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DTU contribution to the task Development and application of ETM dissemination strategies
Final Report

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Publication date:
2013

Document Version
Publisher's PDF, also known as Version of record

Socio Economic Research on Fusion

EFDA Technology Workprogramme 2012

WP12-SER-ETM-3-01

DTU contribution to the task Development & application of ETM dissemination strategies

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Final Report, March 2013

Abbreviations

CCS	Carbon Capture and Storage
CHP	combined heat and power
CO_2	carbon dioxide
EFDA	European Fusion Development Agreement
EIA	Energy Information Administration (US DOE)
EJ	Exajoule 10^{18} Joule
ETP	Energy Technology Perspectives (IEA)
ETSAP	Energy Technology Systems Analysis Programme
EU	European Union
GHG	Greenhouse gasses
Gt	Gigatonne
GW	Gigawatt
IEA	International Energy Agency
IPCC	Ineregovernmental Panel on Climate Change
kt	Kilotonne
kW	Kilowatt
kWh	Kilowatt hour
MARKAL	Market Allocation (optimisation model developed by the IEA)
Mt	Megatonne
MW	Megawatt
MWe	megawatt, electric
MWh	megawatt hours
NEMS	National Energy Modeling System (US DOE)
PJ	Petajoule 10^{15} Joule
SAGE	System to Analyze Global Energy (US DOE)
SERF	Socio Economic Research on Fusion
TIMES	The Integrated Markal EFOM System
TWh	terawatt hours 10^{12} Wh
VEDA	VErsatile Data Analyst (model interface)
WEO	World Energy Outlook (IEA)

DISCLAIMER

This work, supported by the European Communities under the contract of Association between EURATOM / DTU was carried out within the framework of EFDA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Preface

This is the final report for Socio Economic Research on Fusion (SERF), EFDA Technology Work programme 2012.

The report summarises the experience from several presentations during 2012, and it schedules two proposals for articles in peer reviewed mainstream energy journal, which will require further documentation and analysis of model assumptions and results before submission.

It also contains presentations for promotion of fusion as a future element in the electricity generation mix and presentations for the modelling community concerning model development and model documentation – in particular for TIAM collaboration workshops.

DTU Risø Campus, March 2013

Poul Erik Grohnheit and Søren Korsholm

1 Introduction

1.1 Task Agreement for WP12

Development & application of ETM dissemination strategies.

This collaborative activity aims at developing an ETM dissemination strategy, corresponding to communication practice employed by main contributors of the global energy debate.

It will provide an overview of various scenarios published by a range of actors (from IEA, IIASA to Shell and Greenpeace) and employing other global models (like TIAM), in order to identify scenario variables and parameters selected by different players for the dissemination of their scenarios when addressing different topics of the energy/environmental debate, and/or different target groups and end users. According to the results of this overview, EFDA TIMES scenarios including fusion will be implemented, run and prepared for dissemination.

A comparison of results produced by mean of the ETM and the TIAM models will be also performed, with a focus on electricity generation. This task will address also possible visualisation frameworks (graphics, web technologies etc) both for scientific dissemination and for broader audience. The outcome of the activity will be preparation of publications showing scenario analysis and addressing the following topics:

1. The role of fusion in scenarios with varying demand growth assumptions, focussing the impacts on electrification rates

2. The impact of unconventional gas and of new fossil fuel technologies for extraction and energy production, on possible paths of fusion penetration. carbon global energy system.

3. Analysis of the competition between fusion and renewable technologies in a low carbon global energy system.

The activity will be divided in the following sub-tasks:

A1. Main global scenario analyses: strategies of communication

A2. Main global scenario analyses: comparison of results, differences between ETM and TIAM model

A3. Dissemination activity: paper for a peer review journal on topic 1

A4. Dissemination activity: paper for a peer review journal on topic 2

A5. Dissemination activity: paper for a peer review journal on topic 3

A6. Proposals for possible visualization frameworks

Deliverables:

Intermediate reports for subtasks A6, A1 and A2 (July 2012).

Draft version of the paper for tasks A3,A 4, A5 (September 2012)

Final version of the reports for subtasks A6, A1 and A2 (December 2012)

Final reports for A3, A4, A5 - Final version of the papers (February 2013).

Comments:

This proposal is similar to those submitted under the previous calls. The concrete work will be co-ordinated with the partners in the EFDA-TIMES team.

1.2 Documentation and dissemination activities

The aim of this report has been to summarise and document the main elements that are needed for presenting issues and results on the role of fusion in the energy system in the second half of the 21st century on the basis of the contributions to the Work programme 2012 – and similar issues addressed in the previous work programmes. Most effort have been devoted to the documentation of input to various versions of the EFDA-TIMES and ETSAP-TIAM models in search for conclusions concerning the prospect for fusion technology and its impact on the future energy system during the 21st Century, as shown in Figure 1.1.

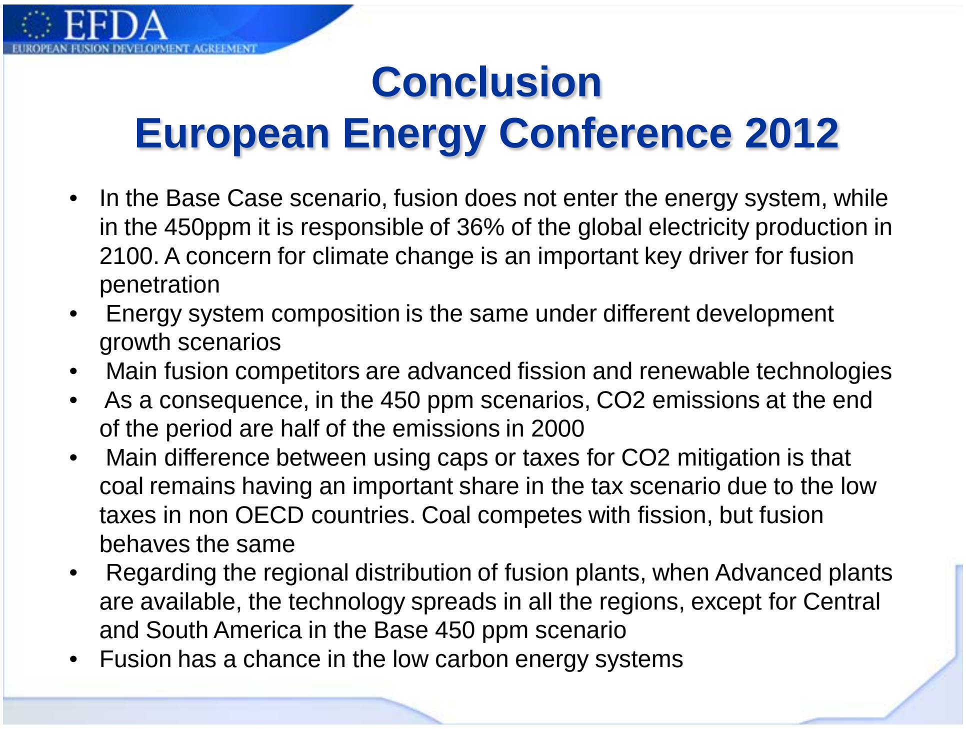


Figure 1.1. Conclusion on the prospect of fusion from the E2C 2012 Conference - prepared for presentation in ETSAP-TIAM workshops.

This presentation represents the state-of-the art for results from EFDA-TIMES. The power Point slide is followed by the following comment:

"Fusion represents a key technological option for future energy system. The key driver for fusion penetration is a concern for climate change. The adoption of environmental measures, even in the weaker form of a CO_2 tax differentiated among regions and with a moderate path of growth, is sufficient to push fusion into the electricity market at the end of the century. Fusion results seem robust against different paths of economic growth. Fusion role is also linked to the tightness of environmental constraints.

Regarding the regional distribution of fusion plants, in the Base 450 ppm scenario, at the beginning fusion power enters the market since 2050, when basic power plants are installed in India, China, Western Europe, USA, South Korea, and other developing Asian countries. However, when advanced plants are available, the technology spreads in all the regions except Central and South America. With higher demand growths, in the HG 450 ppm scenario, from 2050 basic power plants are installed in all the regions, with less capacity in Central and South America, Mexico and Canada. Then, when Advanced plants are available, the technology spreads in all the regions. "

The work during 2012 is illustrated in this report mainly by presentations prepared for workshops on ETSAP-TIAM collaboration and within the EFDA organisation.

- ETSAP-TIAM Workshop, Sophia Antipolis, France 15, February 2012
- Euratom DTU Steering Committee Meeting, Risø Campus, Denmark, 24 April 2012
- 2nd European Energy Conference (E2C 2012), Maastricht, Netherlands, 17 April 2012 (presentation by Helena Cabal, CIEMAT).
- ETSAP-TIAM Workshop, Cape Town, June 2012 (not presented)
- EFDA-TIMES Workshop, CIEMAT, Madrid, Spain 9 July 2012
- Fusion physics class for science talents. Information for teachers, Sorø, Denmark, 6. November 2012
- ERANET Electrimobility+, EV-STEP Kick-off Meeting, Paris, 20 November 2012
- ETSAP TIAM Workshop, Lisbon, December 2012 (not presented)
- DTU EURATOM Association Day, Risø Campus, 11 December 2012
- Annual Workshop, Garching, Germany,17-18 December 2012
- IEA Modelling Workshop - Global Dispatch Model Paris 23 January 2013 (not presented)
- ETSAP TIAM Workshop, scheduled for Paris June 2013 or Denmark, November 2013.

