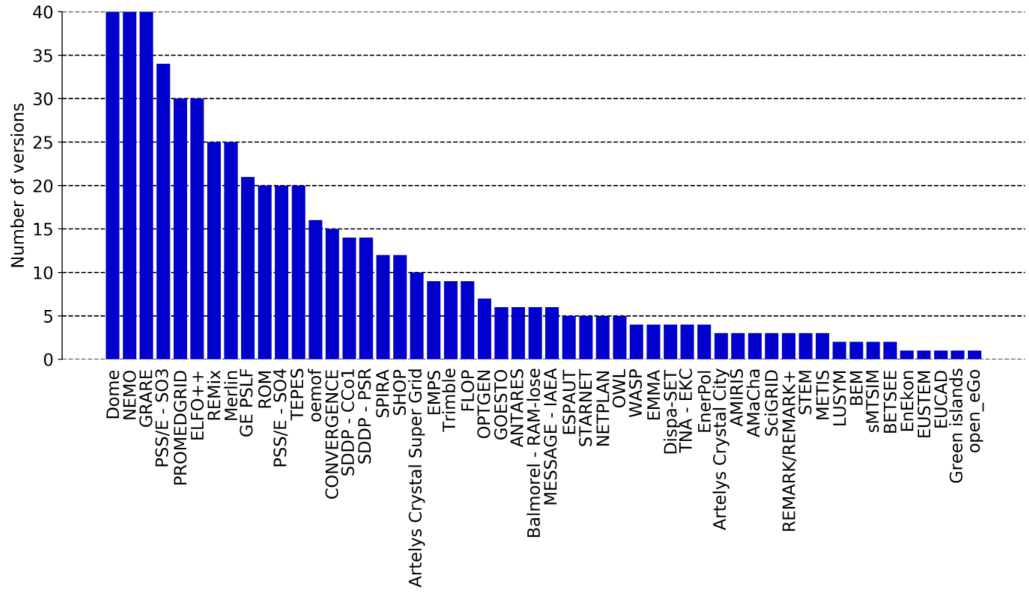
There are models for which first versions have been released more than forty years ago; for instance, three models, namely `EMPS`, `PSS/E - SO1`, and `WASP`, have been released in the 70s. The last versions of `EMPS` and `PSS/E` have been issued during 2017. `SHOP` and `SDDP` have been used since the 90s while the rest of models were released in the twenty-first century. The most recent models are `PLEXOS EU 2030` and `open_eGo` which have been made available in 2017. However, it can be noted how the number of versions (Figure 4) made available varies across the model regardless of the release year; for instance, `Dome` and `NEMO` have released more than 100 versions in just 7 and 3 years, respectively. This is because their models are continuously being updated.

Figure 5 shows the relative percentage of models lying within the categories of the required training period for each group of number of users. Note that the model is within the *Not applicable* category when no answer was given for those questions.

First, the distribution of models within the group describing the number of users is as follows: 52% with less than 20 users, 21% between 20 and 50 users, 15% between 50 and 1000 users, 5% with more than 1000 users, and the rest lies within the *Not applicable* category. According to Figure 5, the training period around one week has a high share regardless of the number of users. However it can be observed that 5% of the models claim to have more than 1000 users of which half of them has a training period of around one week (GE PSLF and SDDP – PSR) and the other half claims a training period of around one month (MESSAGE – IAEA and WASP). Therefore, even if the required training period by the models is one week or one month, the number of users is not necessarily low. For those models with a training period above one month such as Plexos, Balmorel or PSS/E, the number of users is less than 1000.

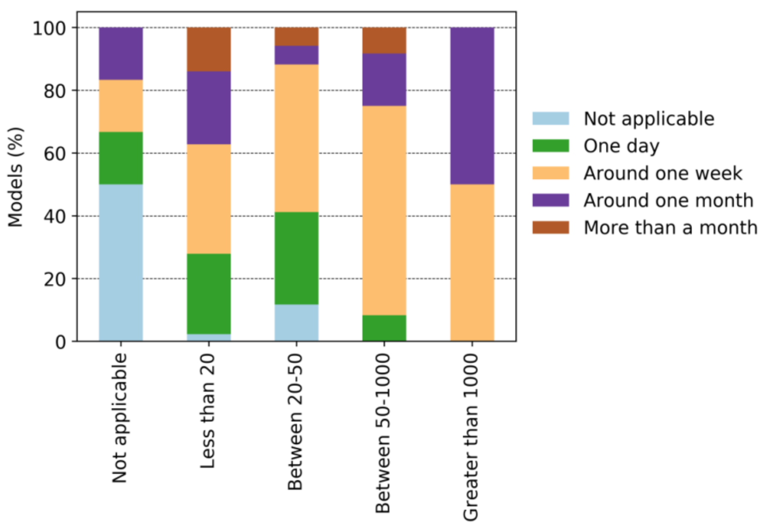
Figure 4. Number of versions released by each model.

(*Editor's note*: Dome, NEMO, and GRARE claimed to have released more than 100 versions)



Source: JRC, 2017.

Figure 5. Training period and number of users (relative percentage of models lying within each of the categories).

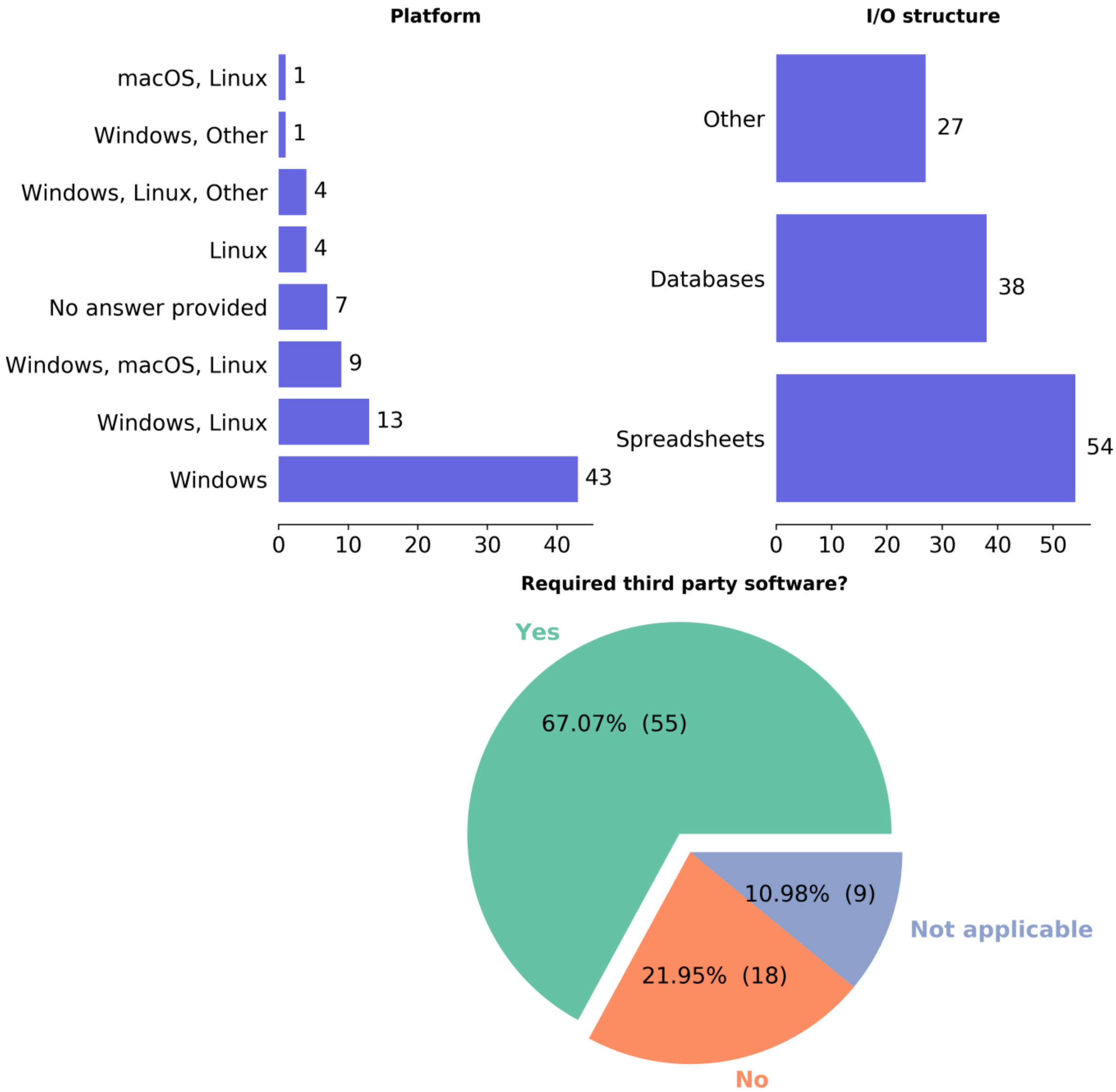


Source: JRC, 2017.

Questions about platform, third party software used, I/O structure and compatibility have been included in the survey. Figure 6 summarises the platforms supported by the models (upper left plot), the I/O data structure (upper right plot) and a poll to find out whether third party software (*e.g.* solvers and modelling languages) is required by the models. Note that many models include compatibility with different I/O data structures and some of them are flexible for the customer.

As can be seen, Windows is the preferred platform for the modellers representing 85% of all models participating in the survey, followed by Linux (38%) and macOS (12%). On the other hand, 67% of participants claim to use third party software including off-the-shelf software (GAMS [67], Matlab [68], Python [69]) or commercial solvers (XPRESS [70], CPLEX [71], Gurobi [72], PATH [73], GLPK [74], etc). Finally, 66% of models prefer spread sheets to organise I/O data followed by databases (46%) and others including text files, script files in Matlab, CSV files, etc. (33%).

Figure 6. Platform, I/O structure and third-part software requirements.



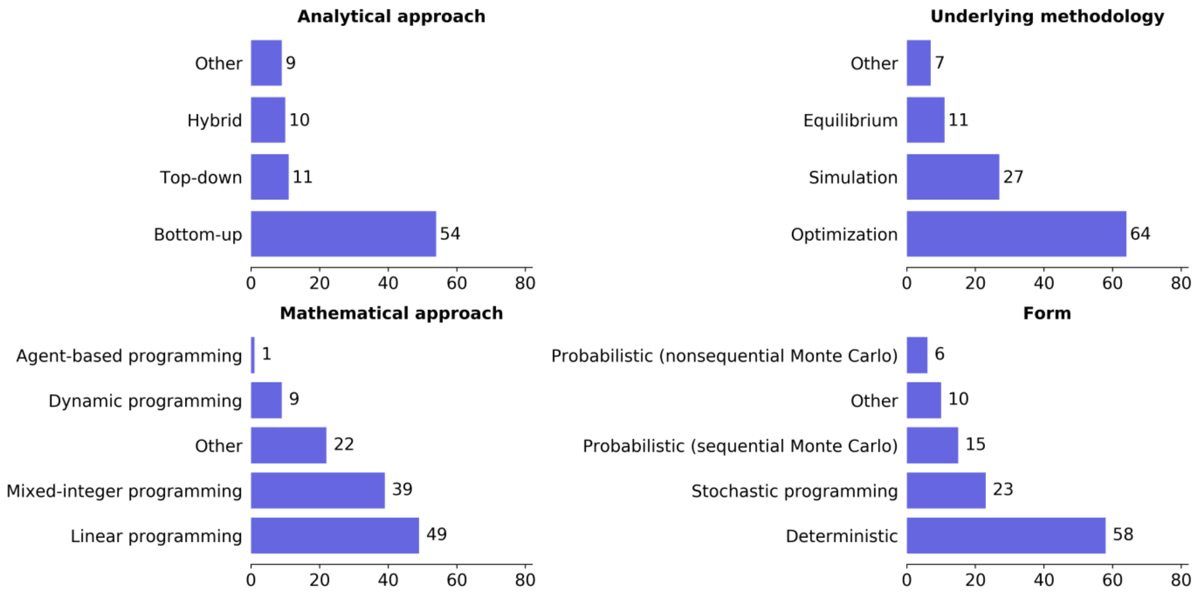
Source: JRC, 2017.

3.2.2 Model-related features

The participants have been asked about the analytical approach, underlying methodology, mathematical approach and form of their models. Figure 7 summarises the participants' answers about these model-related features. As can be seen, the most typical analytical approach is bottom-up (54 out of 82) whereas other approaches such as top-down or hybrid methods are less used (11 and 10 out of 82, respectively).

Regarding the underlying methodology, the models are mostly defined as optimization problems (78%) rather than simulation (33%) or equilibrium problems (13%). The mathematical approach is mainly based on either linear (60%) or mixed-integer (48%) programming. Dynamic or agent-based programs are less common among the participating models. However, many respondents have pointed out that other approaches can be applied to power system models (*e.g.* quadratic programming, non-linear programming, etc.). Finally, 71% of the models claim to solve a deterministic problem versus 41% of the models solving probabilistic or stochastic problems. Note that the sequential Monte Carlo approach is more common than the non-sequential Monte Carlo one for probabilistic problems.

Figure 7. Model-related features: analytical approach, underlying methodology, mathematical approach and form.

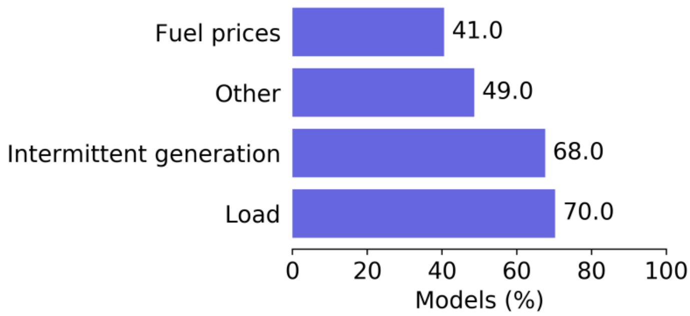


Source: JRC, 2017.

There are 37 respondents handling uncertainty in their models. Most typical uncertainty features incorporated in power system models are related to fuel prices, intermittent generation and load. Figure 8 provides the percentage of models (out of 37) taking into account the stochasticity of the aforementioned variables and parameters. 70% of stochastic or probabilistic models claim to take load uncertainty into consideration, which is closely followed by renewable energy uncertainty (68%). Other important variables such as hydro inflows, thermal power plants' availability or investment costs are usually stochastically modelled. There are also models including specific uncertainties to address specific research questions; for instance, `Balmorel – RAM-lose` takes into account uncertainty on the policy framework, *e.g.* taxes and support.

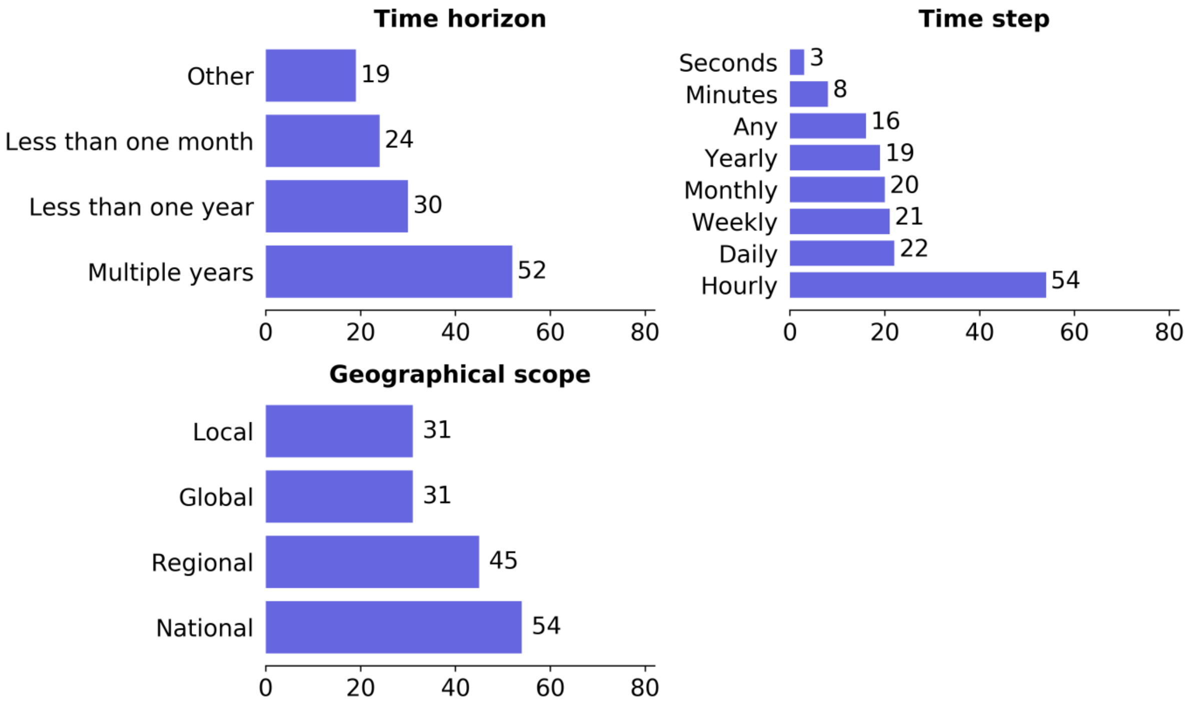
The last model-related features which have been analysed are time horizon, time step and geographical coverage of the model. The results of the survey, reported in Figure 9, show how these features are highly dependent on the problem(s) solved by each model. Nevertheless, they give an idea of the most used time horizons, time steps, and geographical scope of the models. 52 out of 82 models can run up to multiple years. The time horizon will depend on the computational complexity of the problem and the time step. The time step ranking gives more insights than the time horizon. We can observe that 55 out of 82 models (67%) use hourly time steps. This is followed by daily, weekly and monthly time steps. However, models using a time step under an hour are less common. Note however that 15 out of 82 are versatile in terms of time step. Regarding geographical scope, regional and national scopes are the main geographical objectives of the models, whereas local and global scopes are less used.

Figure 8. Uncertainty handled by models.



Source: JRC, 2017.

Figure 9. Model-related features: time horizon, time step and geographical scope.



Source: JRC, 2017.

3.3 Power system problems

This subsection summarises the power system problems that each tool is able to model (subsection 3.3.1), the corresponding constraints included in the model (subsection 3.3.2), as well as the key I/O data (subsection 3.3.3).