1.3 Report Contents

Chapter 2 describes the search for benchmark scenarios to use for comparison of different model version and presentation of key results. It concludes recommending the global CO_2 constraint at 550 ppm as the benchmark scenario. *Chapter 3* summarises previous work on discounting – including discounting used stepwise (myopic) optimisation versus full foresight. *Chapter 4* discusses aggregation of technologies – not only for infrastructure, but also for electricity generation technologies, emphasising the similar role for the energy system of fusion and other large-scale thermal technologies. *Chapter 5* focuses on analysis of the objective values, which are minimised through the optimisation. A standardised presentation of regional objective values and their components is used as the first validation of new optimisation results. describes the issues for introducing endogenous infrastructure for electricity, natural gas and heat within regions. *Chapter 6* summarises the recent development in model documentation, emphasising the use of the archive of reports on the EFDA-TIMES development. *Chapter 7* contains a summary of key presentations of model results and schedules two approaches for articles in peer reviewed journals, as well as the requirements for finalising such articles. Finally, *Chapter 8* contains the contribution to the annual report 2012 of Association Euratom – DTU with summary of the issues presented in this report.

2 Scenario definitions

This chapter describes the common assumptions used for most scenarios in the EFDA-TIMES December 2009 version and later.

2.1 The Reference (BASE) Scenario

In the Base Scenario a carbon price, representative of a moderate concern about climate change, has been included; the scenario contains no incentives for CO_2 reduction at 2010 and a carbon price differentiated between OECD and non-OECD regions for the following periods. The carbon price gradually increases from 10 $/t$CO_2$ in 2020 to 25 $/t CO_2 in 2100 in non OECD regions and from 20 $/T CO_2 to 50 in 2100 in OECD regions.

The electricity generation in the Base Scenario shows an annual growth rate of nearly 2.6% in 2000-2050 period and of 1.5% in 2050-2100. The growth of energy production in EFDA Base Scenario (31400 TWh in 2030) is very close to the Reference case of IEA's World Energy Outlook 2008 (33265 TWh in 2030). In the EFDA scenario electricity production grows up to 67300 TWh in 2050, and 105200 TWh in 2100.

Investment costs for LWR reports fission investment costs are those included in IEA ETP projections.

Results from the Base Scenario are normally uninteresting with the electricity generating mix dominated by fossil fuels and nuclear fissions with shares that are dependent only on their relative costs.

2.2 CO_2 Constraints

Figure 2.1 shows the global emission profile for the two scenarios Emi550 and Emi450.

The profile 550 ppm allows global CO_2 emissions to increase to 33 Gt by 2030 and decrease to less than 20 Gt by the end of the century, while the 450 Gt profile will already decrease from 28 Gt in 2015 to a level of 10 Gt during the last decades of the century. These profiles will have a significant impact on the technology choice.

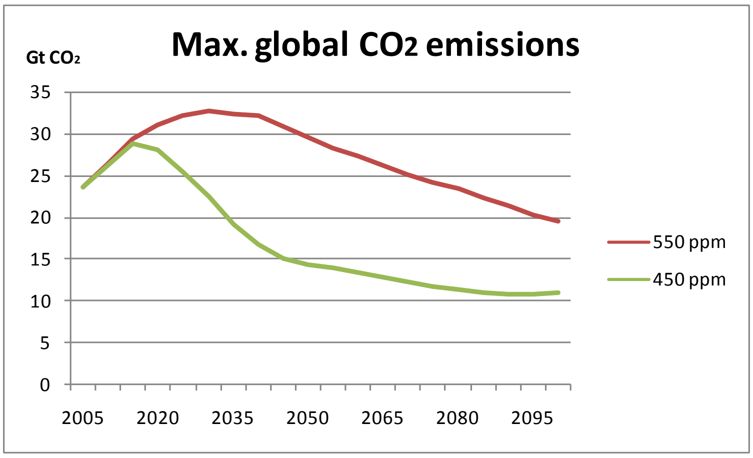


Figure 2.1. Global CO_2 emission profiles for the 450 and 550 ppm .

The 550 ppm scenario was chosen for a background or "Core Scenario" for the sensitivity analysis using EFDA-TIMES December 2009 version. However, for the summary of conclusions, see Figure 1.1. For presentations focusing on the role of CCS from fossil fuel plants, the 450 ppm constraint was preferred, see Figure 4.2 and Figure 7.2, below.

2.3 Selection of benchmark scenarios

In the final report from Risø DTU (Grohnheit, 2010a) the aim was to identify the combination of assumptions that would allow biomass and CCS to play a significant role by 2050 and after. By the end of the century fusion might replace biomass or fossil fuel with CCS

For WP 2011 (Grohnheit, 2012b) the issue was modelling of infrastructure

Such analyses require that a stable scenario is available, which can be used as the benchmark scenario for runs different variants of the model – both parameter studies and modifications of the topology.

The background scenario is different from the Base Scenario, which has a minimum of constraints. The background scenario must have a set of constraints that will allow a broad range of scenarios to be chosen by the model. For the first analysis of CCS and biomass two constraints were chosen:

- Global electricity production in a carbon constrained scenario equivalent to restricting the atmospheric CO_2 concentration to 550 ppm (equivalent),
- Nuclear fission should not increase above 25 % of electricity generation each region during the rest of the century.

For comparisons with different versions of TIAM the 550 ppm constraint was chosen, because the 450 ppm constraint is being consideres as increasingly extreme during recent years.

2.4 Tool for management and presentation of many scenarios

The Excel workbook that was developed in the previous tasks is used for the management of a large number of cases for sensitivity analysis, which is also used for other versions of TIMES, e.g. ETSAP-TIAM. Recently the workbook was split in two: management of scenarios with capture of results (regional distribution of components of objective values) and result database with presentation of the captured results.

3 Discounting

The issue of discounting has been widely discussed in RISOE and in ENEA TW6-TRE-ETM-UPS Final Reports; in the conclusions of ENEA report was suggested to perform a sensitivity analysis in order to test the effects of changes of the discount rates on technology evolution and energy consumption. In particular the report suggested to verify whether or not the hurdle rates currently used in the model were able to reproduce actual consumer and producer behaviour. According to these conclusions a sensitivity analysis will be performed in order to compare ETM hurdle rates with an alternative set of sectoral/regional specific hurdle rates found in literature reviews or applied in bottom-up models.

In addition, a sensitivity analysis aimed at evaluating a "prescriptive" approach, as discussed in the ENEA report (Ciorba and Gracceva, 2010) will be illustrated.

3.1 ENEA Report

The controversy between the "prescriptive" and the "descriptive" approach to discounting can be solved with a synthesis in bottom-up models of the TIMES family. A general discount rate, lower than market interest rates, and with a decreasing path when appropriate, can be used to discount annual flow of costs; at the same time, the annual rate of Capital Recovery Factor can be evaluated by mean of region/technology specific hurdle rates. The adoption of sectoral specific hurdle rates does not lead to a contradiction with the prescriptive approach as showed by IPCC SAR.

In conclusion, the possibility to include a decreasing discount rate is a solution widely recommended in presence of long time horizon analysis, while for sake of realism, interest market rates (or even higher sectoral hurdle rates) can be maintained.

Raising hurdle rates determine an increase in CO_2 emissions. The small differences between the three cases with hurdle rates (default, alternative and alternative decreasing) show that the default level of hurdle rates is, on average, sufficient to model the real consumer behaviour. It is not suggested to change it unless it would be useful to evaluate specific efficiency sectoral targets.

Specific discount rates in ETM

In the EFDA-TIMES model for all final energy sectors the "SubRes_B-NewTechs_Trans" (see table below) defines both:

- region based and
- sector based discount rates.

The regional differences can be synthesized as follows:

- Africa and India are the two regions with the highest discount rates;
- the discount rates applied to the most "developed" regions (Australia, Canada, Japan, USA and Western Europe) are half of the corresponding value used for Africa and India.

The sectoral differences can be synthesized as follows:

- in Africa and India discount rates are:

- o between 20% and 36% in the transport sector;
- o in the residential sector the applied rate is 1.3 times the value used for transportation Road demand (TRT*, TRL*, TRE*, TRW*), which is 30%;
- o in the commercial sector the applied rate is 0.85 times the value used for transportation Road demand (TRT*, TRL*, TRE*, TRW*), which is 30%;
- o for industry, "SubRes_B-NewTechs_Trans" the applied rate is 20% in India and AFR and lower for the other regions (industrial rates converge to 10% for all regions in 2010).

– Sectoral discount rates in the five "developed" regions (Australia, Canada, Japan, USA and Western Europe) can be easily calculated from the previous ones.

– The discount rate for electricity and heat technologies is 10%, without any difference between different regions.

3.2 Myopic model

The myopic model is much less sensitive to high discount rates, because the number of years in each step will be limited, while the full foresight model is incompatible with high discount rates, because all payments in the distant future will be discounted to negligible values, as shown in Table 4.1. At 5 % discount rates costs in 50 years time will be reduces to less than 10 % and after 100 years less than 1 %.

Table 3.1. Discount factors

Discount rate, % p.a.	Number of years				
	1	5	10	20	50
0	1.00	1.00	1.00	1.00	1.00
1	0.99	0.95	0.91	0.82	0.61
2	0.98	0.91	0.82	0.67	0.37
5	0.95	0.78	0.61	0.38	0.09
10	0.91	0.62	0.39	0.15	0.01
15	0.87	0.50	0.25	0.06	0.00

3.3 Time horizon and discount rate

In NEMS (US regional model) projections are made for each year from the present through 2025. The same time horizon was used for the global SAGE model. EFDA-TIMES and TIAM is used with the more distant time horizon 2100. It means that most of the arguments for sectoral and regional differentiation of discount rates disappears. In the longer perspective the economy will adapt to the new technology, infrastructure and institutions that take decades to develop. Regional differences may not disappear, but the distribution of wealth among regions will be different and unpredictable.

The pragmatic approach to modelling will avoid arbitrary parameter differences, This will be a key argument to drop sectoral and regional discount rates. Sensitivity analyses on different general discount rates is important, and hyperbolic variations, i.e. decreasing discount rates over time, is important to consider.

4 Aggregation of technologies

In recent work programmes heat transmission infrastructure was introduced into the regions with temperate climate as a very aggregated technology with parameters concerning losses. Further, very aggregated technologies is being considered for electricity and gas grids within regions.