3.3.1 Problems

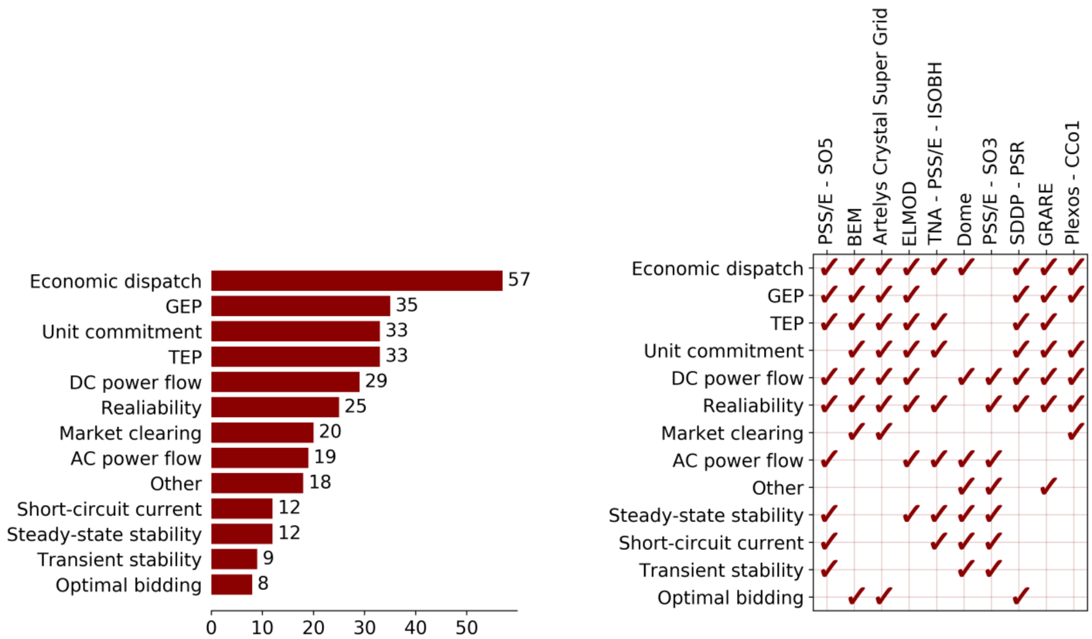
The participants have been asked what power system problems the tool can model among 13 choices (the *Other* category is also included).

Figure 10 summarises these results: in the left plot the problems addressed by the participating tools are ranked, so it is possible to observe the most modelled problems in power systems; in the right plot, the top ten tools modelling more power system problems are provided. The figure encompassing all the participating models is provided in Annex 4.

As can be seen, the Economic Dispatch (ED) problem is widely modelled with a share of approximately 70% of the participating tools, followed by the Generation Expansion Problem (GEP), Unit Commitment (UC), and Transmission Expansion Problem (TEP) with around 40–43% each. All these problems belong to planning and operation activities of the power system sector. The typical time step granularity for both ED and UC problems is hourly, whereas the typical one for both GEP and TEP can range from hours to months (depending on the time horizon). Therefore, this result is in line with the one observed in Figure 9 wherein hourly time steps are used by 67% of the models. On the other hand, the problems less modelled by the participating tools are short-circuit current calculations (15%), steady-state and transient stability problems (15% and 11% respectively), and optimal bidding (10%). Within the *Other* category, there are tools able to model other market-related problems (*e.g.* balancing markets), security-constrained problems considering *N–1* security criterion, hydro or gas management problems, among others.

Figure 10. Power system problems addressed by the participating tools (left plot) and mapping of the top ten tools modelling more power system problems (right plot).

(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

The ranking of the top ten tools addressing more power system problems based on the given choices is the following:

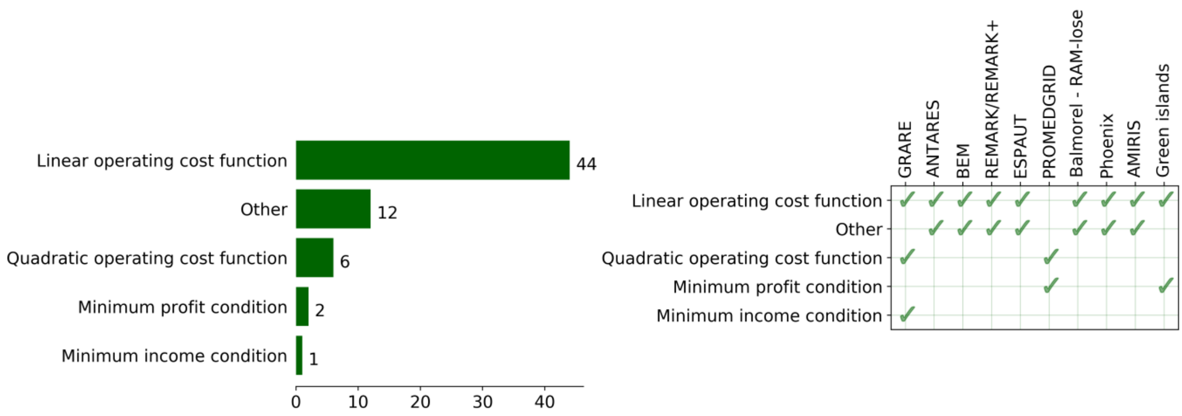
- PSS/E – SO5 (9 out of 13 problems).
- BEM, Artelys Crystal Super Grid and ELMOD (8 out of 13 problems).
- TNA - PSS/E - ISOBH, Dome, PSS/E – SO3, SDDP – PSR, and GRARE (7 out of 13 problems).
- Plexos – CCo1, REMix, GE PSLF, CONVERGENCE, PSS/E – SO1, PLEXOS EU 2030, EMPS, REMARK/REMARK+, EnerPol, and Balmorel – RAM-lose (6 out of 13 problems). ([11])

3.3.2 Constraints

The survey also included some multiple-choice questions regarding typical economic and technical constraints. The participants could choose among 5 choices for the economic constraints and 17 choices for the technical constraints, although the spectrum of constraints investigated in the questionnaire is not the widest.

Figure 11 and Figure 12 show the results for the economic and technical constraints, respectively: in the left plot the constraints considered by the participating tools are ranked so it is possible to observe the ones that are usually enforced; and, in the right plot, the top ten tools including more constraints are shown. The figures encompassing all the participating models are provided in Annex 4.

Figure 11. Economic constraints considered by the participating models (left plot) and mapping of the top ten models incorporating more economic constraints (right plot).



Source: JRC, 2017.

Regarding the economic constraints, it can be clearly observed how most of the tools include linear operating cost functions – 85% ([12]) – versus the 11.5% of models incorporating quadratic operating cost functions. In addition, the minimum profit or minimum income conditions, which are specific in some European electricity markets ([13]), are rarely modelled. However, other important economic features or constraints are modelled by the participating tools, as indicated in the *Other* category such as investment budget constraints, investment costs, or risk constraints on profits.

([11]) Note that the right plot of Figure 10 shows the ten first models only. However, there are 10 models claiming to address 6 out of 13 problems.

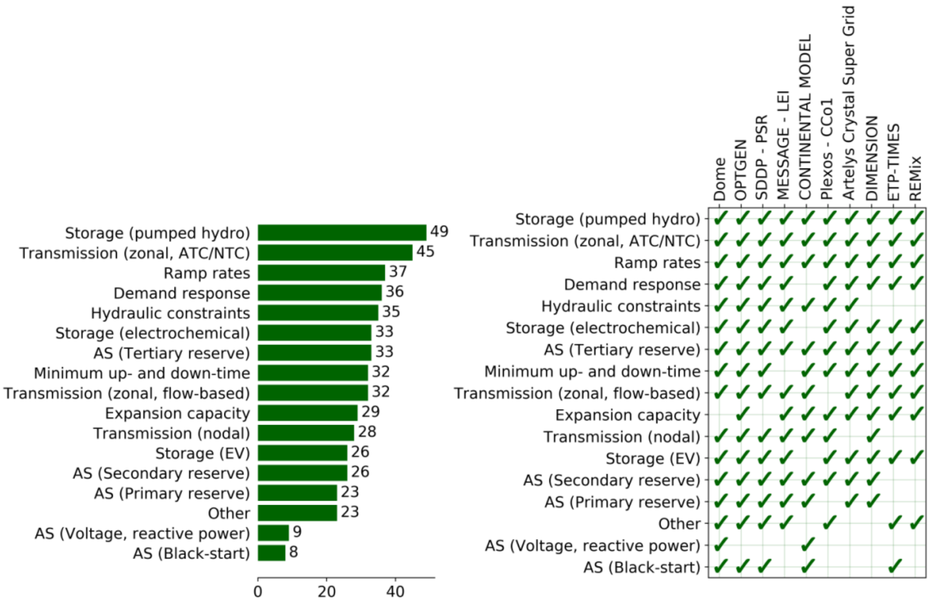
([12]) This percentage is computed with respect to the total number of tools which provided an answer to this question, *i.e.*, 52.

([13]) Examples of minimum income conditions can be found in EPEX spot market (http://www.apxgroup.com/trading-clearing/day-ahead-auction/), or the Iberian electricity market (http://www.omel.es/en/home/markets-and-products/electricity-market/our-electricity-markets/daily-market).

Regarding the technical constraints, it can be noted how pumped-hydro storage is typically modelled (60%). However, modelling electrochemical storage, *i.e.*, batteries (40%) and electric vehicles (32%) is getting more and more importance due to recent technological and policy advances on those areas. Zonal transmission capacity constraints based on Net Transfer Capacities (NTCs) are modelled more frequently than zonal flow-based transmission capacity constraints (55% versus 39% respectively). However, nodal transmission constraints are less common among the tools (34%). Ramp rate, demand response, hydraulic, tertiary reserve, and minimum up and down time constraints are often included in the modelling tools (with more than 30 out of 82 tools). Except for the tertiary reserve, the rest of ancillary services are the least common constraints, especially voltage control, reactive power provision, and black-start (approximately 10.5%). Finally, it is worth to point out that several models can include more constraints or other constraints such as gas-related constraints, minimum load levels, start-up times, offer-block-related constraints, maintenance scheduling, renewable potentials, environmental constraints, etc.

Figure 12. Technical constraints considered by the participating models (left plot) and mapping of the top ten models incorporating more technical constraints (right plot).

(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

The ranking of the top ten tools incorporating more technical constraints based on the given choices is the following:

- Dome and OPTGEN (16).
- SDDP – PSR (15).
- MESSAGE – LEI (14).
- CONTINENTAL MODEL, Plexos – CCo1, Artelys Crystal Super Grid, and DIMENSION (13).
- ETP-TIMES (12).
- REMix, TNA – PSS/E - ISOBH, EUCAD, GRARE, ENTIGRIS, EnerPol, and METIS (11). ([14])

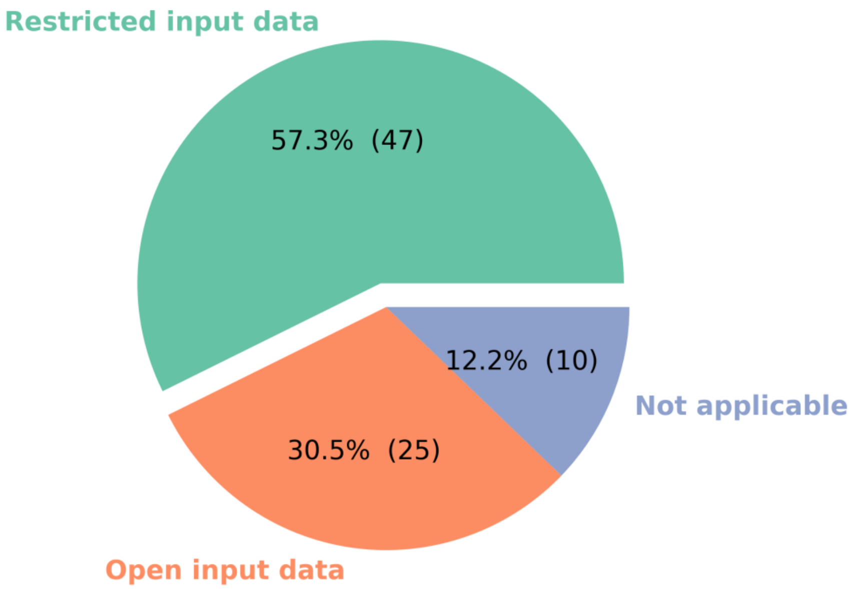
([14]) Note that the right plot of Figure 12 shows the ten first models only. However, there are 7 tools claiming to model 11 out of 17 constraints.

3.3.3 Data

Multiple-choice questions regarding key I/O data have been also asked to the participants, who could choose among 19 input data choices and 29 output data choices, although the spectrum of input and output data investigated in the questionnaire is not the widest.

First, the openness of input data used by the participating tools is analysed. Most of the models (57%) have restricted input data versus a 31% of models which claim to have open input data, as shown in Figure 13.

Figure 13. Open versus restricted input data.



Source: JRC, 2017.

Figure 14 and Figure 15 provide the results for the key I/O data, respectively. In the left plot the key data considered by the participating tools are ranked so it is possible to observe the ones that are usually used; and, in the right plot, the top ten tools in terms of key data are shown. The figures encompassing all the participating models are provided in Annex 4.

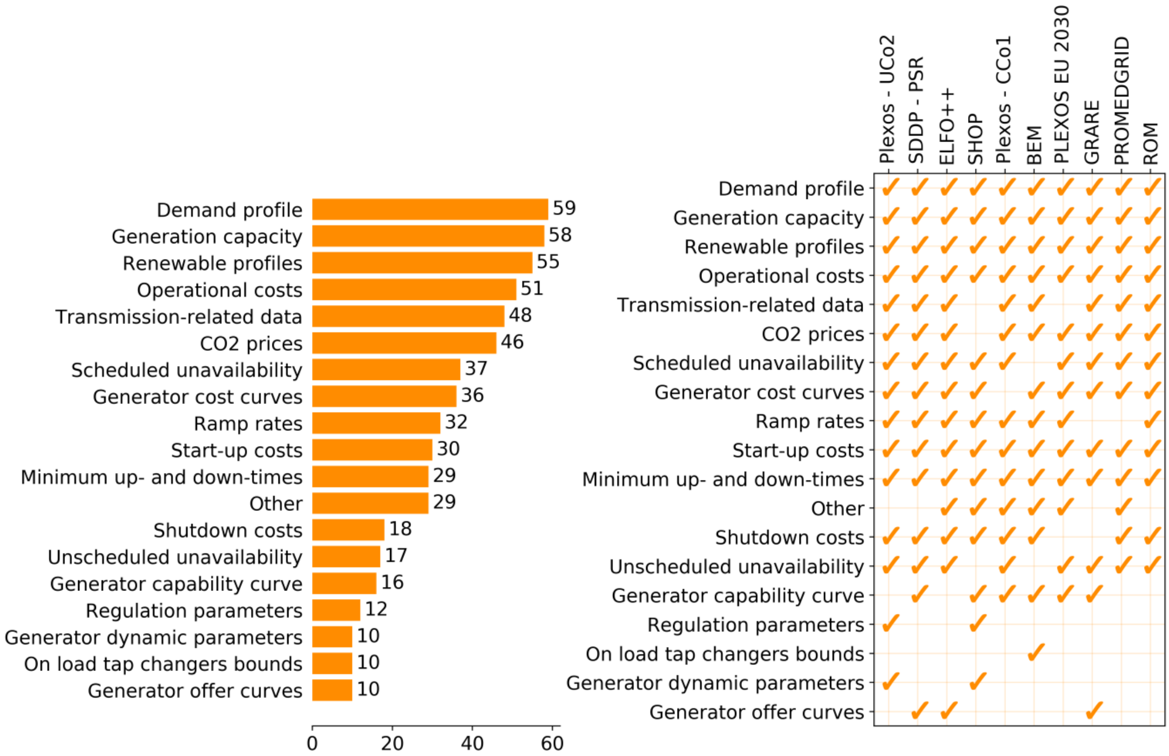
As expected, the demand profile, generation capacity, renewable profiles, and operational costs are musts in most of power system problems and represent key input data for almost 70–80% ([15]) of the models. Bearing in mind that 57 tools model an ED problem, this result is consistent since demand, generation, and cost data are strictly necessary to solve such problem. Transmission-related data are also highly used by the tools (65%) followed by CO_2 prices (62%). On the other hand, the least common key input data are regulation parameters, generator dynamic parameters, On Load Tap Changers (OLTC) bound values, and generator offer curves (approximately 14–16%). *Other* key input data that have not been included among the possible choices in the survey but participants highlighted include start-up costs, fuel costs, minimum load levels, hydro fleet (inflows and reservoir levels), demand elasticity, renewable energy policies and emission caps, district heating data, heating curves for Combined Heat and Power (CHP) plants, generator efficiencies, time delays for hydrothermal problems, etc.

([15]) This percentage is computed with respect to the total number of tools which provided an answer to this question, *i.e.*, 74.

The ranking of the top ten tools considering more key input data based on the given choices is the following:

- `Plexos – UCo2`, `SDDP – PSR`, and `ELFO++` (15).
- `SHOP`, `Plexos – CCo1`, and `BEM` (14).
- `PLEXOS EU 2030`, `GRARE`, `PROMEGRID`, `ROM`, `REMix`, and `METIS` (13). ([16])

Figure 14. Key input data considered by the participating models (left plot) and mapping of the top ten models incorporating more key input data (right plot).



Source: JRC, 2017.

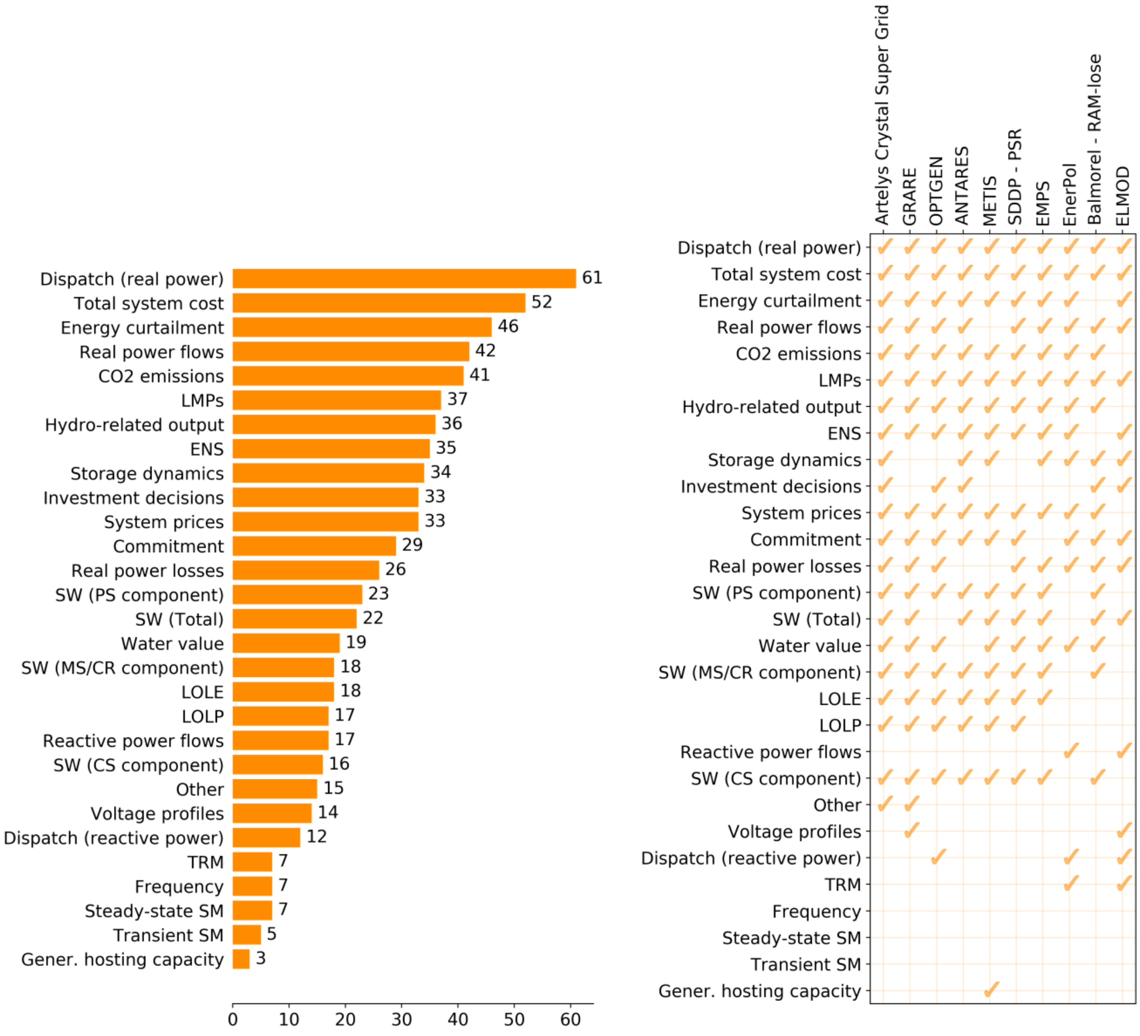
Regarding the key output data summarised in Figure 15, real power dispatch, total system cost, and energy curtailment are the most common outputs with a share around 60.5–80.0% ([17]) of models, followed by real power flows and CO_2 emissions (54%). As expected, the commitment is an output for 38% of the models, approximately half of models whose output is the real power dispatch. This is in line with the results shown in Figure 10, since the UC problem is modelled by approximately half of the models addressing an ED problem. Also, there are other similarities between Figure 10 and Figure 15; for instance, outputs from a market clearing, *e.g.*, Social Welfare-related (SW-related) outputs, are output of more models than the outputs from an AC power flow, *e.g.*, reactive power flows, voltage profiles, and reactive power dispatch. Finally, the least common outputs are related to stability analysis such as steady-state or transient stability margins (6.5–9.2%).

([16]) Note that the right plot of Figure 14 shows the ten first models only. However, there are 6 tools claiming to consider 13 out of 19 key input data.

([17]) This percentage is computed with respect to the total number of tools which provided an answer to this question, *i.e.*, 76.

Figure 15. Key Output data considered by the participating models (left plot) and mapping of the top ten models incorporating more key output data (right plot).

(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

The ranking of the top ten tools considering more key output data based on the given choices is the following:

- Artelys Crystal Super Grid (21).
- GRARE (20).
- OPTGEN (19).
- ANTARES, METIS, and SDDP – PSR (18).
- EMPS (17).
- EnerPol and Balmorel – RAM-lose (16).
- ELMOD, PROMEGRID, and REMARK/REMARK+ (15). ([18])

([18]) Note that the right plot of Figure 15 shows the ten first models only. However, there are 3 tools claiming to consider 15 out of 29 key output data.

3.4 Technologies

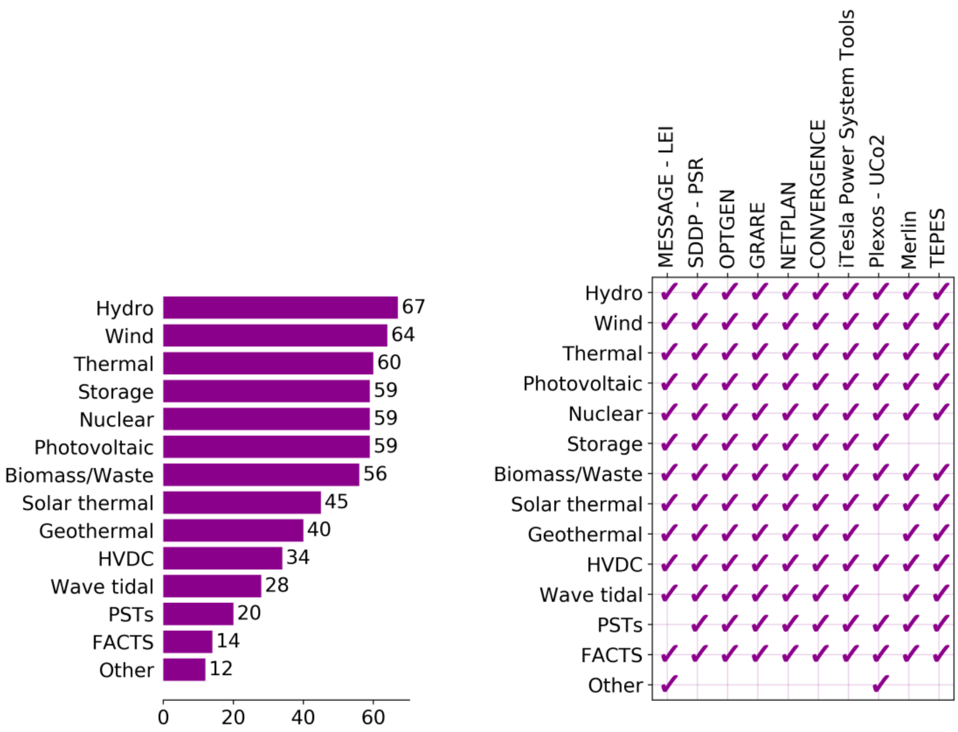
In order to rank the most often modelled technologies, the participants have been asked to provide the technologies modelled in their respective tools through a multiple-choice question.

Figure 16 provides the results about modelled technologies: in the left plot technologies are depicted, while in the right plot the top ten tools in terms of technologies are shown. The figures encompassing all the participating models are provided in Annex 4.

As can be seen in Figure 16, hydro, wind, thermal, storage and nuclear technologies are widely modelled with a share around 83–94% ([19]) of the models. Biomass/waste, solar thermal and geothermal technologies are still modelled by more than 50% of the models. However, HVDC, wave tidal, PSTs, and FACTS are not often found unless the analysis is specifically performed for those technologies.

Figure 16. Technologies considered by the participating models (left plot) and mapping of the top ten models taking into account more technologies (right plot).

(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

The ranking of the top ten tools considering more technologies based on the given choices is the following:

- `MESSAGE - LEI`, `SDDP - PSR`, `OPTGEN`, `GRARE`, `NETPLAN`, `CONVERGENCE`, and `iTesla Power System Tools` (13).
- `Plexos - UCo2`, `Merlin`, `TEPES`, `ANTARES`, `GE PSLF`, and `REMARK/REMARK+` (12). ([20])

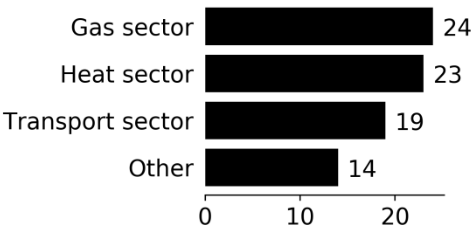
([19]) This percentage is computed with respect to the total number of tools which provided an answer to this question, *i.e.*, 71.

([20]) Note that the right plot of Figure 16 shows the ten first models only. However, there are 6 tools claiming to consider 12 out of 14 technologies.

3.5 Sectorial coverage

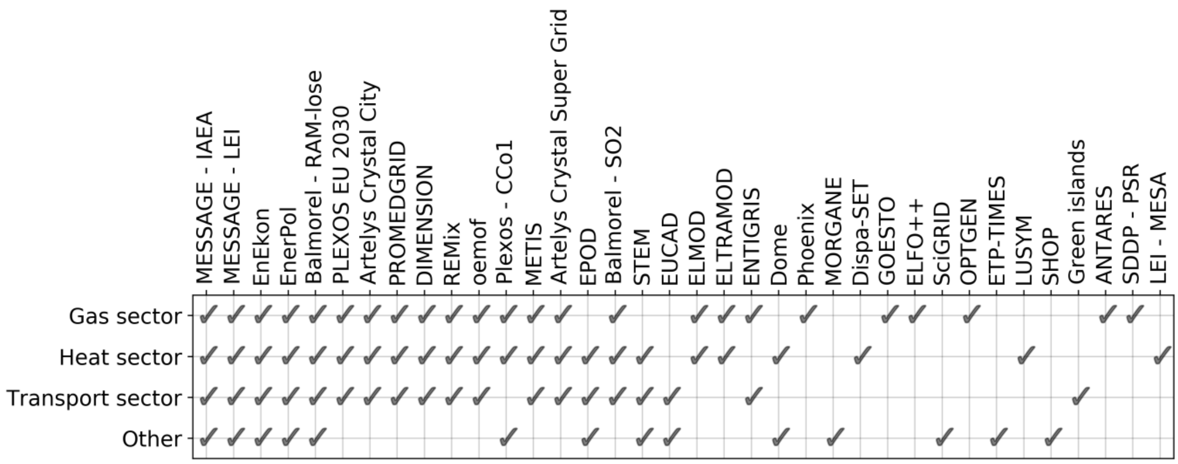
Apart from the electricity sector, the current trend is to link the power system sector with other key sectors such as gas, heat or transport ones in order to increase accuracy of the results and to analyse the interdependencies among different sectors. In the set of analysed models, only 36 (44%) declare links with other sectors. As shown in Figure 17, gas and heat sectors are represented by 64–66% of models whereas the transport sector is modelled by 53% of models. 39% of models claim links with other sectors such as water, agricultural, land, telecommunication sectors, to name a few. In Figure 18, the sectorial coverage of these 36 models is represented. It can be noted that all sectors are modelled in `MESSAGE - IAEA`, `MESSAGE - LEI`, `EnEkon`, `EnerPol`, `Balmorel - RAM-lose`, `PLEXOS EU 2030`, `Artelys Crystal City`, `PROMEGRID`, `DIMENSION`, `REMix`, and `oemof`.

Figure 17. Sectorial coverage ranking.



Source: JRC, 2017.

Figure 18. Sectorial coverage of the power system models.



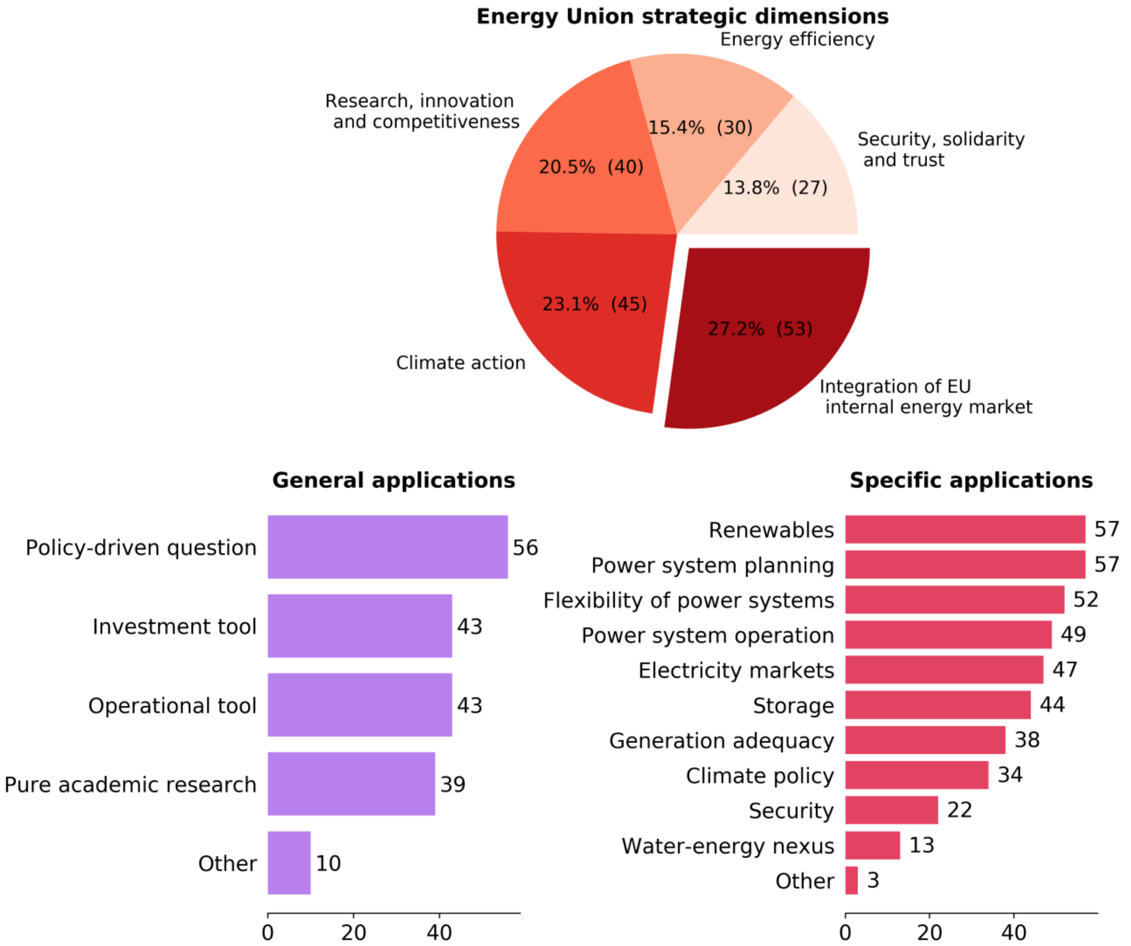
Source: JRC, 2017.

3.6 Applicability of models

This section is based on the response of the participants to section F of the survey. Hence it is based on the participants' subjectivity to indicate for which applications their tools are best suited for. Figure 19 presents the aggregated results in which the power system model would be best suited for three different categories:

- EU's Energy Union strategic dimensions. ([21])
- General applications.
- Specific applications.

Figure 19. Summary of applications in which the models are best suited for.



Source: JRC, 2017.

As can be seen in the top chart in Figure 19, the integration of EU internal energy market would be the strategic dimension out of the 5 ones with the highest share (27%), followed by climate action (23%), and research, innovation and competitiveness (21%). However, energy efficiency represents one of the lowest shares (15%).

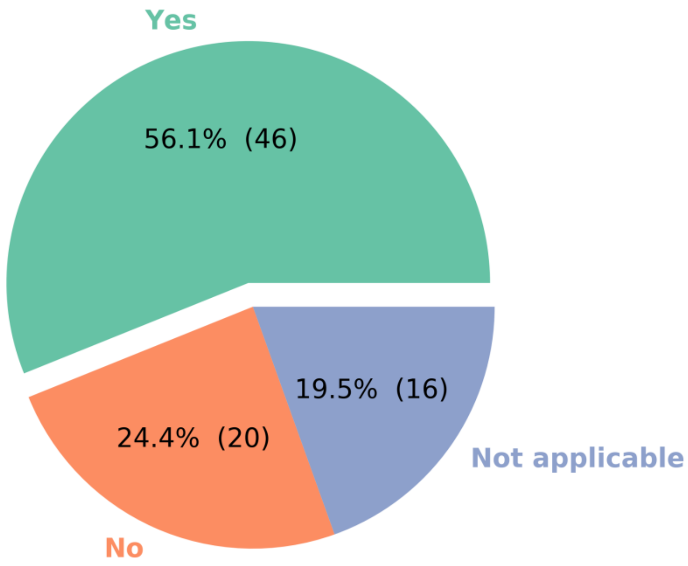
([21]) The EU's Energy Union strategic dimensions are 5: security, solidarity and trust, energy efficiency; research, innovation and competitiveness; climate action – decarbonisation of the economy; and integration of EU internal energy market. For more information about the 5 dimensions, the reader is referred to https://ec.europa.eu/commission/priorities/energy-union-and-climate_en

From a general perspective, 56 out of 82 models have declared to be best suited for answering policy-driven questions against 39 out of 82 models which have claimed to be best suited for academic research, although both choices are also compatible.

In addition, 52% of the models have claimed to be operational and/or investment tools. From a more specific viewpoint (right-lower plot in Figure 19), renewables and power system planning are handled by around 70% of models, closely followed by the flexibility of power systems and power system operation with 60–63% of models.

Figure 20 shows the results of a poll to check whether a policy question has ever been answered by the model. We can observe that more than half of the participants pointed out to have answered a policy question in their analyses.

Figure 20. Poll whether a policy question has been answered by the model according to the respondents.



Source: JRC, 2017.

4 Conclusions and future steps

The *Knowledge for the Energy Union* Unit of the Joint Research Centre has conducted a survey in the form of an online questionnaire to gather information about power system models available in and/or used by European organisations. Detailed and relevant information about 82 power system models has been collected, processed, and presented in a compact way throughout this manuscript.

This report presents a comprehensive mapping of power system models and its applications and identifies possible gaps from a modelling and a methodological perspective. However, the suitability of a modelling tool to answer specific research or policy questions cannot be merely based on the rankings provided in this report. Several remarks can be drawn:

- A mapping of power system models and organisations is available in this report. In addition, key information about each power system model is individually displayed in a factsheet.
- Most commercial models participating in the survey (76%) declare that the total cost is above 10000 €.
- The number of versions of each model does not depend on the first release date. For instance, relatively new models such as `Dome` or `NEMO` have released more than 100 versions, probably due to a continuous update.
- The typical training period is around one week and there is no correlation between the number of users and the training period.
- Windows is the preferred platform for modellers (85%), followed by Linux (38%) and macOS (12%).
- Third party software is declared by 67% of the participating models. This third party software includes off-the-shelf software, *e.g.* GAMS, Matlab or Python, and commercial solvers such as CPLEX, Gurobi, XPRESS, PATH, etc.
- Regarding key I/O data organisation, 66% of models indicate the spreadsheets as the preferred option. However, compatibility among different types of data arrangement can be found in several models.
- Regarding model-related features, bottom-up approaches (66%), optimization problems (78%), linear or mixed-integer linear programming (48–60%), and deterministic methods (71%) are the most popular choices among the participating models. Moreover, around 70% of tools capturing some degree of uncertainty in their models take into account intermittent generation and demand uncertainty.
- An analysis of the power system problems, constraints and key data suggests that most of the tools mainly model economic-dispatch-based problems or capacity expansion problems rather than going into the details of an AC optimal power flow or stability problems.
- The most common existing technologies (hydro, wind, thermal, storage, nuclear and photovoltaic) are usually taken into account in most of the tools.
- Less than half of the participating models, presents a link with other sectors, mostly with gas or heat sectors.
- The applicability of the models to the EU's Energy Union strategic dimensions is also analysed in the report based on the participants' answers: 27% claim that their models are best suited for in the area of integration of EU internal energy market, followed by the climate-related policy area.
- A high share of models (68%) declares that they are suitable to answer policy-driven questions. In fact, 56% state that their models have ever answered a policy-related question. Regarding specific applications, renewable integration, power system operation and planning, and flexibility of power systems are tackled by 60–70% of models.