The level of details and the number of competing or complementary technologies shall also be considered for conversion technologies. A well-known drawback of linear optimisation model is that "the winner takes it all" meaning that a technology, which is marginally cheaper than others may sweep the market. A solution may be to introduce more generic aggregated technologies, which can be split among specific technologies using exogenous parameters.

4.1 Modelling infrastructures

The impact of introducing infrastructure to EFDA-TIMES is very dependent on the contents and quality of the rest of the model. The impact may be nothing or quite significant.

Introducing endogenous infrastructure for electricity, natural gas and heat within regions will better allow a proper modelling of technologies that require piped transmission and distribution of energy carriers. Each grid is defined in the topology by commodity flows in and out, efficiencies (losses), and investment and O&M costs per GJ of annual flows. However, these parameters are very aggregated, and their numerical values can be selected only as a result of systematic parameter studies.

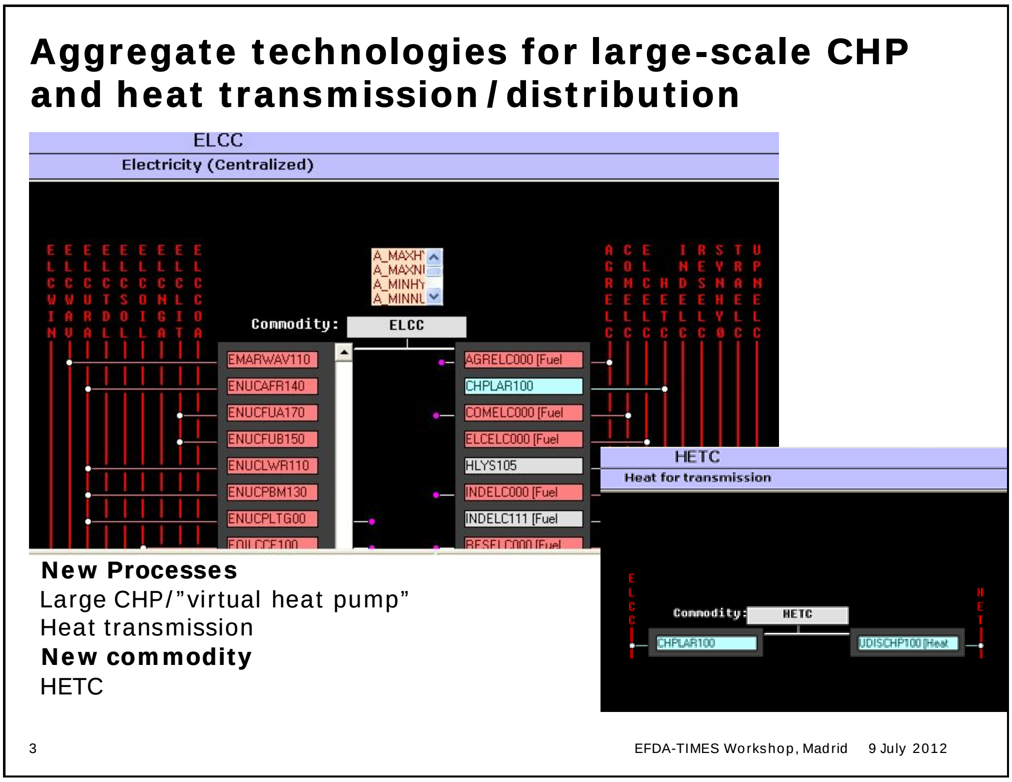


Figure 4.1. Topology modifications for heat transmission infrastructure – from VEDA Front End.

The topology of heat infrastructure is illustrated in Figure 4.1, using the presentation tool in VEDA Front End., while Figure 4.2 shows the impact on the model results of this feature. The impact has been significant for the distribution of heat technologies (right graph). It has been limited on the mix of electricity generation technologies. The graph to the left has been used in several presentations to illustrate the possible role of CCS:

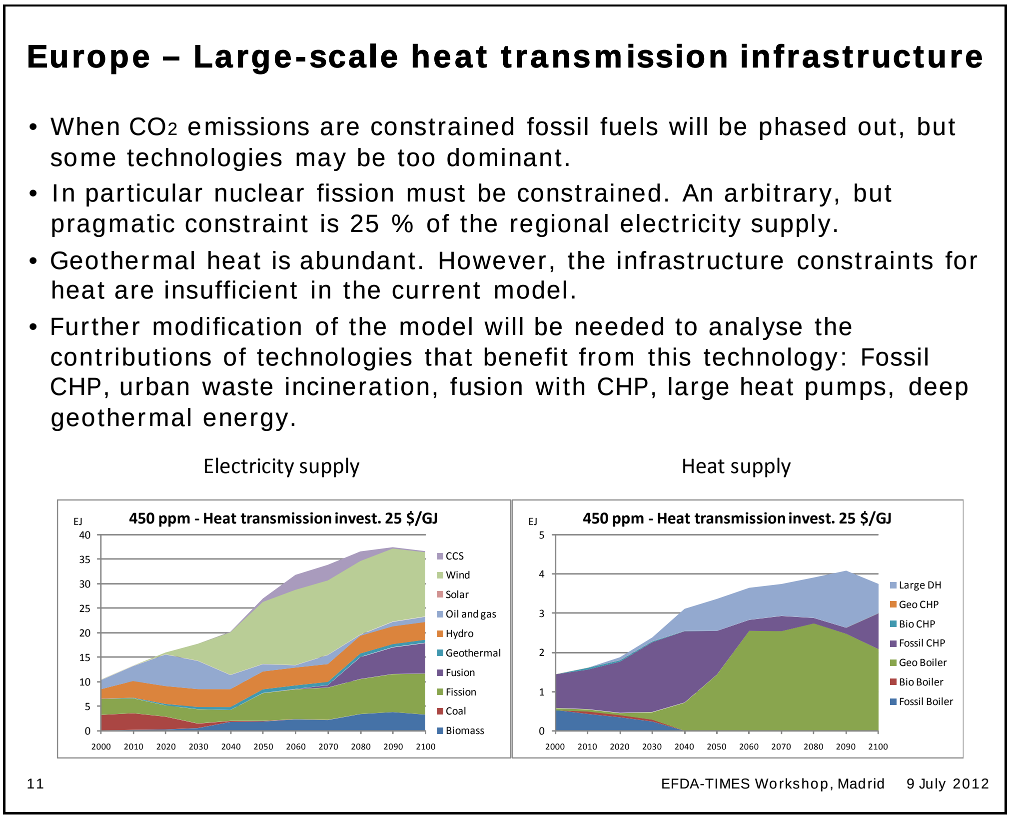


Figure 4.2. Presentation of the impact of teat transmission infrastructure.

Long-distance transmission of electricity from off-shore wind and CSP solar will require a slight modification of the topology. Figure 4.3 shows a presentation of a proposal for modification of the topology – presented within the EFDA-TIMES team – to consider long-term electricity transmission within regions. So far, this feature has not been tested. It will require a series of parameter variations, focusing on transfer capacity, losses and investment volumes.

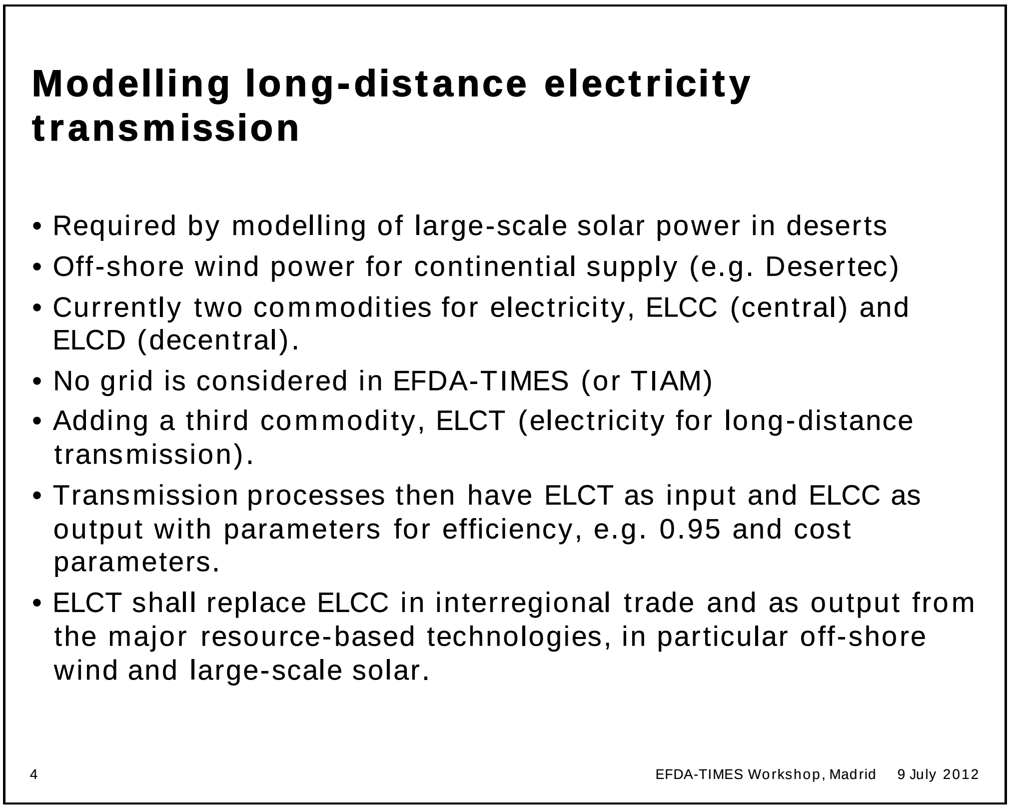


Figure 4.3. Proposal for modification of electricity infrastructure.

5 Analysis of objective values

This chapter describes presentations mainly for the modelling community

5.1 Overall objective values

Variations in the overall objective value is very useful for a quick analysis of the results of parameter studies. Table 5.1 shows the result of variations of two constraint parameters: CO_2 constraints and the maximum share of nuclear fission in each region after 2030, In addition the impact of heat transmission infrastructure is shown for two values of annual aggregated cost. The 25% constraint for fission was chosen as background. The 50$/GJ cost has very little impact, because the cost is too high to allow investment, while the 25 $ cost has some impact, which is also shown in the right graph of Figure 4.2.

Table 5.1. EFDA-TIMES:Objective value

	Objective value			Background scenario=100		
Selected Scenarios	Base	Emi550	Emi450	Base	Emi550	Emi450
Base	180.15	180.38	181.82	99.01	99.14	99.93
NucReg30		180.44	181.91		99.17	99.98
NucReg25		180.47	181.94		99.19	100.00
NucReg20		180.50	182.00		99.21	100.03
NucReg15		180.55	182.07		99.24	100.07
NucReg10		180.62	182.17		99.27	100.12
NucReg05		180.73	182.33		99.33	100.21
NucReg25 - Heat 50$/GJ		180.46	181.94		99.19	100.00
NucReg25 - Heat 25$/GJ		180.44	181.91		99.17	99.98
Biomass_High		181.67	183.05		99.85	100.61

5.2 Regional objective values – comparing global TIMES results

The Excel workbook, which is mentioned in Section 2.4 was developed for the management of a large number of cases for sensitivity analysis, which is also used for other versions of TIMES, e.g. ETSAP-TIAM.

This workbook contains a database for scenario assumptions and selected results, which are imported into the workbook. It is used to manage the dd-files that are created by VEDA-FE with documentation of assumptions and results. A small part or the results is stored in a database sheet in the workbook. These results are regional objective values divided into investment, fixed and variable costs, etc.

The GAMS software provides a tool for selection of output. Figure 5.1 shows a presentation, which was used to describe this selection.

These results are just a small selection of the results that are used by VEDA Back End (the database tool for handling the detailed results from the model).

The results in the graph in Figure 5.2 are comparing two cases, which are looked up from the database. The database and graph are flexible concerning the regional breakdown of the global models. The current version covers EFDA-TIMES/ETSAP-TIAM (15 regions), TIAM-World (16 regions) and the new version of EFDA-TIMES (17 regions) from February 2012.

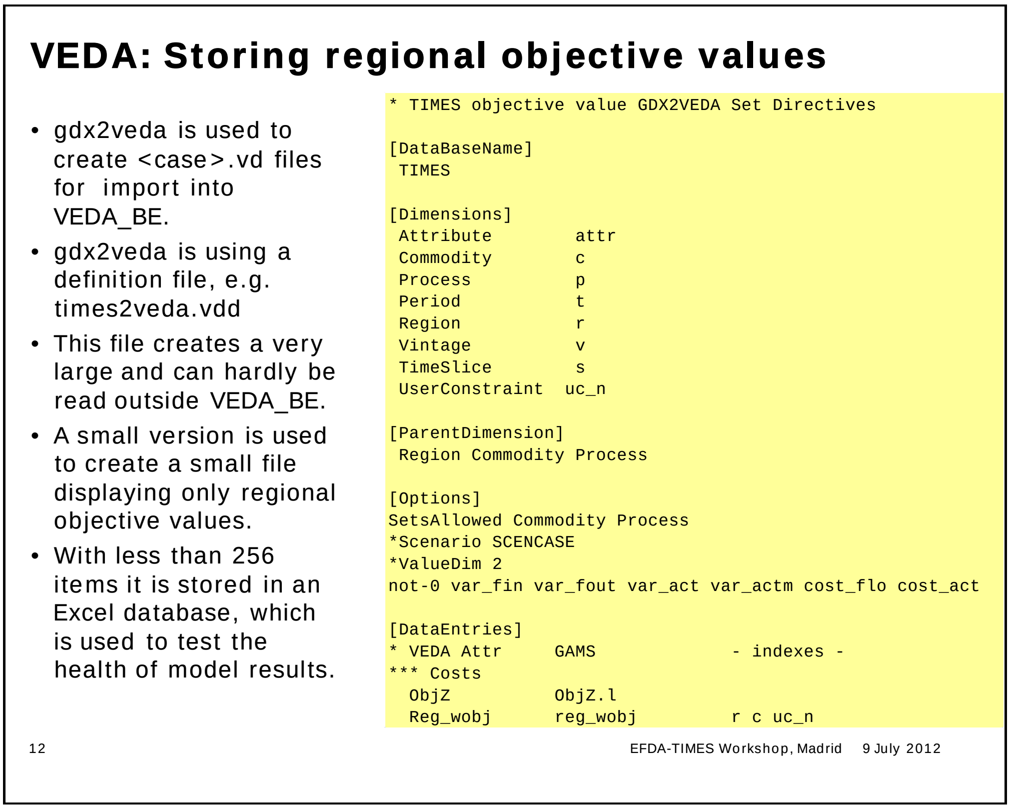


Figure 5.1. GAMS tool for selection of output

5.3 Results from different global models

In Figure 5.2 the presentation tool is used to compare results of EFDA-TIMES and ETSAP-TIAM. The two model versions have the same number of regions. The main difference is the starting year (2000 for the previous versions of EFDA-TIMES and 2005 for ETSAP-TIAM). The objective value (shown in the upper right corner) is some 35 % higher for the ETSAP-TIAM result than for EFDA-TIMES.

The pattern of the distribution of the objective function is similar, although the investment volume is larger for the ETSAP-TIAM results. The ETSAP-TIAM case also contains the fusion module from EFDA-TIMES. However, the impact of this module has not yet been analysed.

5.4 Aggregated regions

Figure 5.3 shows a proposal for a regional aggregation, which will allow a direct comparison of results from the various versions of EFDA-TIMES and TIAM.

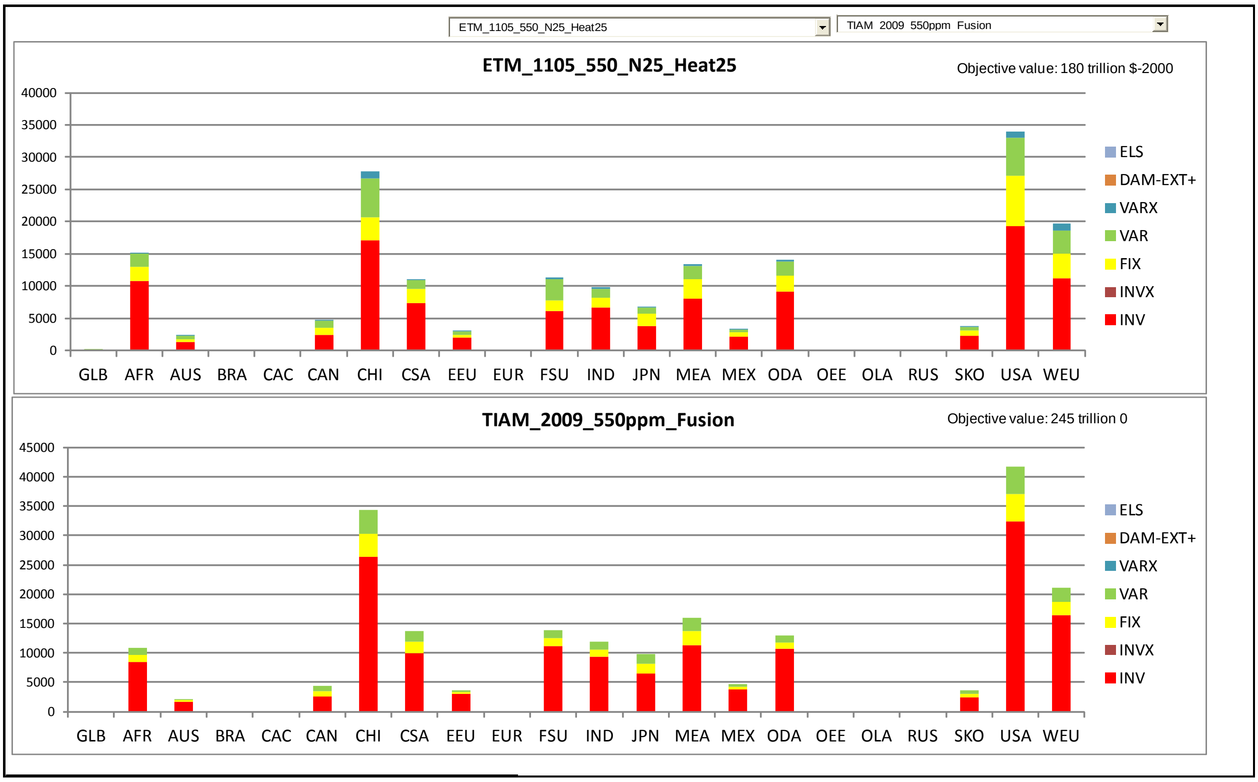


Figure 5.2. Regional Objective Values comparing global ETM results.