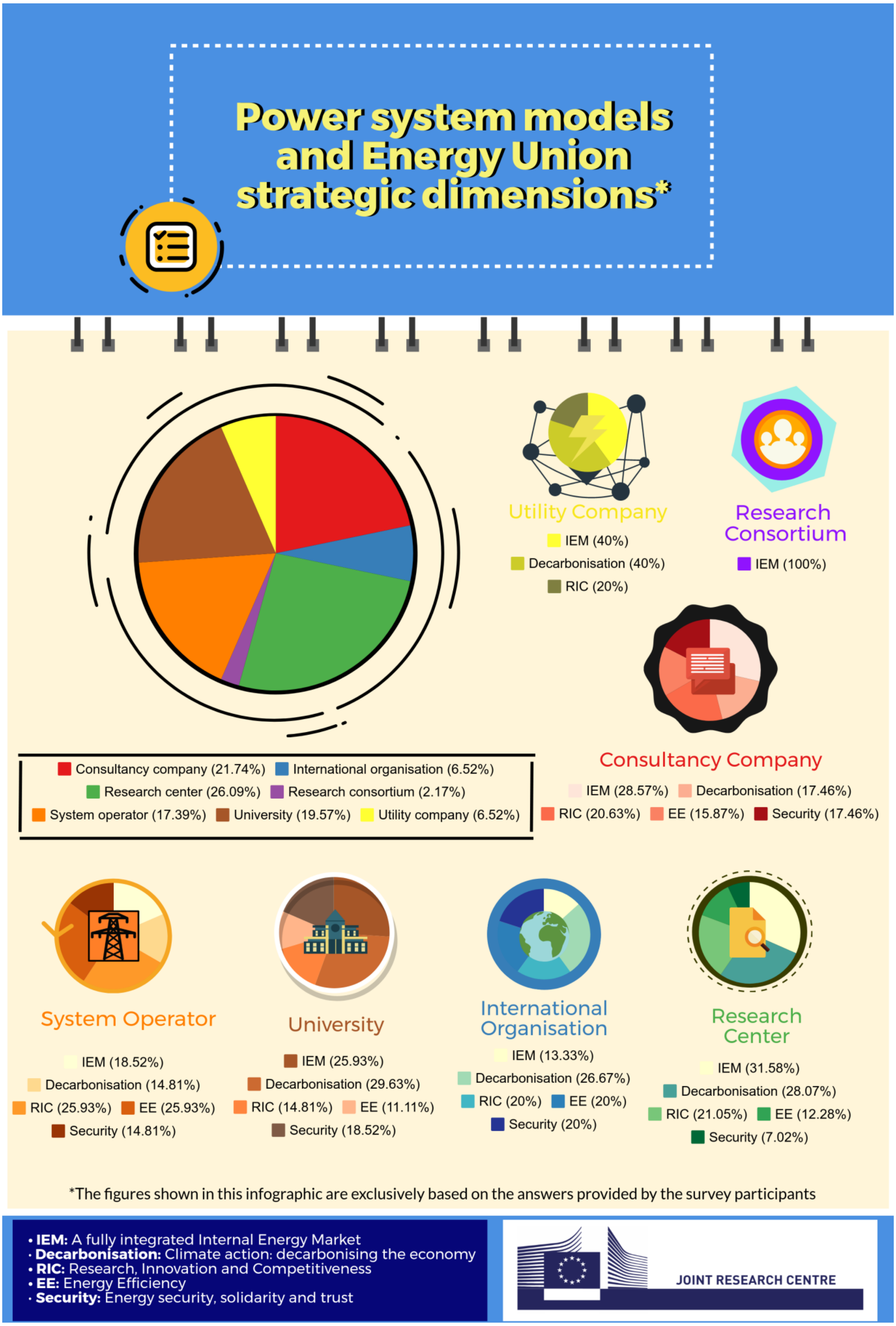
Table 3 shows some of the outcomes obtained by analysing the survey results, categorised according to the thematic area, as well as JRC recommendations on future research avenues.

Table 3. Analysis of survey results – JRC findings.

Theme	Outcomes from the survey	JRC recommendations
Model-related features – Uncertainties	Most typical uncertainty features incorporated in power system models are related to fuel prices, intermittent generation and load.	The integration of renewable energy sources would call for stochastic or probabilistic approaches to deal with the stochasticity nature of those resources. More attention should be devoted to other uncertainty features such as hydro inflows, thermal power plant's availability, investment costs or policy impacts.
Model-related features – Geographical scope	Regional and national scopes are the main geographical objectives of the models, whereas local and global scopes are less used.	Local and global scales are less used probably because of the involved high complexity. Local and global scales should be further explored by models while keeping the computational complexity within acceptable limits
Problems	Most of the tools mainly model economic-dispatch-based problems or capacity expansion problems.	Research effort on AC optimal power flow and models dealing with stability analysis should be intensified since those models play an important role in the power system planning and operation of transmission and distribution activities. Further collaboration among modellers in different kind of organisations (*e.g.* academia and industry) should be made in order to intensify such research effort on AC optimal power flow and models dealing with stability analysis.
Constraints	Nodal transmission constraints are less common among the tools (34%).	Increase modelling efforts in representing nodal transmission constraints while maintaining an adequate use of computational resources.
Technologies	The most common existing technologies (hydro, wind, thermal, storage, nuclear and photovoltaic) are usually taken into account in most of the models.	Additional research efforts in modelling HVDC, PSTs, or FACTS technologies should be made.
Sectorial coverage	Less than half of the participating models, presents a link with other sectors, mostly with gas or heat sectors.	The gas-power, heat-power, water-power or other links with different sectors (food, ecosystem, etc.) should be increased in the coming years in order to analyse the implications of other sectors over the electricity one and how the sectors will impact on the secure and reliable operation of the power system.
Applicability of models – Energy Union strategic dimensions	Energy efficiency is analysed by 15% of the models.	More efforts should be made in modelling and analysing energy efficiency in power system tools.
	27% claim that their models are best suited in the area of integration of EU internal energy market, followed by the climate-related policy area.	Features related to climate, security, water-energy, energy-transport nexus as well as hydrogen-to-power policies should be further developed.

Source: JRC, 2017.

The information gathered in this report could be useful for mapping the suitability of models for informing and providing evidence in policy-making decisions, although this would be part of a future research work since a quick-scoping review or a systematic review would be necessary yet time- and effort-consuming. In line with this, further work will be devoted to performing systematic maps of policy-related studies.



Source: JRC, 2017.

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List of abbreviations and definitions

AC PF	Alternate Current Power Flow
AGPL	GNU Affero General Public License
AS	Ancillary Services
BSD	Berkeley Software Distribution
CC	Creative Commons
CESI	Centro Elettrotecnico Sperimentale Italiano
CHP	Combined Heat and Power
CR	Congestion Rent
CS	Consumer Surplus
CSV	Comma Separated Values
DC PF	Direct Current Power Flow
DG	Directorate-General
ED	Economic Dispatch
EDF	Electricité de France
EERA	European Energy Research Alliance
EKC	Electricity Coordinating Center
ENS	Energy Not Served
ER&S	Energy Research and Scenarios
EU	European Union
EUPL	European Union Public License
EV	Electric Vehicle
FACTS	Flexible AC Transmission Systems
Fraunhofer ISE	Fraunhofer-Institut für Solare Energiesysteme
GAMS	General Algebraic Modeling System
GPL	GNU General Public License
GEP	Generation Expansion Planning
GLPK	GNU Linear Programming Kit
HVDC	High Voltage Direct Current
IAEA	International Atomic Energy Agency
IIT	Institute for Research in Technology
ISC	Internet Systems Consortium
I/O	Input/Output
JRC	Joint Research Centre
LEI	Lithuanian Energy Institute
LMP	Locational Marginal Price
LOLE	Loss of Load Expectation
LOLP	Loss of Load Probability

MIT	Massachusetts Institute of Technology
MPL	Mozilla Public License
MS	Merchandise Surplus
NTC	Net Transfer Capacity
OLTC	On Load Tap Changers
OVGU	Otto-von-Guericke-University of Magdeburg
PESS	Planning and Economic Studies Section
PIK	Potsdam Institute for Climate Impact Research
PS	Producer Surplus
PSI	Paul Scherrer Institute
PST	Phase-Shifting Transformer
RLI	Reiner Lemoine Institute
RTE	Réseau de transport d'électricité
RSE	Ricerca sul Sistema Energetico
R&D	Research and Development
SM	Stability Margin
SW	Social Welfare
TEP	Transmission Expansion Planning
TRM	Transmission Reliability Margin
TSO	Transmission System Operator
TU Dresden	Technische Universität Dresden
UC	Unit Commitment

List of figures

List of tables

Annexes

Annex 1. Survey template

The survey is mainly based on those provided by [1], [2], and [12]. The list of questions is listed below.

A. Basic information - Organisation

A.1. Name of Organisation (Institution, University department, Research Centre or Company):

A.2. Brief description of the main projects carried out in the Organisation:

A.3. Key web link:

A.4. Contact information of the Organisation:

A.5. How many power system modelling tools are available in your Organisation?

A.6. Please provide the list of tools along with the contact from your Organisation. Please fill out as many surveys as tools you may have.

B. Basic information - Tool

B.1. Name of power system modelling tool:

B.2. Brief description of power system tool in a sentence:

B.3. Responsible organisation(s) of the power system modelling tool:

B.4. Key web link:

B.5. Are you the developer or primary user of the power system tool? No ☐ Yes ☐

a. If no, could you provide the contact details of the organisation where the developer or primary user of the power system modelling tool is working at?

C. Users and uses

C.1. How many people or organisations have used the tool?

Not applicable ☐ Less than 20 ☐ Between 20-50 ☐ Between 50-1000 ☐ >1000 ☐

C.2. What is the required training period in order to use the tool for a typical application?

One day ☐ Around one week ☐ Around one month ☐ More than a month ☐

C.3. Could you state the most relevant projects (up to three) at either national or European level where the tool has been applied?

D. Software characteristics

D.1. When was the first release? Please specify date.

D.2. When was the latest release? Please specify date.

D.3. How many versions of the software have been released to date?

D.4. Availability of the power system tool:

Commercial ☐ Free to download ☐ Open source ☐ Other ☐

a. If other, please describe the type of availability of the tool:

b. If commercial, please provide the cost of the tool:

Less than 1000 € ☐ Between 1000 and 5000 € ☐ Between 5000-10000 € ☐ More than 10000 € ☐

c. If open source, please provide the license (*e.g.* GPL, MIT, BSD, etc):

GPT ☐ MIT ☐ BSD ☐ Other ☐

c1. If other, please provide which one(s):

D.5. Platform for the power system tool:

Windows ☐ Mac ☐ Linux ☐ Other ☐

a. If other, please provide which one(s):

D.6. Does the tool require the use of third party software (*e.g.* solvers and modelling languages)?

No ☐ Yes ☐

a. If yes, please provide which one(s):

D.7. Data input/output structure:

Spread sheets ☐ Data bases ☐ Other ☐

a. If other, please provide which one(s):

D.8. Is there any standard in the data input/output compatibility (*e.g.* CIM)?

E. Modelling properties and mathematical description

E.1. Please provide the category or categories in which the power system tool is best suited:

Short-circuit current calculations ☐ Transient stability ☐

Steady-state stability (*e.g.* continuation power flow, etc) ☐ AC power flow ☐

DC power flow ☐ Economic dispatch ☐ Unit commitment ☐ Reliability ☐ Market clearing ☐

Optimal bidding ☐ Generation expansion planning ☐ Transmission expansion planning ☐

Other ☐

a. If other, please elaborate:

E.2. Please provide the analytical approach of the power system modelling tool:

Top-down ☐ Bottom-up ☐ Hybrid ☐ Other ☐

a. If other, please elaborate:

E.3. Please provide the underlying methodology of the power system modelling tool:

Equilibrium ☐ Optimization ☐ Simulation ☐ Other ☐

a. If other, please elaborate:

E.4. Please provide the mathematical approach of the power system modelling tool:

Linear programming ☐ Mixed-integer programming ☐ Dynamic programming ☐

Agent-based programming ☐ Other ☐

a. If other or multiple choices, please specify and elaborate:

E.5. Please provide the form of the power system modelling tool:

Deterministic ☐ Probabilistic (sequential Monte Carlo) ☐

Probabilistic (nonsequential Monte Carlo) ☐ Stochastic programming ☐

Other ☐

a. If other, please elaborate:

b. If stochastic/probabilistic, please indicate which uncertainty features are formulated in the tool:

Load ☐ Intermittent generation ☐ Fuel prices ☐ Other ☐

b.1. If other, please elaborate:

E.6. What time horizon can be used for the analysis?

Less than one month ☐ Less than one year ☐ Multiple years ☐ Other ☐

a. If other, please elaborate:

E.7. What time step can be used for the analysis?

Any ☐ Seconds ☐ Minutes ☐ Hourly ☐ Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐

E.8. What is the geographic scope of the power system modelling tool?

Local ☐ Regional ☐ National ☐ Global ☐

a. Please indicate specific locations/regions considered:

E.9. If applicable, could you list the technical constraints included in the model?

Ancillary services (Primary reserve) ☐

Ancillary services (Secondary reserve) ☐

Ancillary services (Tertiary reserve) ☐

Ancillary services (Voltage control and reactive power provision) ☐

Ancillary services (Black-start) ☐

Demand response constraints ☐

Expansion capacity constraints ☐

Hydraulic constraints ☐

Minimum up- and down-time constraints ☐

Ramp rate constraints ☐

Storage constraints (pumped hydro) ☐

Storage constraints (electrochemical) ☐

Storage constraints (electric vehicles) ☐

Transmission constraints (zonal, ATC/NTC) ☐

Transmission constraints (zonal, flow-based) ☐

Transmission constraints (nodal, full network detail) ☐

Other ☐

a. If other, please elaborate:

E.10. If applicable, could you list the economic constraints including in the model?

Linear operating cost function ☐

Minimum income condition ☐

Minimum profit condition ☐

Quadratic operating cost function ☐

Other ☐

a. If other, please elaborate:

E.11. Could you provide the key input data?

CO2 prices ☐

Demand profile ☐

Generation capacity ☐

Generator cost curves ☐

Generator offer curves ☐

Generator capability curve ☐

Generator dynamic parameters (*e.g.* inertia, time constants, transient/subtransient reactances, etc) ☐

Minimum up- and down-times ☐

On Load Tap Changers (OLTC) bound values ☐

Operational costs ☐

Ramp rates ☐

Regulation parameters (frequency, voltage, etc) ☐

Renewable profiles ☐

Scheduled unavailability (*e.g.* maintenance plans, etc) ☐

Shutdown costs ☐

Start-up costs ☐

Transmission-related data (capacity, sensitivity factors, impedance matrix, etc) ☐

Unscheduled unavailability (*e.g.* fault probability, mean time to repair, mean time to failure, etc) ☐

Other ☐

a. If other, please elaborate:

b. Could you also indicate whether your input data is open or restricted?

Open input data ☐

Restricted input data ☐

b1. If open, where are they published?

E.12. Could you provide the key output data?

Commitment ☐

CO2 emissions ☐

Dispatch (real power) ☐

Dispatch (reactive power) ☐

Energy Not Served (ENS) ☐

Energy curtailment (*e.g.* RES curtailment) ☐

Frequency ☐

Generation hosting capacity in distribution systems ☐

Hydro-related output (reservoir levels, discharges, etc) ☐

Investment decisions (generation, transmission, distribution) ☐

Locational marginal prices ☐

Loss of Load Expectation (LOLE) ☐

Loss of Load Probability (LOLP) ☐

Real power flows ☐

Real power losses ☐

Reactive power flows ☐

Social welfare (Total) ☐

Social welfare (Producer surplus component) ☐

Social welfare (Consumer surplus component) ☐

Social welfare (Merchandise surplus/Congestion rent component) ☐

Steady-state stability margin ☐

Storage dynamics ☐

System prices ☐

Total system cost ☐

Transient stability margin ☐

Transmission Reliability Margin (TRM) ☐

Voltage profiles ☐

Water value ☐

Other ☐

a. If other, please elaborate:

E.13. Is there any link of the power system tool with one of the following sectors?

Heat sector ☐ Transport sector ☐ Gas sector ☐ Other ☐

a. If other, please elaborate:

E.14. If applicable, could you please indicate the technologies included in the system?

Biomass/Waste ☐

Geothermal ☐

High Voltage Direct Current (HVDC) ☐

Hydro ☐

Nuclear ☐

Other Flexible AC Transmission Systems (FACTS) ☐

Photovoltaic ☐

Phase-Shifting Transformers (PSTs) ☐

Solar thermal ☐

Storage ☐

Thermal ☐

Wave tidal ☐

Wind ☐

a. If needed, please elaborate:

E.15. Could you please elaborate on the main modelling assumptions taken into account in your model?

F. Applications

F.1. In which application(s) would your power system modelling tool be best suited?

Policy-driven question ☐ Pure academic research ☐ Operational tool ☐ Investment tool ☐

Other ☐

a. If other, please elaborate:

F.2. In which EU's Energy Union strategy dimension(s) would your power system tool be best suited?

Security, solidarity and trust ☐

Integration of EU internal energy market ☐

Energy efficiency ☐

Climate action – decarbonisation of the economy ☐

Research, innovation and competitiveness ☐

Not applicable ☐

F.3. Specifically, in which framework(s) would your power system modelling tool be best suited?

Climate policy ☐

Electricity markets ☐

Flexibility of power systems ☐

Generation adequacy ☐

Power system operation ☐

Power system planning ☐

Renewables ☐

Storage ☐

Security ☐

Water-energy nexus ☐

Other ☐

a. If other, please elaborate:

F.4. Has the tool ever been applied in a case study to answer to a policy making question?

No ☐ Yes ☐

a. If yes, please could you provide the reference(s)?

b. If no, please could you give a brief description of the case studies analysed?

G. References

G.1. Please provide the reference of the report or manual (preferably in English) in which the power system modelling tool is properly described:

G.2. Please provide the relevant publications in which the tool has been applied to specific case studies and they are not included in E.3:

H. Further information

H.1. According to your knowledge, what are (up to three) the most used power system modelling tools in your organisation?

H.2. According to your knowledge, what are (up to three) the most used modelling tools in the power system world?

H.3. Could we contact you in the future if we have further questions? No ☐ Yes ☐

H.4. Would you like to review a copy of the report or paper of the reviewed tools? No ☐ Yes ☐

H.5. Would you like to be explicitly mentioned in the results? No ☐ Yes ☐

H.6. Would you like to be included in the official power model inventory that will be developed by the European Commission? No ☐ Yes ☐

Annex 2. Modelling tools reviewed in the literature

Table 4, Table 5, Table 6 show the name of the modelling tools respectively related to the electricity sector, energy sector, and others such as water-energy nexus or transport and energy. The models analysed by means of the mapping described in the main report are highlighted in red.

Table 4. Reviewed electricity system models within the selected reviews.