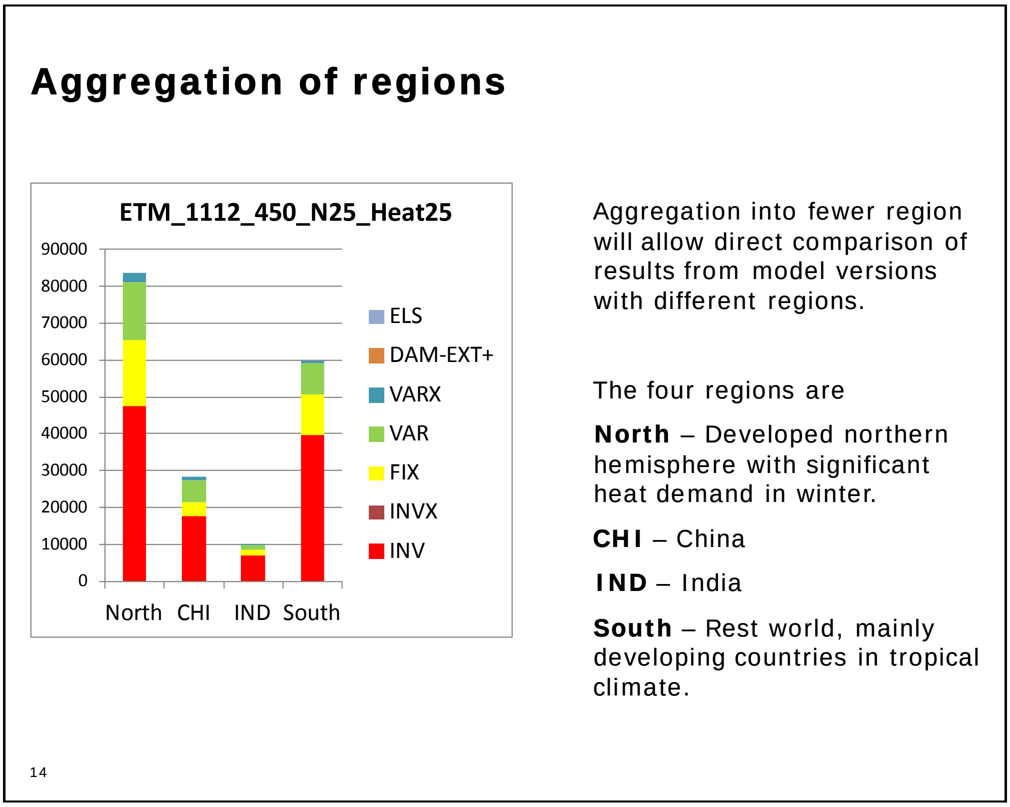


Figure 5.3. Proposal for aggregation of regions.

6 Model documentation

Both EFDA-TIMES and TIAM have been used for scenario studies and analyses over a period of nearly ten years. In the same period a number of versions have been developed with focus on different study issues and model features. The development of the GAMS code for TIMES has been very consistent and well documented.

In contrast, the application use of the model has involved many different teams and institutions. During 2011 and 2012 some effort has been made for exchange of experience among the users of ETSAP-TIAM with some support from ETSAP.

In 2012 an agreement was made between the EFDA Leader and ETSAP, which will allow comparison of model assumptions and results. Together with contributions to semi-annual collaboration workshops on TIAM this will allow the small EFDA-TIMES team to benefit from the much larger TIAM community.

6.1 EFDA-TIMES development and versions

EFDA-TIMES was developed within the framework of Socio-Economic Research on Fusion within EFDA. Figure 6.1 summarise the development of SERF. Earlier analyses date back to the 1980s. and Figure 6.2 focuses on the recent development of EFDA-TIMES. An interesting description of the early development of the model titled "Genesis of TIAM (TIMES Integrated Assessment Model)" was given by Richard Loulou during the ETSAP semi-annual workshop in Stuttgart, November 2006.

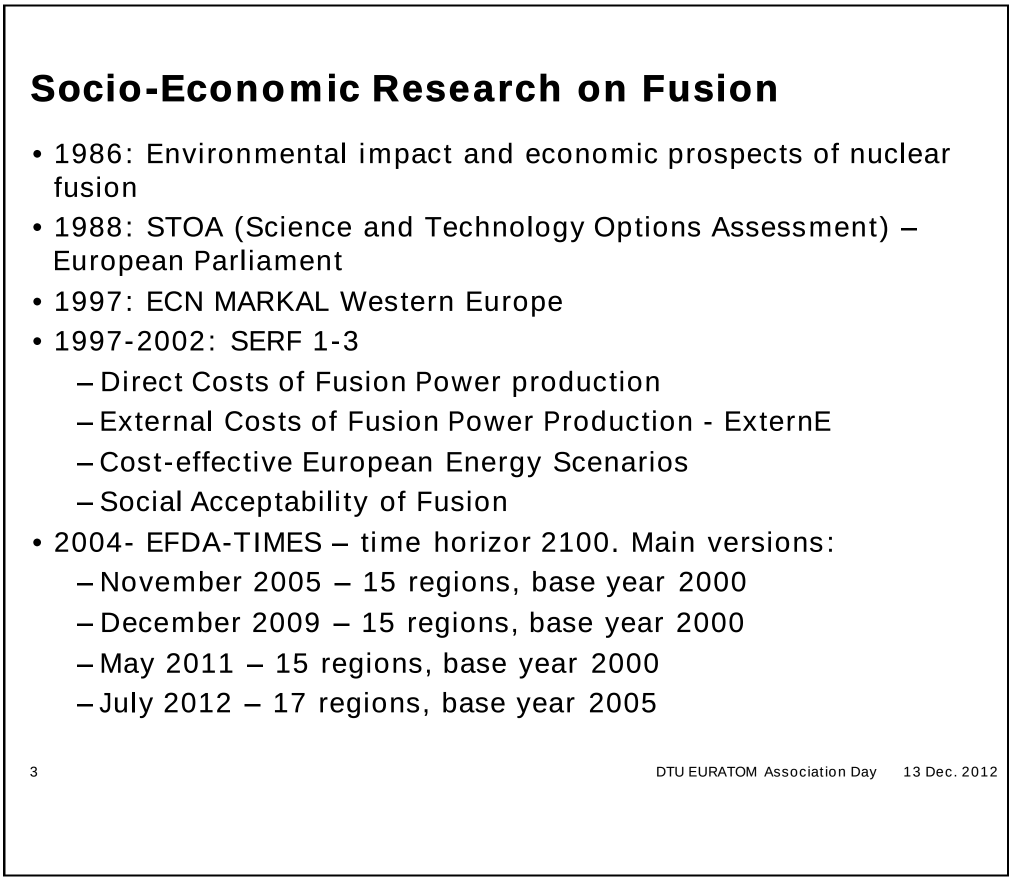


Figure 6.1: History of SERF and EFDA-TIMES

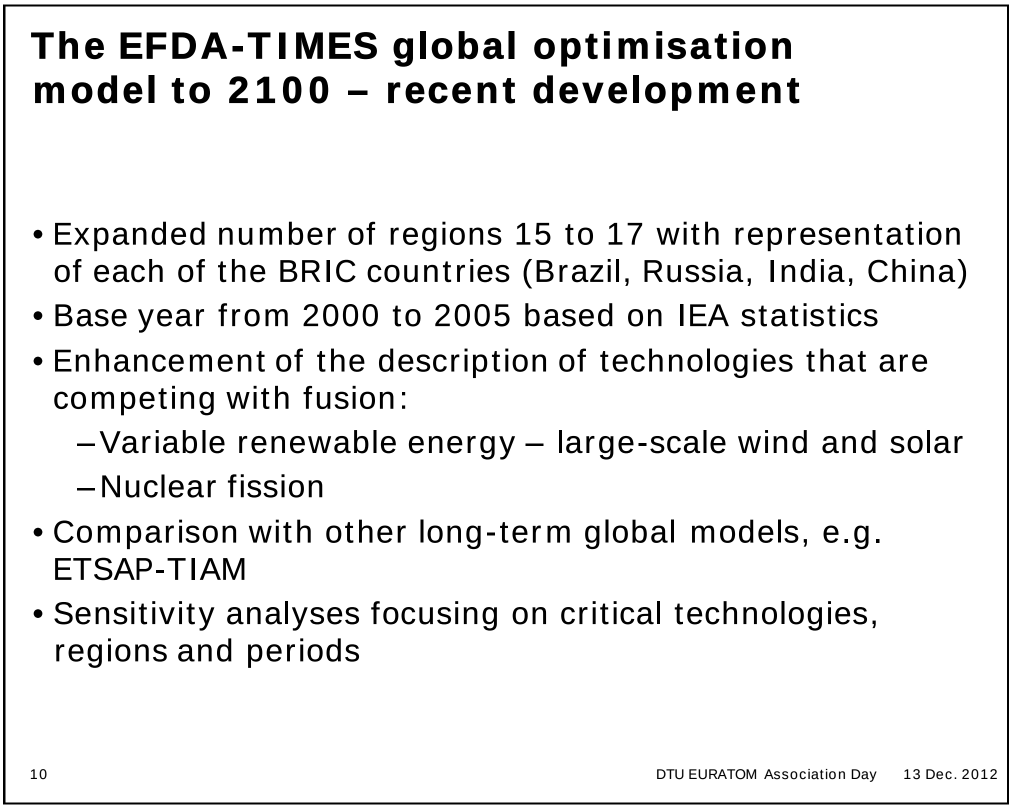


Figure 6.2. Recent development of EFDA-TIMES.

6.2 Input documentation

The GAMS software includes further tools that are useful for documentation and validation of EFDA-TIMES. All the data (sets and parameters for input and equations and variables for output) for each run of the optimisation is stored by GAMS in a gdx file, which is quite large – typically 150-200 MB for EFDA-TIMES scenario results, but much smaller than database files containing the same information. The standard tool used for VEDA Back End is gdx2veda, but several additional steps are needed to create graphs for presentation.

A useful tool for documentation of input is a gdx file containing input only and gdx2xls, which creates an Excel workbook, which can be used directly for look up of parameter values. Figure 6.3 shows a short summary of results from using this tool for the base-year data only. It was included in the presentations for workshops on TIAM collaboration.

The gdx files for base year input of different model versions may be compares using gdxdiff and then gdx2xls. Obviously, this works best if there are few differences. This method has been used systematically for documentation of the development of the recent versions of EFDA-TIMES. Figure 6.4 summarises the result of this analysis in a graph.

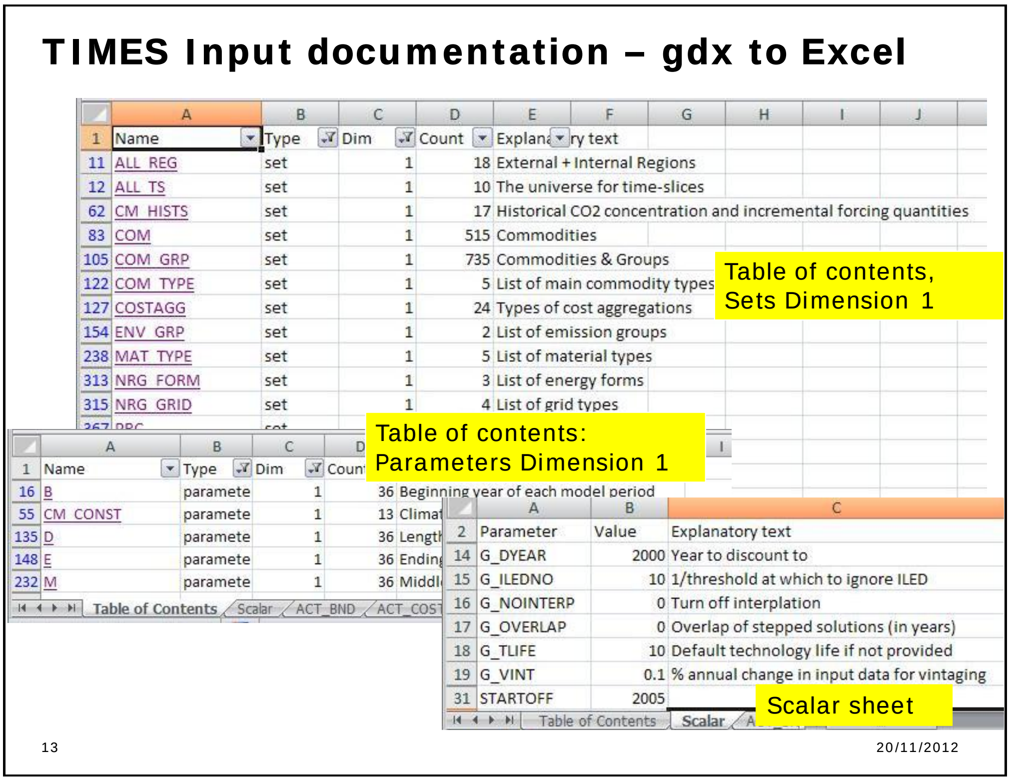


Figure 6.3. Summary of input documentation.

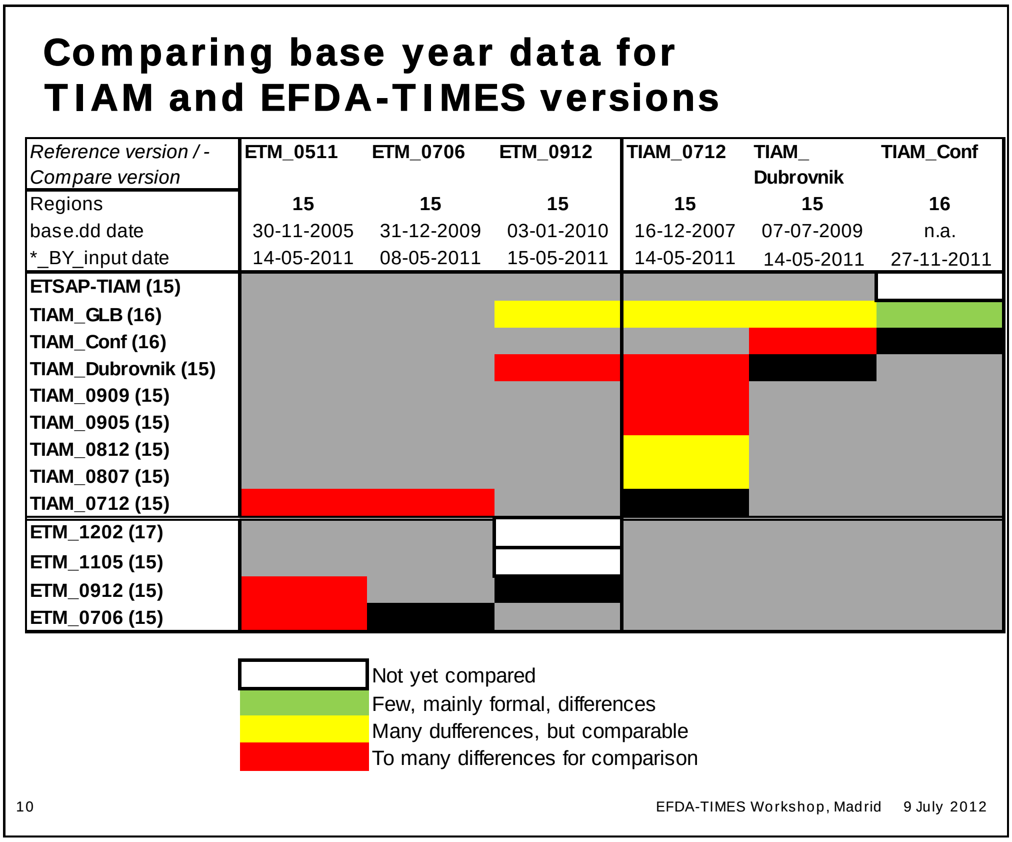


Figure 6.4: summary of analysis of base-year data for different model versions.

7 Dissemination of model analyses and results

This chapter contains a summary of key presentations of model results and schedules two approaches for articles in peer reviewed journals, as well as the requirements for finalising such articles

Although the main target of submitting an article for a peer reviewed mainstream energy journal was not yet successful, a good step was taken to shape the model to allow submission of more than one article. Another target: to include fusion properly in other long-term model has partly been achieved.

7.1 Key presentations for modelling fusion

Figure 7.1 was first presented in Danish as information for teachers for the Science talents, see Section 7.3, below. In contrast to Desertec, it focuses on the market for regional large-scale electricity generating units, which includes fusion.

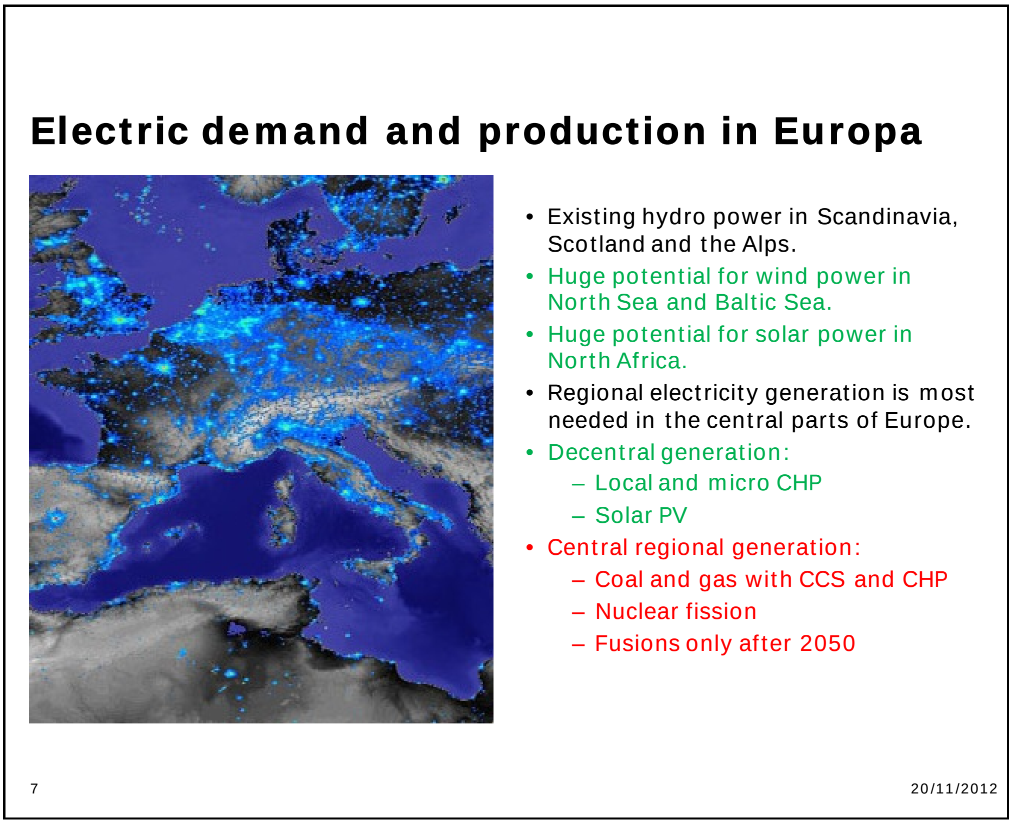


Figure 7.1. Illustration of the market for large-scale thermal power.

Figure 7.2 is similar to Figure 4.2, but focusing mainly on electricity. In contains some generation by CCS, which is later replaced by fusion. Fission is constrained to 25 % from 2030, with the consequence that wind becomes dominant by the end of the century. Figure 7.3 shows the same scenario for China, which is a region with a huge demand increase. Fusion will have some role by the end of the century. In contrast to Europe, wind has a limited share, and solar becomes dominant.

These results illustrate that further analysis is needed to develop more balanced results.