(*Editor's note*: Models included in the report are highlighted in red)

Reference	[1]	[3]	[4]	[5]	[6]
Models	CEEMU	AWPPS (More-Care)	AURORAxmp	ATP-EMTP	ENGAGE
	eTransport	AWPT	EMCAS	DigSILENT	MARKAL
	Fi.Si. (Field Simulator)	HIRPOM	GTMax	DINIS	NEMS
	Flexibility forecasting tool	LocalPred-RegioPred	PLEXOS	DYMOLA	PLEXOS
	Flextool	Prediktor	UPLAN	EMTP-RV	REMIND
	HESA	RAL (More-Care)	WASP IV	ERACS	TIMES
	HMms	SIPREÓLICO	WILMAR	ETAP	WITCH
	Intelligator	WPPT		ETRAN	
	IPSYS	Zephyr		IPSA	
	LDM-SG			MATLAB	
	LV Planning			Opal-RT	
	Ma.Re.			OpenDSS	
	MODERNE			PowerWorld	
	MONET			PSCAD/EMTDC	
	MST			PSS Sincal	
	OPAL/ SAMREL			PSS/E	
	PowerMatcher			RTDS	
	Probabilistic Load MODELLING			SKM Power Tools	
	Prodnett				
	Samnett				
	SCUDO				
	SPREAD				
	VoCANT				
	VPP				

Source: JRC, 2017.

Table 5. Reviewed energy system models within the selected reviews.

(*Editor's note*: Models included in the report are highlighted in red)

Reference	[2]	[7]	[8]	[9]	[10]	[11]	[12]		[13]
Models	AEOLIUS	EFOM	DER-CAM	2050-Calc-ERI	ARES	Balmorel	4see	IPAT	Balmorel
	BALMOREL	LEAP	EAM	CGE-NCEPU	Dymola/Modelica	COMPOSE	ADEPT	LEAP	Calliope
	BCHP Screening Tool	MARKAL	H2RES	CREAM-ERI	HOMER	DER-CAM	AEOLIUS	MARKAL	DESSTinEE
	COMPOSE	MESAP	HOMER	DCGE-SIC	Hybrid Designer	EnergyPLAN	AMOSENVI	MATLAB	DIETER
	E4cast	NEMS	MARKAL/TIMES	EEM-ERI	HYBRID2	ENPEP-BALANCE eTransport	BALMOREL	MCA	EMLab-Generation
	EMCAS	POLES	RETScreen	IO-TU	HYBRIDS	HOMER	BCHP	MDM-E3	EMMA
	EMINENT	RESGEN		IPAC-ERI	HybSim	LEAP	BREDEM	MEDEE	Energy Transition Model
	EMPS	SAGE		IPAT-CUMT	HySim	RETScreen	BREHOMES	MERGE-ETL	EnergyNumbers-Balancing
	EnergyPLAN	TIMES		LEAP-TU	HYSYS	SIVAEL	BRM	Mesap PlaNet	EnergyRt
	energyPRO	WEM		MARKAL-TU	iGRHYSO	STREAM	BVCM	MESSAGE total	Ficus
	ENPEP-BALANCE			MESSAGE-UCAS	iHOGA	TIMES	CDEM	MiniCAM	Genesys
	GTMax			MRIO-CAS	INSEL	TRNSYS	CMAQ	MODEST	MultiMod
	H2RES			MSCGE-DRC	IPSYS		COMPOSE	NEMS	NEMO
	HOMER			PMP-TU	RAPSIM		DECarb	ORCED	ONSSET
	HYDROGEMS			POM-USTC	RETScreen		DECC 2050 calculator	OSeMOSYS	OSeMOSYS
	IKARUS			TEDCGE-RU	SOLSIM		DECC energy model	Other MARKAL	Oemof
	INFORSE			TIMES-TU	SOLSTOR		DENO	PERSEUS	PLEXOS Open EU
	Invert			TOM-RU	SOMES		DER-CAM	PLEXOS	PowerMatcher
	LEAP				TRNSYS		DNE21	POLES	PyPSA
	MARKAL/TIMES						DTI energy model	PRIMES	Renpass
	Mesap PlaNet						DynEMo	ProdRisk	SIREN
	MESSAGE						E3MG	RAMSES	SciGRID
	MiniCAM						E4cast	REDGEM	StELMOD
	NEMS						ELESA	REMIND	Temoa
	ORCED						ELMOD	RESOM	URBS
	PERSEUS						EMCAS	RETScreen	
	PRIMES						EMINENT	SAP	
	ProdRisk						EMPS	SELMA	
	RAMSES						EnerGIS	SHIPMod	
	RETScreen						EnergyPLAN	SimREN	
	SimREN						energyPRO	SIVAEL	
	SIVAEL						ENPEP	State-task network	
	STREAM						ENUSIM	STREAM	
	TRNSYS16						ESME	TDM	
	UniSyD3.0						GAINS	TEMOA	
	WASP						GCAM	TIMER	
	WILMAR Planning Tool						GEM-E3	TRNSYS	
							GET	TURN	
							GRAPE	UKDCM2	
							GTMax	UKENVI	
							H2RES	UKTCM	
							HOMER	UniSyD3	
							HYDROGEMS	VantagePoint	
							IKARUS	WADE	
							IMACLIM	WASP	
							IMAGE	WEPS	
							INFORSE	WILMAR	
							Invert	WITCH	

Source: JRC, 2017.

Table 6. Other models within the selected reviews.

(*Editor's note*: Models included in the report are highlighted in red)

Reference	[14]		[15]
Models	DSATools DYNA4 Simulation Toolkit EasyPower EDSA Paladin Toolkit EMCAS EnergyPLAN ETAP toolkit FASTSim GREET Grid 360/iEnergy GridLAB-D GridSpice GTMax HOMER HYPERSIM/ePOWERgrid iGRHYSO IKARUS InterPSS IPSA	MARKAL/TIMES MesapPlaNet MiPower Modelica Toolkit NEPLAN|Electricity OpenDSS ORCED PLEXOS POM Applications Suite PowerFactory PSAT RAPSim Saber Simpow SOMES SPARD Power THYME V2G-Sim Xendee Tool	CLEWS FORESEER GCAM MARKAL/TIMES PRIMA ReEDS SATIM The WEF nexus tool (Qatar Environment and Energy Research Institute) TIAM-FR WEAP/LEAP/OSeMOSYS ADVANCE ADVISOR AVL CRUISE CASPOC COMPOSE CYME

Source: JRC, 2017.

Annex 3. Factsheets of modelling tools

This annex provides the factsheets of modelling tools according to the information collected from the respondents: this has an impact on degree of homogeneity in the insight between different factsheets.

Note that the factsheets are in alphabetical order as given in Table 2.

1-node model

Organisation	Chalmers University of Technology
Description	Regional investment and dispatch model accounting for viability and a range of variation management strategies such as thermal cycling, DSM and batteries.
Availability	Open source, Other (model is shared internally, working on getting it open source. All equations are published)
First Release	2016-01-20
Last Release	2017-04-24
Users of the tool	Less than 20
Platform	Windows, macOS, Linux
Third-part software	GAMS
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Less than one year
Time step	Hourly
Geographical coverage	Regional
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	

AMaCha

Organisation	RSE S.p.A.
Description	It analyses historical data of power production from FER (wind and photovoltaic), and it generates some new realistic series that have the same statistical features. The objective is to use these new series like input in Monte Carlo cycles
Availability	Other (free download upon request signing agreement with RSE)
First Release	2013-06-27
Last Release	2017-01-27
Users of the tool	Less than 20
Platform	Windows
Third-part software	Matlab
I/O structure	Spread sheets
I/O compatibility	no
Horizon	Multiple years
Time step	Hourly
Geographical coverage	Local, Regional, National, Global
Analytical approach	
Underlying methodology	
Mathematical approach	
Form	Probabilistic (sequential Monte Carlo)
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

AMIRIS

Organisation	German Aerospace Center, Department of Systems Analysis and Technology Assessment
Description	The agent-based simulation model AMIRIS offers an innovative approach for the analysis and evaluation of energy policy instruments and mechanisms for the integration of renewable energies into the electricity markets.
Availability	Other (in house development and application)
First Release	2011-01-01
Last Release	2017-05-01
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	Repast Simphony, Java
I/O structure	Other (csv, xml)
I/O compatibility	
Horizon	Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	National
Analytical approach	Bottom-up, Other (nested models: agents base their decisions on internal models)
Underlying methodology	Simulation
Mathematical approach	Agent-based programming
Form	Probabilistic (sequential Monte Carlo)
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

ANTARES

Organisation	RTE
Description	ANTARES performs adequacy and economy simulation on large interconnected systems.
Availability	Commercial
First Release	2007-01-01
Last Release	2017-04-19
Users of the tool	Between 20-50
Platform	Windows, Linux
Third-part software	
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly
Geographical coverage	Regional, National, Global
Analytical approach	Top-down, Bottom-up, Hybrid
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming, Mixed-integer programming
Form	Probabilistic (sequential Monte Carlo)
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Artelys Crystal City

Organisation	Artelys
Description	Artelys Crystal City is designed to support local policy maker in the design of their multi-energy local energy system. The software includes detailed demand modelling capabilities, with a fine geographical scale and accounting for energy uses and sectors.
Availability	Commercial
First Release	
Last Release	2016-11-24
Users of the tool	Less than 20
Platform	Windows
Third-part software	FICO XPRESS solver / Coin CLP
I/O structure	Spread sheets, Data bases, Other (customized I/O function for various data sources can be devised)
I/O compatibility	
Horizon	Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Local, Regional
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Artelys Crystal Super Grid

Organisation	Artelys
Description	Artelys Crystal Super Grid is designed for capacity expansion planning. It simulates the operation of power systems on an hourly basis for a whole year, while also factoring in uncertainties like weather variations. The software computation capabilities allow to optimize both production dispatch and capacities at once while taking into account a large number of weather scenarios.
Availability	Commercial
First Release	
Last Release	2017-03-15
Users of the tool	Between 20-50
Platform	Windows, Linux, Other (macOS compatibility has not been heavy tested yet)
Third-part software	FICO XPRESS / Coin CLP
I/O structure	Spread sheets, Data bases, Other (customized I/O function for various data sources can be devised)
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years
Time step	Minutes, Hourly, Daily
Geographical coverage	Regional, National
Analytical approach	Top-down, Bottom-up, Hybrid, Other (power mix is bottom-up modelled but capacities are optimised according to top-down constraints)
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming, Other (decomposition for large scale problems)
Form	Deterministic, Probabilistic (sequential Monte Carlo), Stochastic programming
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Balmorel – SO2

Organisation	Open source model
Description	Balmorel is a partial equilibrium model for analysing the electricity and combined heat and power sectors in an international perspective.
Availability	Free to download, Open source
First Release	2001-01-01
Last Release	
Users of the tool	Between 20-50
Platform	Windows
Third-part software	GAMS
I/O structure	Spread sheets, Data bases, Other (text files)
I/O compatibility	No
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Local, Regional, National, Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Balmorel – RAM-lose

Organisation	RAM-lose (www.RAM-lose.dk), Systems Analysis Group at Department of Management Engineering at DTU, the Technical University of Denmark (http://www.sys.man.dtu.dk), Ea Energy Analyses (www.eaea.dk)
Description	Balmorel is a highly versatile partial equilibrium model for analysing the electricity and combined heat and power sectors in an international perspective.
Availability	Free to download, Open source
First Release	2001-04-01
Last Release	2016-02-03
Users of the tool	Between 20-50
Platform	Windows, Linux
Third-part software	GAMS modelling system and some appropriate solver
I/O structure	Other (text files)
I/O compatibility	GAMS provides import/export facilities with i.a., Excel, Acces,
Horizon	Multiple years
Time step	Hourly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Equilibrium, Optimization, Other (calibrations methods based on top-down information available)
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy

BEM

Organisation	Paul Scherrer Institute (PSI)
Description	Multilevel equilibrium market model for Europe of Nash-Cournot type
Availability	Other (Available for academic collaborative projects / open source for consulting projects)
First Release	2015-12-01
Last Release	2017-05-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS, PATH
I/O structure	Spread sheets
I/O compatibility	
Horizon	Other (Bi-level approach: one investment step , different hourly load periods for production)
Time step	Hourly
Geographical coverage	Regional
Analytical approach	Bottom-up, Hybrid
Underlying methodology	Equilibrium, Optimization
Mathematical approach	Linear programming, Other (Nash-Cournot equilibrium: linear for each player, in case the risk constraint is relaxed)
Form	Deterministic, Stochastic programming
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Research, innovation and competitiveness

BETSEE

Organisation	EKC
Description	Platform for the simulation of regional cross-border balancing market
Availability	Commercial
First Release	2006-10-01
Last Release	2010-06-30
Users of the tool	Between 50-1000
Platform	Linux
Third-part software	
I/O structure	Spread sheets
I/O compatibility	
Horizon	Other (one day)
Time step	Hourly
Geographical coverage	Regional
Analytical approach	
Underlying methodology	
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Research, innovation and competitiveness

CAPE

Organisation	Electrocon Inc.
Description	Modelling of power system short circuit currents and impedances
Availability	
First Release	
Last Release	
Users of the tool	Less than 20
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	
Time step	
Geographical coverage	
Analytical approach	
Underlying methodology	
Mathematical approach	
Form	
EU strategy dimensions	

CONTINENTAL MODEL

Organisation	EDF R&D
Description	Multi-zone electric system optimization and simulation, for mid to long-term analysis
Availability	Commercial
First Release	
Last Release	2017-03-30
Users of the tool	Between 20-50
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	Multiple years
Time step	Hourly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Equilibrium, Optimization, Simulation
Mathematical approach	Linear programming, Mixed-integer programming, Dynamic programming
Form	Probabilistic (sequential Monte Carlo), Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

CONVERGENCE

Organisation	RTE
Description	Convergence is a collaborative grid study platform providing tools leveraging studies from Real Time to Long Term Planning
Availability	Commercial
First Release	2009-01-02
Last Release	2017-04-04
Users of the tool	Between 50-1000
Platform	Windows, Linux, Other (Linux RedHat on Server side, Windows & Linux on Client side)
Third-part software	Versant Object Database, RedHat JBoss EAP, HTCondor, Apache Thrift
I/O structure	Data bases, Other (files)
I/O compatibility	CGMES, CIM ENTSO-E v1, UCTE format
Horizon	Less than one month, Less than one year, Multiple years, Other (from close to real time to long term, +20 years)
Time step	Seconds, Minutes, Hourly, Daily
Geographical coverage	Local, Regional, National, Global
Analytical approach	Top-down, Bottom-up, Hybrid
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming, Mixed-integer programming, Other (Non-linear programming)
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy

DIMENSION

Organisation	ewi ER&S
Description	European electricity and neighbouring sectors (heat, industry, mobility) market model.
Availability	Other (Individual contracts)
First Release	2010-01-01
Last Release	
Users of the tool	Between 20-50
Platform	Windows
Third-part software	GAMS, linear solver
I/O structure	Spread sheets, Data bases
I/O compatibility	no
Horizon	Multiple years
Time step	Hourly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy

Dispa-SET

Organisation	European Commission - DG JRC - Knowledge for the Energy Union
Description	The Dispa-SET model is an open-source unit commitment and dispatch model developed within the "Joint Research Centre" and focused on the balancing and flexibility problems in European grids. Its pre and post-processing tools are written in Python and the main solver can be called via GAMS or via PYOMO. The selected Mixed-Integer Linear Programming (MILP) solver is CPLEX.
Availability	Open source
First Release	2009-06-30
Last Release	2017-06-06
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	GAMS
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Other (Time horizon limit is just computational)
Time step	Hourly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Dome

Organisation	Federico Milano
Description	High-performance tool for power system dynamic analysis
Availability	Commercial, Other (source is shared among collaborators of the main developer)
First Release	2010-09-01
Last Release	2017-04-26
Users of the tool	Between 20-50
Platform	Windows, macOS, Linux
Third-part software	SuiteSparse, GSL, CVXOPT, Python, NVidia drivers, and many others
I/O structure	Spread sheets, Data bases
I/O compatibility	Yes
Horizon	Other (up to several tens of minutes)
Time step	Seconds
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up
Underlying methodology	Equilibrium, Optimization, Simulation
Mathematical approach	Linear programming and Mixed-integer programming in a very marginal part of its code; and Other (time-domain analysis of a set of nonlinear differential-algebraic equations, stochastic differential-algebraic equations, delay differential-algebraic equations)
Form	Deterministic, Other (mainly dynamic stochastic analysis)
EU strategy dimensions	Research, innovation and competitiveness

eGo

Organisation	Reiner Lemoine Institut, Next Energy, ZNES
Description	Development of a holistic grid planning tool as an integral part of an open energy modelling platform aiming at the determination of an optimal grid and storage expansion in Germany.
Availability	Open source
First Release	
Last Release	
Users of the tool	
Platform	Windows, macOS, Linux
Third-part software	Pypsa
I/O structure	Spread sheets, Data bases
I/O compatibility	No
Horizon	Multiple years
Time step	Hourly
Geographical coverage	National
Analytical approach	Top-down
Underlying methodology	Optimization
Mathematical approach	Linear programming, Other (Newton-Raphson-method)
Form	Deterministic
EU strategy dimensions	Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

ELFO++

Organisation	REF-E srl
Description	Elfo++ (ELectricity FOrecasting) is proprietary and core model for simulation of the electricity market and optimum power system dispatching over short, medium and long-term time horizon with both deterministic and stochastic approach.
Availability	Commercial
First Release	2008-06-15
Last Release	2016-12-20
Users of the tool	Between 20-50
Platform	Windows, Other (web application available)
Third-part software	
I/O structure	Spread sheets
I/O compatibility	Every input and output has a simple predetermined structure decided by the developer (REF-E). Input and output are csv files.
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly
Geographical coverage	Global
Analytical approach	Other (system variable cost constrained optimization)
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming, Dynamic programming (in unit commitment), Other (optimal dispatching is a continuous quadratic problem)
Form	Deterministic, Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

ELMOD

Organisation	TU Dresden
Description	ELMOD is a large-scale spatial optimization model of the European electricity market including both generation and the physical transmission network on DC Load Flow approach in its basic version.
Availability	
First Release	
Last Release	
Users of the tool	Between 20-50
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	Less than one year
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up, Hybrid
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market

ELTRAMOD

Organisation	TU Dresden
Description	ELTRAMOD (Electricity Transshipment Model) is a dispatch and investment model which allows fundamental analysis of the European electricity market and of each member state.
Availability	
First Release	
Last Release	
Users of the tool	
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	Less than one month, Multiple years
Time step	Hourly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

EMMA

Organisation	Neon
Description	The Electricity Market Model EMMA is a techno-economic model of the North-Western European power market, simultaneously modelling hourly) dispatch and (yearly) investments in power plants.
Availability	Open source
First Release	2013-01-01
Last Release	2017-01-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS + linear solver (e.g., CPLEX)
I/O structure	Spread sheets
I/O compatibility	
Horizon	Multiple years
Time step	Hourly
Geographical coverage	National
Analytical approach	
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market