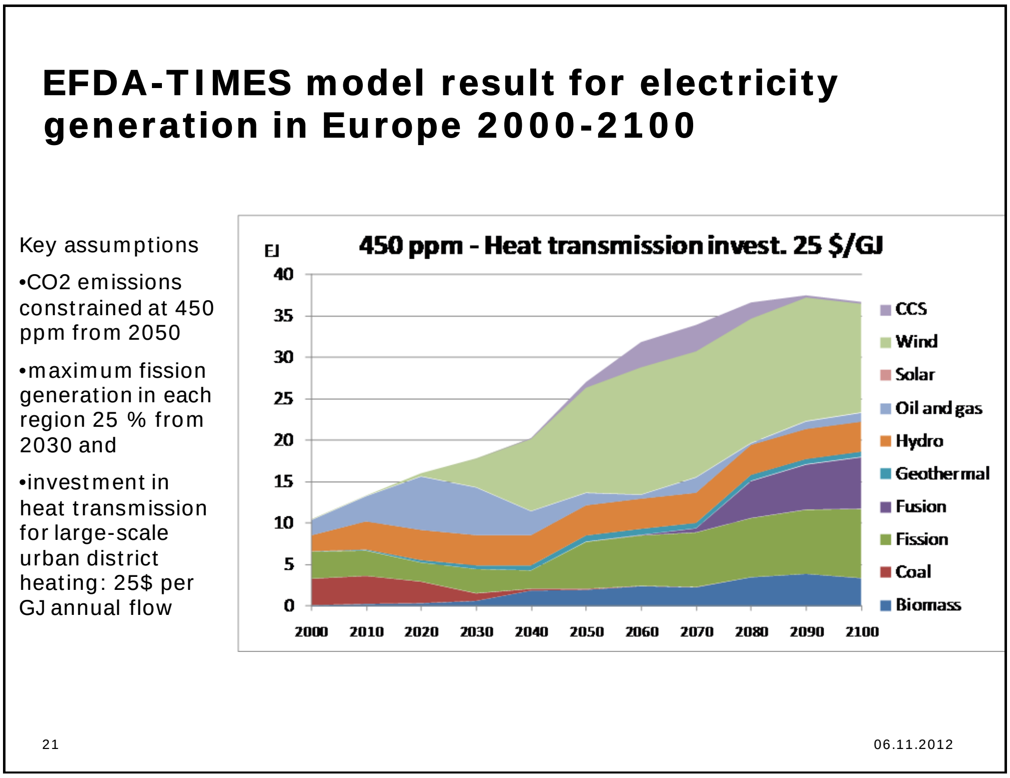


Figure 7.2. Presentation of result for CCS and fusion

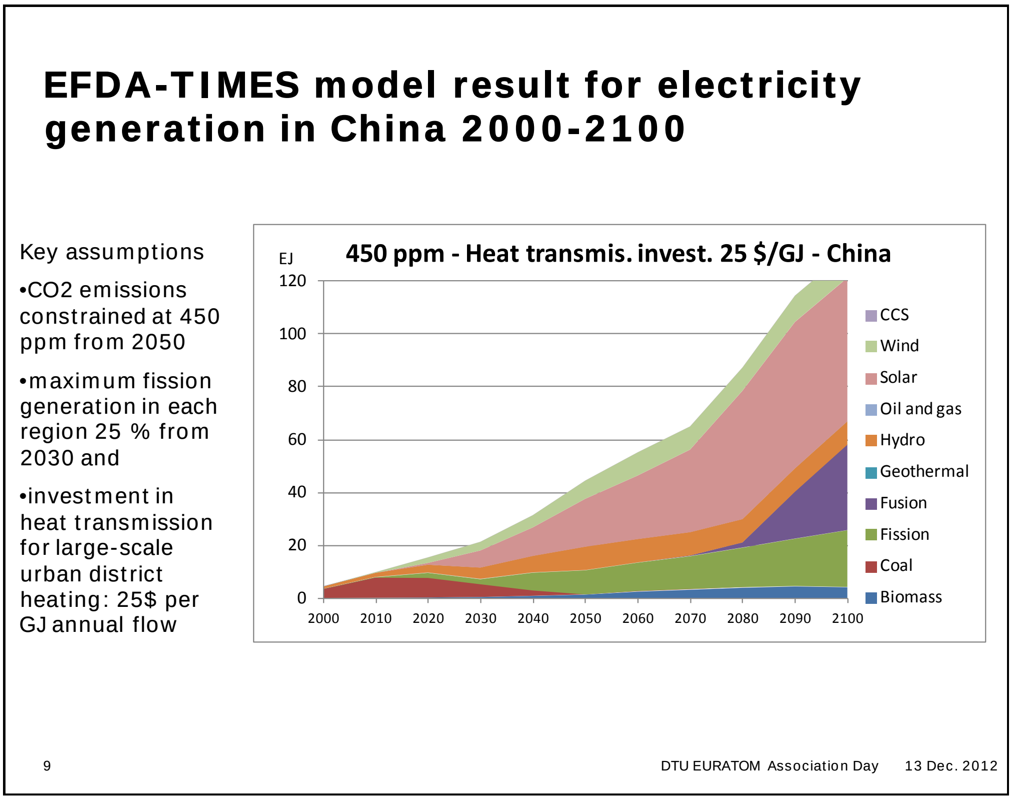
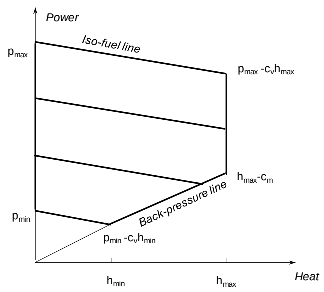


Figure 7.3. Electricity generation mix in a region with a huge demand increase.

Figure 7.4 explains large-scale CHP from extraction-condensing units as virtual heat pumps. This slide was created as a background for Figure 7.4 and first presented at the ETSAP semi-annual workshop at Cork, November 2010. Figure 7.4 presents the same idea as in Figure 4.1, It was prepared for the IEA workshop 24 January 2013.on preparation of the IEA Energy Technology perspectives 2014, but not presented.

CHP as a virtual heat pump

Production of electricity and heat in extraction-condensing units.



District heating systems (in Denmark some 50% of the heat market) supplied by physical heat pumps (using electricity) and virtual heat pumps (generating electricity) has a very large larger potential as complementary technologies for variable power from wind and solar.

Technology	Power -loss-ratio	Effi-ciency factor
Electricity driven heat pump	n.a	3
Nuclear CHP	0.25	4
Coal/gas CHP; Fission Gen. IV and Fusion.	0.15	7
Low-temperature DH	n.a.	10
Conservative average for heat transmission	n.a.	5
CCS with heat recovery	n.a.	n.a.

Acknowledgement: William Orchard, 11th IAEE European Conference, Vilnius, September 2010.

TIMES: Generic CHP units and virtual heat pumps may replace a wide range of specific CHP technologies

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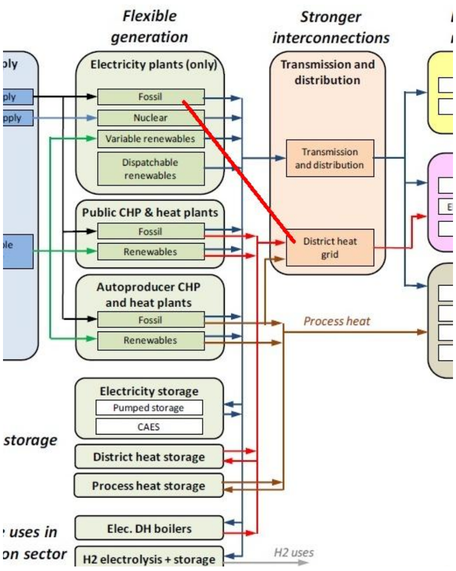
Figure 7.4. Explaining CHP as a virtual heat pump.

Heat supply from large power plants to urban district heating



- Extraction-condensing steam turbines can supply heat for district heating at some 15 % loss of electricity output.
- The additional investment costs compared to an electricity-only condensing plant are small.
- The flow on the link is constrained by the location of existing and new plants – and the heat transmission and distribution infrastructure.
- Aggregated generic technologies for conversion technologies and infrastructure to be used in TIMES models.
- The key parameter for infrastructure is the cost of annual flow, e.g. 25 € or $ per GJ.

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Figure 7.5. The missing link in ETP-TIMES – from large power plants to urban district heating.

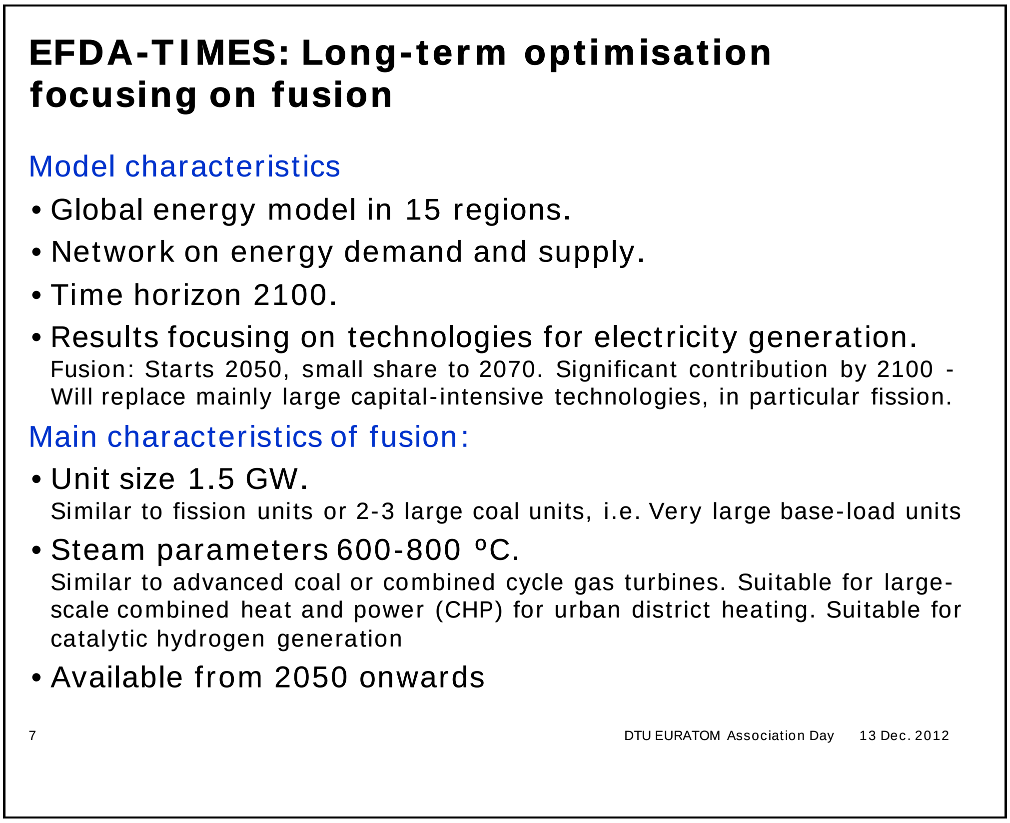

Figure 7.6. Short presentation of fusion technology in the EFDA-TIMES model.

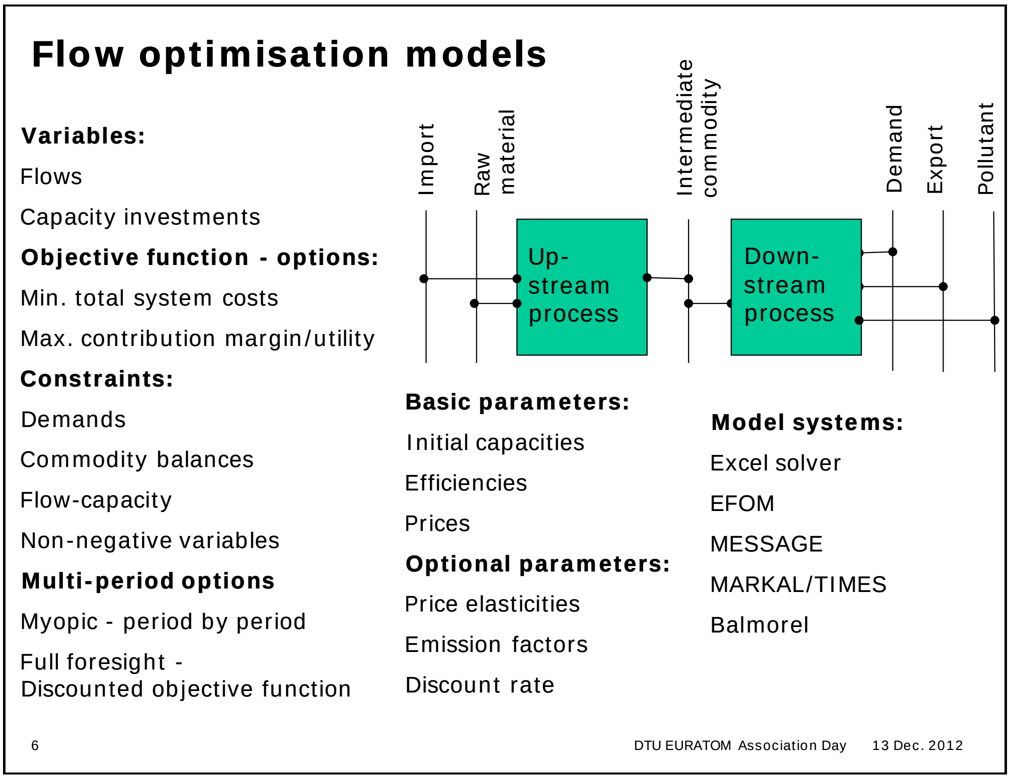

Figure 7.7. Generic presentation of flow optimisation models.

Finally, Figure 7.6 summarises the main features of fusion power plants for a long-term optimisation model. It was first presented for the European Environmental Agency in

November 2009. The last slide Figure 7.7 is a generic presentation of long-term optimisation model, which has been used in several presentations.

7.2 Preparation of peer reviewed articles

The framework for an article in a peer reviewed, mainstream energy journal is described in the conference paper Grohnheit et al (2011). However, the current EFDA-TIMES model is not yet suitable for such a presentation.

7.2.1 Abstract: The effect of large scale district heating on (the implementation of) CCS and fusion

Among the technologies for mitigating greenhouse gasses, carbon capture and storage (CCS) and nuclear fusion are interesting in the long term. In several studies with time horizon 2050 CCS has been identified as an important technology, while nuclear fusion cannot become commercially available before 2050. The modelling tools developed by the International Energy Agency (IEA) Implementing Agreement ETSAP include both multi-regional global and long-term energy models till 2100, as well as national or regional models with shorter time horizons. Examples are the EFDA-TIMES model, focusing on nuclear fusion and the Pan European TIMES model, respectively. In the next decades CCS can be a driver for the development and expansion of large-scale district heating systems, which are currently widespread in Europe, Korea and China, and with large potentials in North America. If fusion will replace fossil fuel power plants with CCS in the second half of the century, the same infrastructure for heat distribution can be used which will support the penetration of both technologies. This paper will address the issue of infrastructure development and the use of CCS and fusion technologies using the available models among the ETSAP tools.

7.2.2 Abstract: The future of regional large-scale thermal electricity generation

Among the technologies for mitigating greenhouse gasses, carbon capture and storage (CCS) and nuclear fusion are interesting in the long term. In several studies with time horizon 2050 CCS has been identified as an important technology, while nuclear fusion cannot become commercially available before 2050.

New technologies will become significant earlier than fusion. Some of them are small-scale technologies located much closer to the consumers. Others are dependent on natural resources located in coastal regions with shallow water or deserts. The potential of these resources is huge by 2050, when fusion may become available, but their production varies with sun and wind, and they require very large investment in long-distance transmission to population centres. All these technologies will reduce the market share of large-scale thermal units, which includes fusion.

The modelling tools developed by the International Energy Agency (IEA) Implementing Agreement ETSAP include both multi-regional global and long-term energy models till 2100, as well as national or regional models with shorter time horizons. Examples are the EFDA-TIMES model, focusing on nuclear fusion and the Pan European TIMES model, respectively.

7.3 Science talents

Over the last couple of years a good contact has been established between Risø DTU and the national science talent center (ScienceTalenter) in Sorø. This resulted in several talks to high school teachers and/or students. However, most importantly, ScienceTalenter has received a grant to make a fusion physics class for 25 science talents from five high schools in 2010.

The fusion physics class is repeated for five other high schools from November 2012 to April 2013. It includes the topic "Fusion Energy in the Energy System", which is addressed by the EFDA-TIMES model.

7.4 Status of the EFDA-TIMES model

Further documentation and validation effort will be needed, before such articles should be submitted to the relevant journals with some chance for acceptance.

The fact that fusion units will operate very similar to other large-scale thermal generating units for supply of industrialised regions and population centres may be used to develop more generic technologies in the EFDA-TIMES model for analyses of the second half of the 21st Century. This technology will be complementary and competitive to technologies that are dependent either on natural resources and long-distant transmission of electricity, such as solar CSP and off-shore wind, or small-scale units, mainly solar PV. From the results of such model analysis the generic technology introduce more generic aggregated technologies can be split among specific technologies using exogenous parameters.

In the model the energy system is optimised by minimising discounted total system cost, subject to constraints. Thus the quality of model results is very dependent on the consistency of techno-economic data, in particular their relative costs.

EFDA-TIMES is a variant of the models used by the IEA Implementing Agreement ETSAP (Energy Technology Systems Analysis Programme), in particular ETSAP-TIAM. Of these models EFDA-TIMES has the longest history. It has been used by a single modelling team with both continuity and gradual change of scientists. The archive of EFDA-TIMES contains information about model issues and solutions which may also contribute to improve the quality of ETSAP-TIAM analyses.

Some of the contents in this report was prepared for a comprehensive model documentation, which is now scheduled for Work programme 2013.

8 Conclusion: Modelling fusion in the energy system

Contribution to Association Euratom - DTU, Technical University of Denmark, Department of Physics - Annual Progress Report 2012.

Within the Socio-Economic Research on Fusion (SERF) programme EFDA and the Associations has developed a multi-region global long-term energy modelling framework (EFDA-TIMES) with time horizon 2100. This horizon will allow a significant contribution by fusion power, if the ongoing research and development become successful during the next 3-4 decades.

In this model technologies are organised into a network of energy flows linking demand and supply. Forecasts of energy demands in the various sectors come from global economic models. The energy system is divided into the following main sectors: Upstream, Electricity, Industry, Residential, and Transport.

Fusion units will operate very similar to other large-scale thermal generating units for supply of industrialised regions and population centres. Other technologies with very large potentials are likely to become significant earlier than fusion. However, these technologies are dependent either on natural resources and long-distant transmission of electricity, such as solar CSP and off-shore wind, or small-scale units, mainly solar PV or micro CHP to be integrated in local grids. The development, deployment and integration of these technologies into the energy system may be even more challenging than that of fusion. It will require far more resources for research and subsidies than the limited research budget, which is currently allocated to fusion.

In the model the energy system is optimised by minimising discounted total system cost, subject to constraints that reflect infrastructure, technology availability and policy objectives, e.g. reduction of CO_2 and other greenhouse gasses. It means that the quality of model results is dependent – not only on the consistency of techno-economic data, but also of the key economic assumptions, such as future energy prices and the choice of discount rates.

EFDA-TIMES is a variant of the models used by the IEA Implementing Agreement ETSAP (Energy Technology Systems Analysis Programme), in particular TIAM. Of these models EFDA-TIMES has the longest history – used by a modelling team with both continuity and gradual change of scientists with different backgrounds. The archive of model results also contains systematic analyses of different methods of discounting, including hurdle rates for different technologies and decreasing discount rates for very long-term optimisation.

The model development during 2012 has focused on three issues:

- enhancement of key technologies that are competing with fusion, in particular variable renewables and nuclear fission,
- revision of regions - now 17 regions with separate regions for the BRIC countries – Brazil, Russia, India and China,
- update of the base year from 2000 to 2005.

An agreement was made between the EFDA Leader and ETSAP, which will allow comparison of model assumptions and results. Together with contributions to semi-annual collaboration workshops on TIAM this will allow the small EFDA-TIMES team to benefit from the much larger TIAM community.

Contributions to EFDA-TIMES from the Systems Analysis Division of DTU Management Engineering) are co-ordinated within the work on the TIAM model within ETSAP. These activities include 2 senior scientists and 3 PhD students.

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