EMPS

Organisation	SINTEF Energy Research
Description	EMPS is a optimization and simulation model for hydrothermal systems
Availability	Commercial
First Release	1975-01-01
Last Release	2017-03-01
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	CPLEX, depending on use
I/O structure	Other (interface in addition to files)
I/O compatibility	
Horizon	Multiple years
Time step	Hourly, Daily, Weekly
Geographical coverage	Local, Regional, National, Global
Analytical approach	Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming, Dynamic programming
Form	Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

EnEkon

Organisation	Lithuanian Energy Institute
Description	a CGE model for the analysis of economic impacts of development of power and other energy systems
Availability	Other (subject of negotiations, it can be implemented in common projects)
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	GAMS
I/O structure	Spread sheets
I/O compatibility	
Horizon	Multiple years
Time step	Yearly
Geographical coverage	National
Analytical approach	Top-down, Hybrid
Underlying methodology	Equilibrium
Mathematical approach	Other
Form	Deterministic
EU strategy dimensions	Climate action - decarbonisation of the economy, Research, innovation and competitiveness

EnerPol

Organisation	Laboratory for Energy Conversion, ETH Zürich
Description	bottom-up, system-wide (on scale of continent or country) scenario-based simulation framework for assessments of energy, transportation and urban infrastructures, and population
Availability	Other (used internally for research & development projects)
First Release	2009-10-03
Last Release	2017-06-30
Users of the tool	
Platform	Linux
Third-part software	MATPOWER
I/O structure	Data bases
I/O compatibility	
Horizon	Multiple years
Time step	Minutes, Hourly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

ENTIGRIS

Organisation	Fraunhofer ISE
Description	The electricity model ENTIGRIS – Europe/Germany is an expansion planning model for electricity system by considering cost projections and long-term climate policies.
Availability	
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS and CPLEX
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy

EPOD

Organisation	Chalmers University of Technology
Description	Electricity system dispatch model accounting for thermal cycling, DSM, storage limitations of Nordic hydropower and load flow limitations on transmission (DC load flow) with European coverage.
Availability	Other (shared amongst researchers in the group, working on getting it open source)
First Release	
Last Release	2017-03-01
Users of the tool	Less than 20
Platform	Windows, macOS, Linux
Third-part software	GAMS
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Less than one year, Multiple years
Time step	Hourly
Geographical coverage	Regional
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

ESPAUT

Organisation	RSE S.p.A.
Description	Selects an optimised network expansion for given scenarios among a set of reinforcement, minimising the overall capital and operational costs over a long term period
Availability	Other (free download upon request signing agreement with RSE)
First Release	2006-02-28
Last Release	2015-02-28
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS CPLEX
I/O structure	Other (ASCII csv)
I/O compatibility	no
Horizon	
Time step	
Geographical coverage	Local, Regional, National, Global
Analytical approach	
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency

ETP-TIMES

Organisation	Energy Technology Policy Division, IEA (TIMES methodology developed by IEA-ETSAP)
Description	The ETP-TIMES Supply model is a global long-term capacity expansion model, divided into 28 world regions, and depicting primary energy supply, power generation and other fuel transformation in a technology-rich least-cost optimization framework. The ETP-TIMES Dispatch model depicts the operation of the electricity system in selected region and for selected years with an hourly resolution to analyse the role of different flexibility measures in a low-carbon electricity system.
Availability	Other (TIMES source code in GAMS available for free. Use of commercial interface tools to develop and analyse the model results is)
First Release	
Last Release	
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	GAMS, commercial solvers for larger models, use of commercial software interfaces (VEDA, ANSWER-TIMES) recommended.
I/O structure	Spread sheets, Data bases, Other
I/O compatibility	As TIMES is based on GAMS, typically GAMS input/output formats can be used, such as GDX. GDX result data can be imported in a dedicated result analysis tool, VEDA-BE.
Horizon	Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Local, Regional, National, Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic, Other (stochastic programming is available, but model size limits size of event tree.)
EU strategy dimensions	Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

EUCAD

Organisation	GAEL, Univ. Grenoble Alpes
Description	Power system operation across 24 European countries and multiple days.
Availability	Other (Equations are publicly available and detailed , but the code itself is not open source)
First Release	2015-09-30
Last Release	2015-09-30
Users of the tool	Less than 20
Platform	Windows, macOS, Linux
Third-part software	GAMS installation, CPLEX solver
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one year
Time step	Hourly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

EUSTEM

Organisation	PSI
Description	Multi regional, long term (2050+) European electricity model
Availability	Other (PSI property and available for applications in joint/collaborative projects)
First Release	2016-01-21
Last Release	2017-01-20
Users of the tool	Less than 20
Platform	Windows
Third-part software	VEDA, GAMS, IBM
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Multiple years
Time step	Hourly, Daily, Weekly, Yearly
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

FLOP

Organisation	Institute for Research in Technology
Description	The objective of the Electric System Reliability Model (FLOP) is to compute these indexes: Expected Energy Non Served (EENS) and Loss Of Load Probability (LOLP). For a pre-specified set of periods in which the year is divided. It uses discrete convolution method.
Availability	Commercial
First Release	2004-07-01
Last Release	2005-01-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one month, Less than one year
Time step	Hourly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Simulation
Mathematical approach	
Form	Probabilistic (non-sequential Monte Carlo)
EU strategy dimensions	

GE PSLF

Organisation	GE Energy Consulting
Description	Power Flow, Short Circuits, Dynamics, Geo magnetic disturbance, Node-Breaker, Optimal Power Flow, Model validation, Power system studies
Availability	Commercial
First Release	
Last Release	
Users of the tool	> 1000
Platform	Windows, Linux
Third-part software	
I/O structure	Spread sheets, Data bases
I/O compatibility	PSLF EPC, PSLF DYD, PSSE RAW, PSSE DYR, IEEE Common format
Horizon	Multiple years, Other
Time step	Any
Geographical coverage	Local, Regional, National, Global
Analytical approach	
Underlying methodology	Simulation
Mathematical approach	Other (Newton-Raphson, Fast Decoupled, DC methods for power flow analyses and partitioned-explicit numerical solver for transient stability analyses)
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Research, innovation and competitiveness

GOESTO

Organisation	EDF R&D OSIRIS
Description	The purpose of the Goesto tool is to cover gas portfolio management process from structuring (contract optimal sizing) to short term (daily nominations) and mid-term (deltas computations, cash flow distribution) horizons. Goesto is a tool box with different models - both deterministic and stochastic - sharing a common data model. The underlying model aims to match a gas demand in the least cost manner while satisfying gas portfolio specific constraints.
Availability	Commercial
First Release	2012-12-13
Last Release	2017-03-27
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	Depending of the algorithm, Goesto requires the use of a solver (Cplex, Coin, Gurobi) or not (infinite market liquidity assumption)
I/O structure	Spread sheets
I/O compatibility	
Horizon	Multiple years
Time step	Daily, Weekly, Monthly, Yearly
Geographical coverage	
Analytical approach	
Underlying methodology	Equilibrium, Optimization, Simulation
Mathematical approach	Linear programming, Mixed-integer programming, Dynamic programming
Form	Deterministic, Stochastic programming
EU strategy dimensions	

GRARE

Organisation	GRARE is property of Terna (www.terna.it) and developed from CESI
Description	It evaluates reliability and economic operational capability using probabilistic Monte Carlo analysis to support medium and long-term planning studies. Suited for large power systems, modelling in detail the transmission network
Availability	Commercial
First Release	2000-11-04
Last Release	2017-05-14
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	MS Office including Access
I/O structure	Spread sheets, Other (3D plot for ENS distribution over the year)
I/O compatibility	GRARE is integrated in SPIRA application that is based on a network Data Base of the system being analysed. CIM, PTI and other standards are compatible with SPIRA.
Horizon	Multiple years, Other (the year horizon is standard, possible to extend to different climatic years)
Time step	Hourly
Geographical coverage	Local, Regional, National, Global
Analytical approach	Top-down, Other (approach is a trade-off simplification and complexity)
Underlying methodology	Optimization, Simulation, Other (Optimisation of thermal unit maintenance and hydro production, minimisation of system costs in unit commitment and dispatching/re-dispatching and solution of energy not supplied problems)
Mathematical approach	Linear programming, Other (Quadratic programming)
Form	Probabilistic (sequential Monte Carlo), Probabilistic (nonsequential Monte Carlo)
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Green islands

Organisation	LEMNA - Laboratory of Economics and Management Loire-Atlantic
Description	It simulates market operation and islanded power systems on renewables and storage.
Availability	Other (Academia cooperation)
First Release	2016-04-01
Last Release	2017-01-10
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS - CPLEX / path
I/O structure	Spread sheets, Data bases
I/O compatibility	yes
Horizon	Multiple years
Time step	Hourly
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Dynamic programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Climate action - decarbonisation of the economy

iTesla Power System Tools

Organisation	iPST consortium: AIA, Artelys, Imperial College, INESCTEC, KTH, Pepite, RSE, RTE, TechRain, Tractebel Engie
Description	iTesla Power System Tools is a Platform able to cope with Load and Renewable Generation uncertainties in order to help the operator assess network security in real time and ease his/her decision making
Availability	Commercial (most computation modules), Free to download, Open source (framework)
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Linux
Third-part software	Eurostag, Hades LF, HELM, AMPL, KNITRO, Xpress, DataMaestro
I/O structure	Data bases, Other (files)
I/O compatibility	CIM v14, UCTE format
Horizon	Less than one month
Time step	Seconds, Minutes, Hourly, Daily, Weekly, Monthly
Geographical coverage	Global
Analytical approach	Top-down, Bottom-up, Hybrid
Underlying methodology	Equilibrium, Optimization, Simulation
Mathematical approach	Linear programming, Mixed-integer programming, Other (Non Linear Programming)
Form	Probabilistic (nonsequential Monte Carlo)
EU strategy dimensions	Security, solidarity and trust

LEI - MESA

Organisation	Lithuanian Energy Institute
Description	The methodology is used for energy security assessment in terms of energy system resistance to disruptions.
Availability	Other (partially open)
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	OSeMOSYS tool, MATLAB software
I/O structure	Other (.txt files, .m files)
I/O compatibility	No
Horizon	Multiple years
Time step	Any
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic, Probabilistic (nonsequential Monte Carlo)

LIMES

Organisation	Potsdam Institute for Climate Impact Research (PIK)
Description	LIMES is a long-term optimization model that optimizes the investment into and dispatch of electricity generation capacities as well as inter-country transmission grid in Europe.
Availability	Other (code available upon request from authors)
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	GAMS, Matlab
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

LUSYM

Organisation	KU Leuven
Description	operational model for electricity generation (unit commitment type)
Availability	Other (mainly internal use)
First Release	2014-06-02
Last Release	2016-09-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	Matlab/Python, GAMS, CPLEX/GUROBI
I/O structure	Spread sheets
I/O compatibility	no
Horizon	Less than one month, Less than one year
Time step	Any, Minutes, Hourly
Geographical coverage	National, Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic, Probabilistic (sequential Monte Carlo), Stochastic programming
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

MaCSIM

Organisation	Electricity Coordinating Center
Description	Market Coupling Simulator (MaCSim) is a web-based software for the simulation of day-ahead European price coupling, in forms of NTC-based and Flow-based Market Coupling.
Availability	Commercial
First Release	
Last Release	2015-02-19
Users of the tool	Between 20-50
Platform	Windows
Third-part software	
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one month
Time step	Hourly
Geographical coverage	Global
Analytical approach	
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market

Merlin

Organisation	EKC
Description	Conversion and merging models in PSS/E and UCTE format
Availability	Commercial
First Release	2005-10-31
Last Release	2015-04-09
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	
I/O structure	Other (files in PSS/E RAW format; files in UCTE format)
I/O compatibility	Siemens PTI RAW format, UCTE format (UCTE-DEF)
Horizon	
Time step	
Geographical coverage	Local, Regional, National, Global
Analytical approach	
Underlying methodology	
Mathematical approach	
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Research, innovation and competitiveness

MESSAGE - IAEA

Organisation	IAEA
Description	Long-term least-cost energy system optimization model
Availability	Free to download, Other (obtainable upon request to the IAEA)
First Release	2001-01-01
Last Release	2016-11-01
Users of the tool	> 1000
Platform	Windows
Third-part software	GLPK or CPLEX or GUROBI
I/O structure	Other (Data input and results through user interface, stored in text files)
I/O compatibility	
Horizon	Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Local, Regional, National, Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

MESSAGE - LEI

Organisation	IAEA, IIASA
Description	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
Availability	Other (free for not commercial use, it can be obtained from IAEA after signing agreement)
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	solver is needed (CPLEX, GLPK, etc.)
I/O structure	Spread sheets, Other (different data input options are possible)
I/O compatibility	
Horizon	Multiple years, Other (it can be applied also for long term and short term analyses)
Time step	Any
Geographical coverage	Local, Regional, National, Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy

METIS

Organisation	Property: DG ENER. Development: Artelys.
Description	METIS simulates the operation of both European energy systems and markets for electricity gas and heat on an hourly basis for a whole year, while also factoring in uncertainties like weather variations.
Availability	Other (METIS model is owned by DG ENER)
First Release	2016-02-01
Last Release	2017-04-06
Users of the tool	Less than 20
Platform	Windows
Third-part software	METIS relies on Artelys Crystal Super Grid platform, property of Artelys, for computation and visualization services.
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one month, Less than one year
Time step	Minutes, Hourly, Daily
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Probabilistic (sequential Monte Carlo)
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

MORGANE

Organisation	EDF R&D OSIRIS
Description	Morgane is EDF Middle Term Hydro Management Tool. It is used for : optimizing Hydro Asset Engineering, Optimizing Unit Maintenance Planning, Preparing Short Term Management.
Availability	Commercial
First Release	2009-01-29
Last Release	2016-12-19
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	Morgane requires the use of a solver (Coin)
I/O structure	Spread sheets
I/O compatibility	
Horizon	Multiple years
Time step	Daily, Weekly, Monthly, Yearly
Geographical coverage	Local
Analytical approach	
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming
Form	Stochastic programming
EU strategy dimensions	

NEMO

Organisation	N/A (Ben Elliston)
Description	Time sequential generation dispatch model
Availability	Open source
First Release	2013-06-13
Last Release	2017-01-06
Users of the tool	Less than 20
Platform	Windows, macOS, Linux
Third-part software	Python plus several freely available Python packages
I/O structure	Other (CSV trace files of demand, generation)
I/O compatibility	
Horizon	Multiple years
Time step	Any
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Other (evolution program)
Form	Deterministic
EU strategy dimensions	Energy efficiency, Climate action - decarbonisation of the economy

NETPLAN

Organisation	PSR
Description	NETPLAN is an integrated computational environment for transmission network planning and analysis which includes basically four models: (i) PSRFlow: for network transmission analysis (AC or DC power flow), (ii) OptNet: for transmission expansion planning, (iii) OptFlow: for optimal AC power flow and expansion planning of reactive resources and (iv) Tariff: for transmission cost allocation.
Availability	Commercial
First Release	2007-01-01
Last Release	2017-07-04
Users of the tool	Between 50-1000
Platform	Windows, Linux
Third-part software	The Xpress solver and license are embedded in our solutions (there is no additional cost for the users).
I/O structure	Spread sheets, Data bases
I/O compatibility	PSR's input data are ASCII formatted files (all documented) and the graphical interfaces presents Excel integration (importation/exportation functionality) for facilitating the input data editing.
Horizon	Less than one year, Multiple years
Time step	Hourly, Weekly, Monthly, Yearly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming, Other (Nonlinear optimization)
Form	Other
EU strategy dimensions	Integration of EU internal energy market, Research, innovation and competitiveness

oemof

Organisation	Center for Sustainable Energy Systems (ZNES) Flensburg, Reiner Lemoine Institute (RLI) Berlin, Otto-von-Guericke-University of Magdeburg (OVGU)
Description	oemof provides a free, open source and clearly documented toolbox developed for the modelling and analysis of energy supply systems considering power, heat and mobility.
Availability	Open source
First Release	2015-11-25
Last Release	2017-03-28
Users of the tool	Between 20-50
Platform	Windows, macOS, Linux
Third-part software	python 2 or 3, solver such as CBC, GLPK, Gurobi, Cplex
I/O structure	Spread sheets, Data bases, Other (interfaces to csv files and databases, plots)
I/O compatibility	no
Horizon	Less than one month, Less than one year, Multiple years
Time step	Any
Geographical coverage	Local, Regional, National, Global
Analytical approach	Hybrid
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market

open_eGo	
Organisation	Research Centre 2
Description	Power system optimization considering storage and electricity grid extension measures.
Availability	Free to download, Open source
First Release	2017-06-30
Last Release	2017-06-30
Users of the tool	Less than 20
Platform	Linux
Third-part software	a linear solver (e.g. GLPK, Gurobi)
I/O structure	Data bases
I/O compatibility	
Horizon	Multiple years
Time step	Hourly
Geographical coverage	National
Analytical approach	Top-down
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Research, innovation and competitiveness

OPTGEN	
Organisation	PSR
Description	Optimal long term energy resources expansion planning model. Its objective is to determine the least cost investment schedule for the construction of new electricity and gas production capacities, transmission network and gas pipelines. The optimality of the expansion plan means minimizing a cost function considering investment and operation costs of generation plants and penalties of energy not supplied, also called deficit costs.
Availability	Commercial
First Release	2002-01-01
Last Release	2017-06-01
Users of the tool	Between 50-1000
Platform	Windows, Linux
Third-part software	The Xpress solver and license are embedded in our solutions (there is no additional cost for the users).
I/O structure	Spread sheets, Data bases
I/O compatibility	PSR's input data are ASCII formatted files and the graphical interfaces present Excel integration for facilitating the input data editing.
Horizon	Multiple years
Time step	Hourly, Weekly, Monthly, Yearly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

OWL	
Organisation	Institute for Research in Technology
Description	(OWL has been developed to efficiently find optimal electrical layouts in affordable computation times. Stochastic wind inputs and component failures are considered in an efficient manner. The tool incorporates the possibility of HVDC connection. Losses are included in the calculation.
Availability	Commercial
First Release	2010-01-01
Last Release	2016-07-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one year
Time step	Hourly
Geographical coverage	Local
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Stochastic programming
EU strategy dimensions	

Phoenix

Organisation	Consultancy company 1
Description	Internal capacity expansion and dispatch model
Availability	Other (internal development team: the tool continuously improves since more than 10 years)
First Release	
Last Release	
Users of the tool	Between 20-50
Platform	Windows, Linux, Other (web based interface)
Third-part software	CPLEX or Gurobi
I/O structure	Data bases, Other (CSV flat files)
I/O compatibility	
Horizon	Less than one month, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Equilibrium, Optimization
Mathematical approach	Linear programming, Other (mixed complementarity models solved iteratively as LPs)
Form	Deterministic, Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

Plexos – UCo2

Organisation	Internal model developed in Plexos
Description	The model seeks the supply/demand balance in each and every European country taking into account the existing power plants, the capacity of cross border connections and minimising the production costs
Availability	Commercial
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	commercial solvers
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years, Other (time horizon is user defined)
Time step	Any
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

Plexos – CCo1

Organisation	Energy Exemplar
Description	Investment and dispatch model with unit commitment constraints
Availability	Commercial
First Release	2000-07-01
Last Release	2017-05-11
Users of the tool	Between 20-50
Platform	Windows
Third-part software	Solver (Gurobi,CPLEX XPRESS)
I/O structure	Data bases, Other (XML)
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years
Time step	Minutes, Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Mixed-integer programming
Form	Deterministic, Probabilistic (sequential Monte Carlo), Stochastic programming
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Climate action - decarbonisation of the economy

PLEXOS EU 2030

Organisation	UCC and Energy exemplar
Description	High temporal resolution model (freely publically available) of 28 country European power & gas systems
Availability	Commercial, Free to download
First Release	2017-02-13
Last Release	2017-02-13
Users of the tool	Less than 20
Platform	Windows
Third-part software	for some solver like Xpress
I/O structure	Spread sheets, Data bases
I/O compatibility	PRIMES EU format for input is currently easiest
Horizon	Other (currently set up for 1 year 2030. 2050 and other years are in development)
Time step	Any
Geographical coverage	Regional
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic, Probabilistic (sequential Monte Carlo), Probabilistic (nonsequential Monte Carlo), Stochastic programming
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Climate action - decarbonisation of the economy

Powel Optimal Multi Asset

Organisation	Powel Smart Energy
Description	Optimises the use of the hydropower resource to maximise profit
Availability	Commercial
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	CPLEX
I/O structure	Data bases
I/O compatibility	No
Horizon	Less than one month
Time step	Minutes, Hourly, Daily
Geographical coverage	Local
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic, Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency

PROMEDGRID

Organisation	CESI/TERNA
Description	PROMEDGRID simulates the unit commitment and dispatching optimization of hydro-thermal generation systems over one year time horizon hour by hour. A specific implemented bidding strategy model allows to apply it for power market simulations.
Availability	Commercial
First Release	2011-01-31
Last Release	2016-01-30
Users of the tool	Between 20-50
Platform	Windows
Third-part software	
I/O structure	Spread sheets
I/O compatibility	
Horizon	Other (one year)
Time step	Hourly
Geographical coverage	National, Global
Analytical approach	
Underlying methodology	Optimization
Mathematical approach	Other (quadratic programming)
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

PSCAD

Organisation	Manitoba Hydro International Ltd
Description	general-purpose time domain simulation tool for studying transient behaviour of electrical networks
Availability	
First Release	
Last Release	
Users of the tool	
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	
Time step	
Geographical coverage	
Analytical approach	
Underlying methodology	
Mathematical approach	
Form	
EU strategy dimensions	

PSS/E – SO3

Organisation	SIEMENS
Description	Tool to simulate power flow and dynamics in electrical networks.
Availability	Commercial
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	PSS/E has integrated python programming language functionality, which extends tool possibility's a lot.
I/O structure	Spread sheets, Other (python and '.raw' format, which is actually text format file.)
I/O compatibility	Only ODMS has full CIM functionality. In PSS/E they implemented new "cim import" function, but it is not for free...
Horizon	Only one network snapshot at a time, using python many simulations (scenarios) are possible
Time step	
Geographical coverage	Local, Regional, National, Global
Analytical approach	Bottom-up
Underlying methodology	
Mathematical approach	
Form	Deterministic
EU strategy dimensions	

PSS/E – SO5

Organisation	SIEMENS
Description	Fast and robust power flow solution for network models up to 200,000 buses. Contingency analysis, including automatic corrective actions and remedial action scheme modelling. Full node-breaker support for detailed modelling of substation topology. Automated PV/QV analysis with plot generation. Powerful program automation and customization with full-featured Python® API. Balanced and unbalanced fault analysis, contingency analysis (deterministic and probabilistic). Modern graphical user interface. Comprehensive power flow and dynamics model library including emerging technologies such as advanced FACTS devices and wind turbines.
Availability	Commercial
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	
I/O structure	Spread sheets
I/O compatibility	CIM
Horizon	Multiple years
Time step	Any
Geographical coverage	Local, Regional, National
Analytical approach	Top-down, Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming
Form	Deterministic, Probabilistic (sequential Monte Carlo)
EU strategy dimensions	Energy efficiency, Research, innovation and competitiveness

PSS/E – SO1

Organisation	Siemens PTI
Description	Load flow, fault current and dynamics modelling and calculation.
Availability	Commercial
First Release	1976-05-01
Last Release	2017-04-02
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	
I/O structure	Spread sheets, Data bases
I/O compatibility	I some of the PSS programs CIM is used.
Horizon	Less than one month, Less than one year, Multiple years
Time step	Any
Geographical coverage	Local, Regional, National
Analytical approach	
Underlying methodology	Simulation
Mathematical approach	
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

PSS/E – SO4

Organisation	Siemens
Description	steady state & dynamic analysis network modelling
Availability	Commercial
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	
I/O structure	Spread sheets, Data bases
I/O compatibility	CIM, RAW, CDU
Horizon	Less than one month, Less than one year, Multiple years
Time step	Any
Geographical coverage	Local, Regional, National
Analytical approach	Hybrid
Underlying methodology	Equilibrium
Mathematical approach	Linear programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Research, innovation and competitiveness

REMARK/REMARK+

Organisation	RSE
Description	Based on a nonsequential/sequential Monte Carlo simulation over an annual time horizon, REMARK/REMARK+ simulate optimal operation and perform adequacy analysis on composite systems
Availability	Other (free download upon request signing agreement with RSE)
First Release	2007-01-31
Last Release	2016-02-29
Users of the tool	Less than 20
Platform	Windows
Third-part software	CPLEX/GAMS
I/O structure	Other (ASCII csv files)
I/O compatibility	no
Horizon	Other (one year)
Time step	Hourly
Geographical coverage	Local, Regional, National, Global
Analytical approach	
Underlying methodology	Optimization
Mathematical approach	Linear programming
Form	Probabilistic (sequential Monte Carlo), Probabilistic (nonsequential Monte Carlo)
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

REMix

Organisation	DLR - German Aerospace Center, Institute of Engineering Thermodynamics, Department of Systems Analysis and Technology Assessment
Description	Energy system model with cost minimization approach for capacity expansion planning and operation optimization
Availability	Other (in house development and application)
First Release	2010-03-01
Last Release	2017-05-11
Users of the tool	Less than 20
Platform	Windows, Linux
Third-part software	GAMS, CPLEX
I/O structure	Spread sheets, Data bases, Other (csv files)
I/O compatibility	
Horizon	Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

RISK-BU

Organisation	EDF
Description	Asset portfolio modelling (customer contracts, generating resources, hedges, etc.) and portfolio management simulation based on a set of price scenarios for management of energy market risks.
Availability	Commercial
First Release	
Last Release	
Users of the tool	Between 20-50
Platform	Windows, Linux
Third-part software	
I/O structure	
I/O compatibility	
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly, Yearly
Geographical coverage	
Analytical approach	
Underlying methodology	Simulation
Mathematical approach	Dynamic programming
Form	Stochastic programming
EU strategy dimensions	

ROM

Organisation	Institute for Research in Technology
Description	The model objective is to determine the technical and economic impact of intermittent generation (IG) and other types of emerging technologies (active demand response, electric vehicles, concentrated solar power, and solar photovoltaic) into the medium-term system operation including reliability assessment.
Availability	Commercial
First Release	2010-05-01
Last Release	2017-05-01
Users of the tool	Less than 20
Platform	Windows, macOS, Linux
Third-part software	GAMS
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one year
Time step	Hourly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Mixed-integer programming
Form	Probabilistic (sequential Monte Carlo), Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

SciGRID

Organisation	NEXT ENERGY, EWE Research Centre for Energy Technology
Description	SciGRID is an open source and open data model of the European transmission network. The tool provides a model to automatically extract the European transmission network structure from the openstreetmap.
Availability	Free to download, Open source
First Release	2015-06-15
Last Release	2016-08-01
Users of the tool	Between 20-50
Platform	Mac, Linux
Third-part software	
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	
Time step	Any
Geographical coverage	Global
Analytical approach	Other
Underlying methodology	Other
Mathematical approach	Other
Form	Other
EU strategy dimensions	Research, innovation and competitiveness

SDDP – CCo1

Organisation	PSR
Description	Dispatch model for hydro dominated systems that calculates water values based on Stochastic Dual Dynamic Programming
Availability	Commercial
First Release	
Last Release	2016-02-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	XPRESS included
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Less than one year, Multiple years
Time step	Hourly, Daily, Weekly, Monthly
Geographical coverage	Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Other (Stochastic Dual Dynamic Programming)
Form	Stochastic programming
EU strategy dimensions	Integration of EU internal energy market

SDDP – PSR

Organisation	PSR
Description	SDDP is the optimal mid and long term stochastic production scheduling model used in more than 60 countries and its objective is to minimize the expected value of operation cost along the planning horizon.
Availability	Commercial
First Release	1998-01-01
Last Release	2017-06-23
Users of the tool	> 1000
Platform	Windows, Linux
Third-part software	The Xpress solver and license are embedded in our solutions (there is no additional cost for the users).
I/O structure	Spread sheets, Data bases
I/O compatibility	PSR's input data are ASCII formatted files and the graphical interfaces present Excel integration for facilitating the input data editing.
Horizon	Less than one month, Less than one year, Multiple years
Time step	Hourly, Weekly, Monthly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming, Other (Stochastic Dual Dynamic Programmin)
Form	Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Energy efficiency, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

SHOP

Organisation	SINTEF Energy Research
Description	SHOP is a deterministic optimization tool for optimal unit commitment and production decisions in complex cascaded watercourses with hydropower.
Availability	Commercial
First Release	1996-01-01
Last Release	2017-07-13
Users of the tool	Between 20-50
Platform	Windows
Third-part software	Cplex, Gurobi or OSI/CLP
I/O structure	Data bases, Other (proprietary ASCII format, Python API, WCF API)
I/O compatibility	No
Horizon	Less than one year
Time step	Any
Geographical coverage	Local, Regional, National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Climate action - decarbonisation of the economy, Research, innovation and competitiveness

SICRE

Organisation	CESI spa
Description	Dynamic Simulator for power system analysis, control and security assessment
Availability	
First Release	
Last Release	
Users of the tool	Between 50-1000
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	
Time step	Any
Geographical coverage	Local, Regional, National, Global
Analytical approach	Hybrid
Underlying methodology	Simulation
Mathematical approach	Dynamic programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust

sMTSIM

Organisation	RSE S.p.A.
Description	Medium Term Model Simulator
Availability	Free to download, Open source
First Release	2005-08-01
Last Release	2016-10-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	It uses Matlab and GAMS, but it can run also without GAMS
I/O structure	Spread sheets
I/O compatibility	no
Horizon	Other (it is flexible, but typical use is one year)
Time step	Hourly
Geographical coverage	Local
Analytical approach	Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming
Form	Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Research, innovation and competitiveness

SPIRA

Organisation	CESI
Description	Power system planning tool
Availability	Commercial
First Release	2000-02-01
Last Release	2017-05-30
Users of the tool	Less than 20
Platform	Windows
Third-part software	MS ACCESS
I/O structure	Spread sheets, Data bases, Other (txt files, diagram and Excel files)
I/O compatibility	CIM, PSS/E, Excel
Horizon	Multiple years
Time step	
Geographical coverage	Regional, National, Global
Analytical approach	
Underlying methodology	Optimization, Simulation
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust

STARNET

Organisation	Institute for Research in Technology
Description	It is a short and medium term model. In the short term demand is modelled chronologically, while in the medium term it considered as a load-duration curve. It can also be called as generalized unit commitment (GUC) because it solves simultaneously the following problems: a) Unit Commitment; b) Hydrothermal Economic Dispatch; c) Optimal Power Flow.
Availability	Commercial
First Release	2001-06-01
Last Release	2010-04-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS
I/O structure	Spread sheets
I/O compatibility	
Horizon	Less than one month
Time step	Hourly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Deterministic
EU strategy dimensions	Integration of EU internal energy market

STEM

Organisation	PSI
Description	In STEM, the Swiss energy system is depicted from resource supply to end-use energy service demands. The model combines a long time horizon (2010-2100) with an hourly representation of weekdays and weekends in three seasons.
Availability	Other (PSI holds the proprietary rights. Can be available for joint/collaborative projects)
First Release	2015-02-01
Last Release	2017-05-01
Users of the tool	Less than 20
Platform	Windows
Third-part software	GAMS, solvers
I/O structure	Spread sheets, Data bases
I/O compatibility	
Horizon	Multiple years
Time step	Hourly, Daily, Weekly, Monthly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic, Stochastic programming
EU strategy dimensions	Climate action - decarbonisation of the economy

SynerGEE – UCo1

Organisation	Utility company 1
Description	System development planning tool
Availability	Commercial
First Release	
Last Release	
Users of the tool	Less than 20
Platform	Windows
Third-part software	
I/O structure	Data bases
I/O compatibility	
Horizon	Multiple years
Time step	Any
Geographical coverage	National
Analytical approach	
Underlying methodology	Equilibrium, Simulation
Mathematical approach	
Form	Deterministic
EU strategy dimensions	

TEPES

Organisation	Institute for Research in Technology
Description	TEPES model presents a decision support system for defining the transmission expansion plan of a large-scale electric system at a tactical level. A transmission expansion plan is defined as a set of network investment decisions for future years. The candidate lines are pre-defined by the user, so the model determines the optimal decisions among those specified by the user, or identified automatically by the model. Candidate lines can be HVDC or HVAC circuits.
Availability	Commercial
First Release	2013-11-01
Last Release	2017-05-04
Users of the tool	Less than 20
Platform	Windows, Mac, Linux
Third-part software	GAMS
I/O structure	Spread sheets
I/O compatibility	
Horizon	Multiple years
Time step	Hourly
Geographical coverage	Global
Analytical approach	Bottom-up
Underlying methodology	Optimization
Mathematical approach	Mixed-integer programming
Form	Stochastic programming
EU strategy dimensions	Integration of EU internal energy market, Climate action - decarbonisation of the economy

TNA – EKC

Organisation	EKC, SEDMS
Description	Network models building, merging, validation and conversion, running Load Flow, contingency analyses, capacity calculations (NTC-based, Flow-based), short circuit analyses. Supporting UCT, CGMES and RAW data formats.
Availability	Commercial
First Release	2010-06-01
Last Release	2017-05-18
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	
I/O structure	Spread sheets, Data bases
I/O compatibility	CIM/CGMES is supported.
Horizon	
Time step	Hourly
Geographical coverage	Regional
Analytical approach	
Underlying methodology	
Mathematical approach	
Form	Deterministic
EU strategy dimensions	Security, solidarity and trust, Integration of EU internal energy market, Research, innovation and competitiveness

TNA - PSS/E - ISOBH

Organisation	TNA: Electricity Coordinating Center PSS/E: Siemens
Description	TNA: Software designed for all operation of validating, fixing and merging and converting the load flow data sets, load flow and contingency calculations, NTC calculation, PTDF/Maxflow calculations, as well as short circuit analyses PSS/E: Software for electric transmission system analysis and planning
Availability	Commercial
First Release	
Last Release	
Users of the tool	Not applicable
Platform	Windows
Third-part software	
I/O structure	Spread sheets
I/O compatibility	UCT, CIM, raw
Horizon	Less than one month, Less than one year, Multiple years
Time step	Any
Geographical coverage	Regional, National
Analytical approach	Top-down
Underlying methodology	Optimization, Simulation
Mathematical approach	Linear programming, Dynamic programming
Form	Deterministic, Probabilistic (sequential Monte Carlo), Stochastic programming
EU strategy dimensions	Energy efficiency, Research, innovation and competitiveness

Trimble

Organisation	Latvenergo AS
Description	Trimble NIS is used for modeling and managing key data of networks and related business processes.
Availability	Commercial
First Release	2006-01-01
Last Release	2017-01-22
Users of the tool	Between 50-1000
Platform	Windows
Third-part software	
I/O structure	Data bases
I/O compatibility	
Horizon	Other (one year)
Time step	Yearly
Geographical coverage	Local, Regional, National
Analytical approach	Top-down, Bottom-up
Underlying methodology	Simulation
Mathematical approach	Linear programming, Other (The Newton-Raphson method, Non-linear)
Form	Deterministic, Probabilistic (sequential Monte Carlo)
EU strategy dimensions	Energy efficiency, Research, innovation and competitiveness

WASP

Organisation	IAEA
Description	Long-term power system model building on probabilistic production cost simulation and optimization to investigate investments in new power plants.
Availability	Free to download, Other (upon request to the IAEA)
First Release	1978-01-01
Last Release	2000-01-01
Users of the tool	> 1000
Platform	Windows
Third-part software	
I/O structure	Other (Data input and results through user interface)
I/O compatibility	
Horizon	Multiple years
Time step	Monthly, Yearly
Geographical coverage	National
Analytical approach	Bottom-up
Underlying methodology	Optimization, Simulation
Mathematical approach	Dynamic programming
Form	Stochastic programming
EU strategy dimensions	Security, solidarity and trust, Climate action - decarbonisation of the economy

WCM	
Organisation	EDF R&D
Description	World-wide optimization and simulation of commodity markets, for mid to long term analysis
Availability	Commercial
First Release	
Last Release	2017-04-12
Users of the tool	
Platform	
Third-part software	
I/O structure	
I/O compatibility	
Horizon	Multiple years
Time step	
Geographical coverage	
Analytical approach	Bottom-up
Underlying methodology	Equilibrium, Optimization, Simulation
Mathematical approach	Linear programming, Mixed-integer programming
Form	Deterministic
EU strategy dimensions	

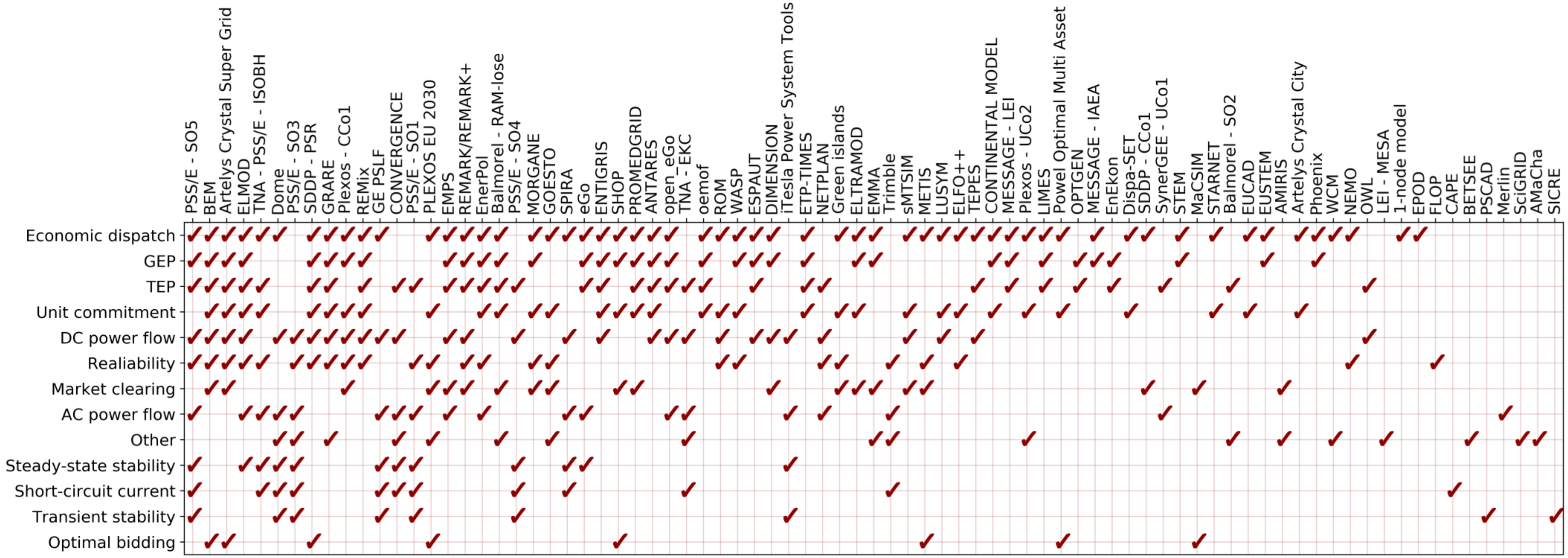
Annex 4. Detailed figures about mapping of modelling tools

This annex contains the detailed figures about the mapping of modelling tools with:

- Power system problems (Figure 21).
- Economic constraints (Figure 22).
- Technical constraints (Figure 23).
- Key input data (Figure 24).
- Key output data (Figure 25).
- Technologies (Figure 26).

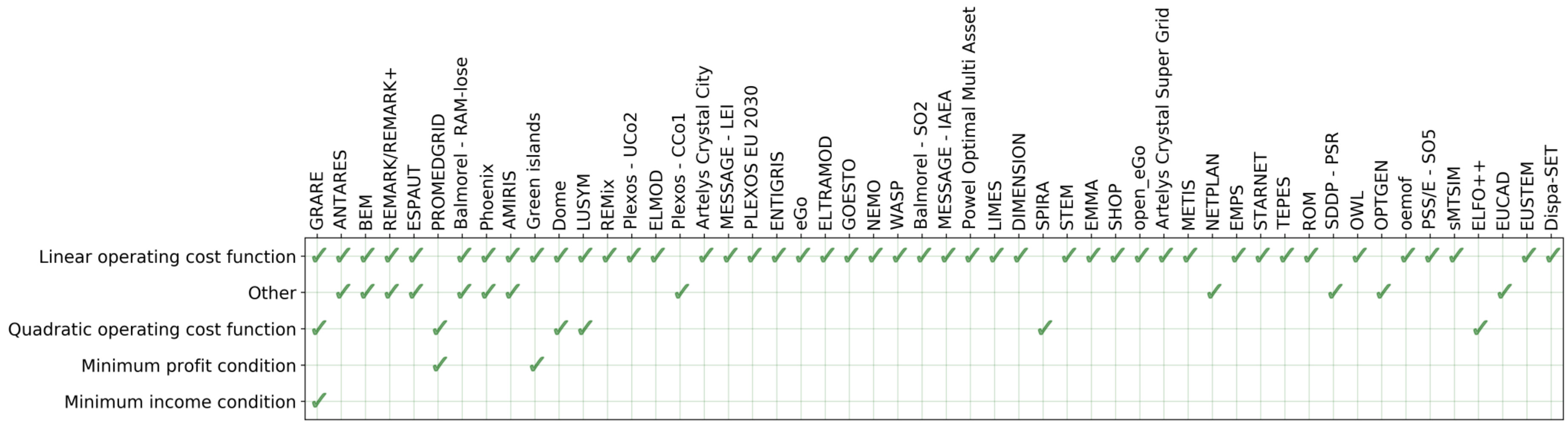
Figure 21. Mapping of power system problems and models.

(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

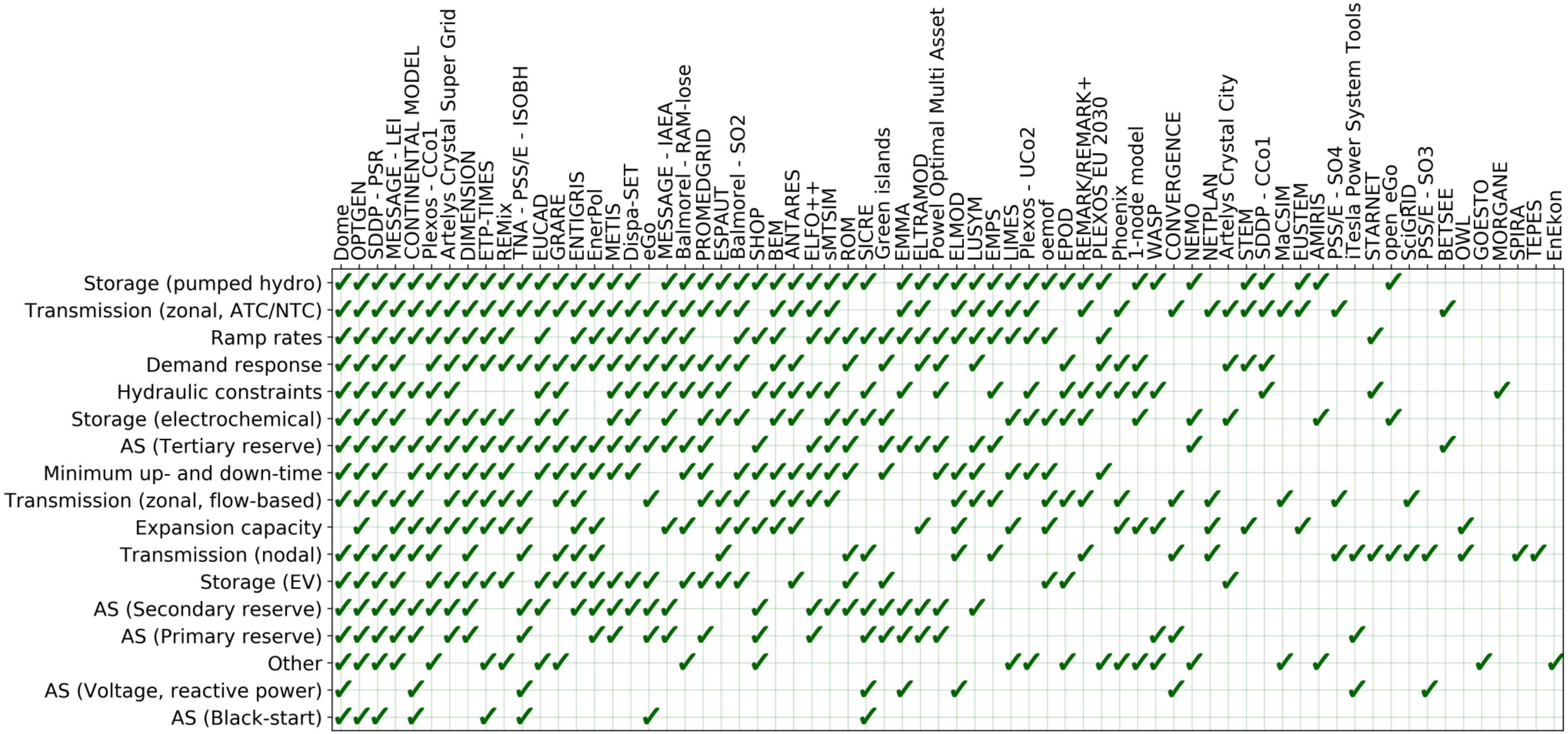
Figure 22. Economic constraints considered by the models according to the survey.



Source: JRC, 2017.

Figure 23. Technical constraints considered by the models according to the survey.

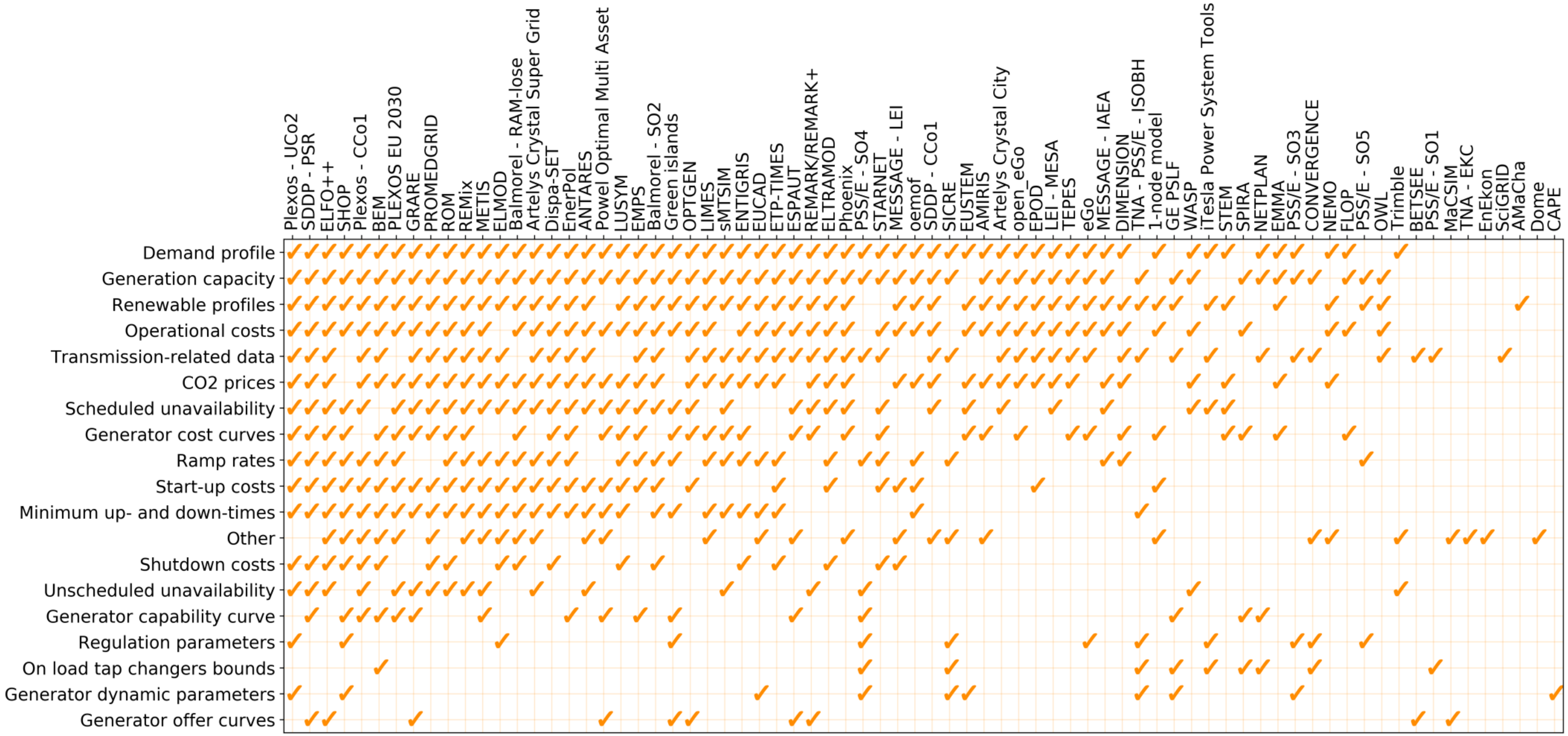
(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

Figure 24. Key input data for all models according to the survey.

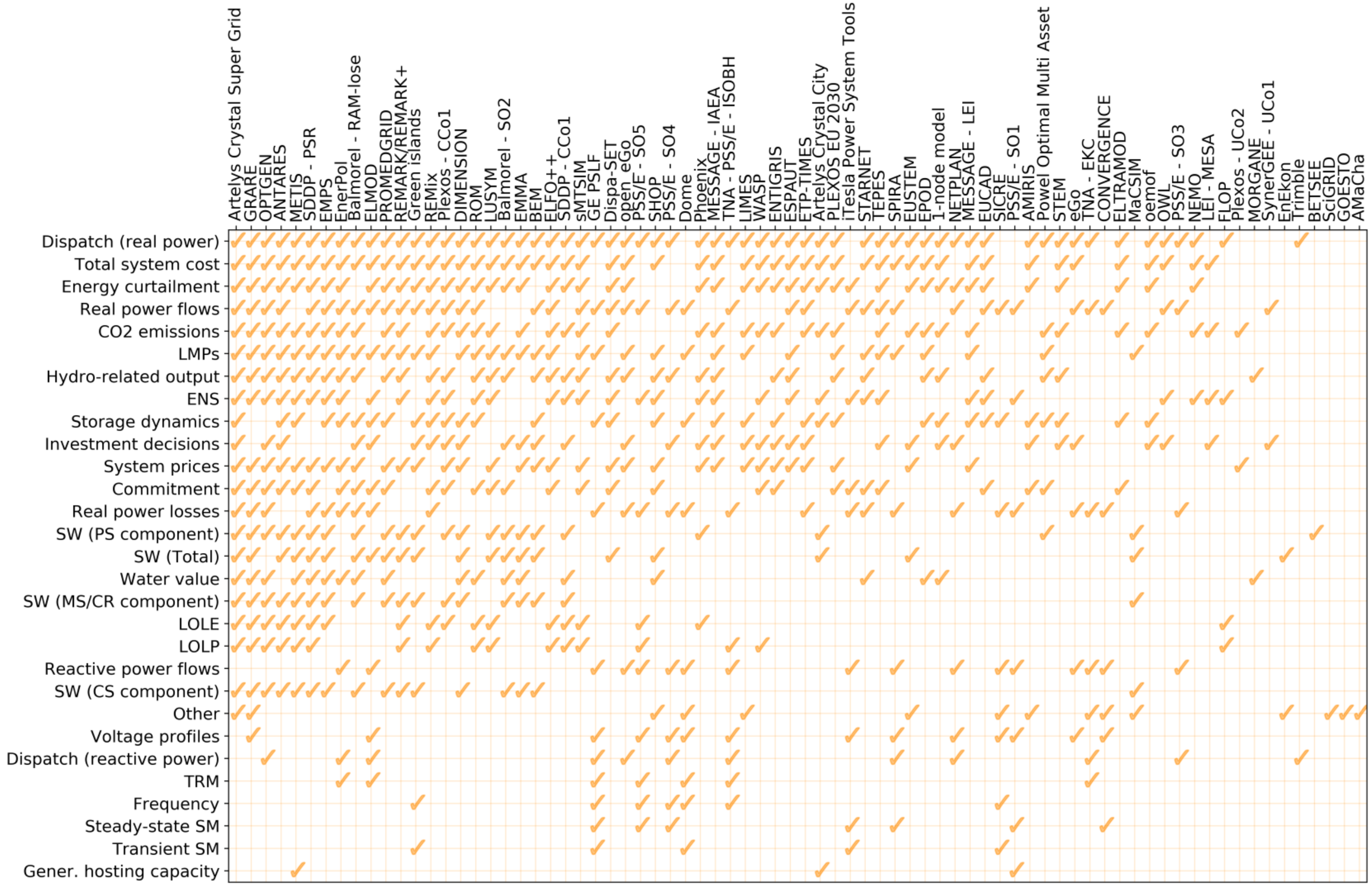
(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

Figure 25. Key output data for all models according to the survey.

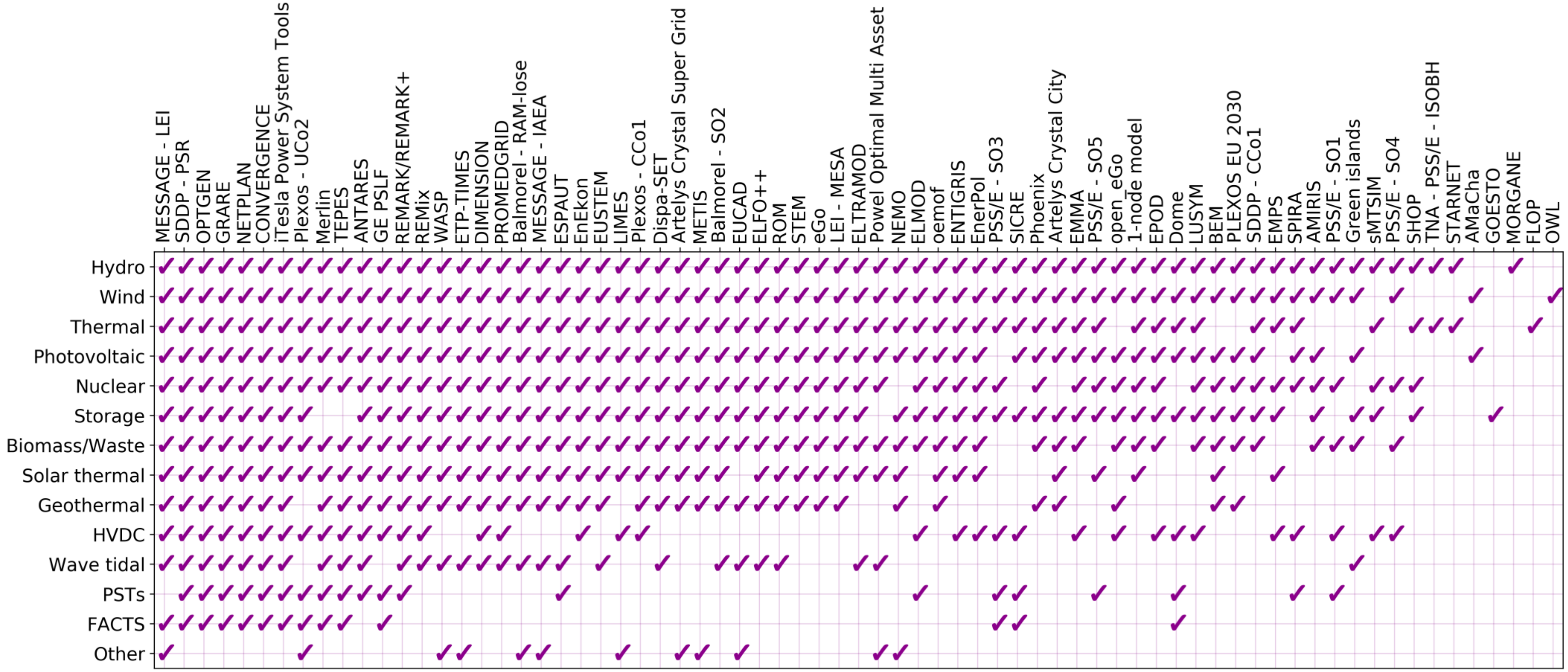
(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

Figure 26. Mapping of technologies and power system models.

(*Editor's note*: the acronyms can be found in the list of abbreviations)



Source: JRC, 2017.

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