Special Issue on Energy Modelling: Introductory Article

Modelling Contributions to the Swiss Energy and Environmental Challenge

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1. Introduction[1]

While the world economy is struggling with the financial and economic crisis, the recent World Energy Outlook by the International Energy Agency (press release, November 9, 2011, London, International Energy Agency, 2011) reminds us of the other challenges the world faces:

> Governments need to introduce stronger measures to drive investment in efficient and low-carbon technologies. The Fukushima nuclear accident, the turmoil in parts of the Middle East and North Africa and a sharp rebound in energy demand in 2010 which pushed CO_2 emissions to a record high, highlight the urgency and the scale of the challenge.

Climate change and energy security concerns are of highest relevance at the international level. Although Switzerland was responsible for only 0.13% of world CO_2 emissions in 2008, it will have to bear its part of emission reductions and has a challenging energy future in sight. On May 2011 the Federal Council decided

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[1] This Special Issue is based on the energy modelling expert workshop that took place in Spring 2010 in Berne. Therefore the idea of this volume and all the model work was done before the earthquake and the tsunami that devastated Fukushima and hence before the decision on the new energy strategy. Results and opinions expressed in this volume are the sole responsibility of the authors of the articles. Special thanks go to the referees who have done a great job in assuring the quality of the papers presented in this Issue. We also thank the Swiss Federal Office of Energy and the EPFL for financial and in-kind support.

to phase out nuclear energy in the medium term. In order to ensure the security of supply, the Federal Council, as part of its new Energy Strategy 2050, is placing emphasis on increased energy savings (energy efficiency), the expansion of hydropower and new renewable energies, and, if necessary, on fossil fuel-based electricity production (cogeneration facilities, gas-fired combined-cycle power plants) and imports. Furthermore, Switzerland's power grid should be expanded without delay and energy research strengthened. Hence Switzerland is at the beginning of a new energy area.

Energy is already today a key factor for the economy and it might become even more important in the medium term future. McKinsey (see Bättig and Ziegler, 2010) estimated that roughly 40% of all sales (almost 400 Billion CHF) in 2008 were to sectors for which energy plays an essential role (energy transformation sectors, sectors where energy efficiency measures have to bring down energy consumption such as transport and the construction and building sector, energy intensive industries and financial services related to energy and climate products). Therefore the revolution of the Swiss energy system will directly and indirectly influence a large part of the Swiss economy. Energy suppliers will have to find new ways to provide clean energy, they will have to introduce new business models in a world where quantities sold should be limited and energy efficiency encouraged. The price of energy will increase and will influence the production structure and final consumption prices. In 2010, final energy consumption expenditure was almost 6% of Swiss GDP. The government cannot stay on the fence line and just watch market forces play it out; there is too much at stake and the energy markets are prone to inefficiencies. Hence energy policy will be a key factor for future economic development in the world and in Switzerland.

Energy policy ought to be effective, cost-efficient and fair. Concrete policy measures cannot be run experimentally to test whether they satisfy these conditions. Therefore, the regulators need the means to simulate policies in a setting with realistic features before implementing them. Economic energy models offer such means, based on these advantages:

- A strong theoretical background, in which markets clear, relative prices adjust, budget constraints hold and decisions follow economic reasoning.
- Representation of key-data, but no need for large datasets as one would need to do a statistical analysis.
- The possibility to analyse "in the dry" the main effects of potential future policies.

These models are not forecast models, but models that tell us how the economy would change, compared to a business-as-usual development, once the potential policy is implemented.

Energy models can roughly be organised into two groups: top-down and bottom-up models. There are further distinctions between optimization and simulation models, between estimated (econometric) and calibrated models, between partial and general equilibrium models etc. Herbst et al. (2012), in the first contribution to this Special Issue, provide an introduction to these different types of energy models, with references to a selection of Swiss and foreign applications. You might consider reading that chapter before proceeding with the next sections of this introductory chapter.

This Special Issue reports on recent state-of-the-art Swiss energy modelling contributions brought together at an energy modelling expert workshop that took place in Spring 2010 in Berne. Section 2 presents a summarized view of the energy models that took part in the survey in preparation for the workshop. The characteristics of the models are compared and discussed. Section 3 introduces the papers of this Special Issue and Section 4 highlights challenges and necessary model developments in the near future.

2. Overview of Economic Energy Models Used in Switzerland

In order to better understand the models that exist for Switzerland and to identify future improvements both from the modeling and the applied perspective, the research program Energy-Economy-Society (EWG) of the Swiss Federal Office of Energy (SFOE) and the Research group on the Economics and Management of the Environment at EPFL (EPFL REME) organized a one-day expert workshop on May 3, 2010 in Berne, at the Swiss National Bank. In preparation of this workshop, we conducted a survey of existing energy models that describe Switzerland. A questionnaire was sent to all research teams dealing with energy modeling, both at academic institutions and consulting firms. The aims of the survey were to establish a list of existing models, to highlight the differences between these models, and to identify and discuss possible future improvements.

Two conditions were required to be part of this survey:

- The model has to describe explicitly Switzerland; models that include Switzerland within a region (for example Europe) were excluded;
- The model has to place particular emphasis on the energy sector.

We did not restrict our analysis a priori to Swiss teams and sent our survey to European teams that manage European models, but in fact only Swiss teams seem to have models that describe separately Switzerland[2]. Six teams replied to our survey and seven models were reported. Taking into account the papers submitted for this special issue, we can add two models that were not listed in the survey, respectively the model MERGE-ETL managed by PSI (see Marcucci and Turton, 2012) and the CEPE model built by Imhof (2012). Five of the seven models, which are described in the survey, resulted in a contribution in this special Issue. The total of nine models listed in this section and the teams responsible of their management are the following:

- CEPE model (managed by ETHZ CEPE);
- CITE (ETHZ CER);
- ETEM (ORDECSYS);
- GEMINI-E3 (EPFL REME);
- GENESwIS (Econability);
- MERGE-ETL (PSI);
- Swiss MARKAL (PSI);
- Swissgem Switzerland (Ecoplan);
- Swissgem Worldwide (Ecoplan).

Table 1 presents a first attempt to establish a typology of these nine models with respect to their underlying methodology (i.e. bottom-up versus top-down models) and their regional coverage (i.e. purely Swiss versus international models). Even though our survey encompasses a large variety of models, six of these nine models are related to the top-down approach and more precisely to the Computable General Equilibrium (CGE) framework. The bottom-up category is represented by two models, ETEM and Swiss MARKAL. Hybrid models are only represented by MERGE-ETL, even if some attempts exist to link top-down models and bottom-up approaches at the Switzerland level, see for example the work done by Sceia et al. (2012) in this Issue, who couple GEMINI-E3 and Swiss Markal. With respect to the regional dimension of the models, six models describe only Switzerland, the others detailing Switzerland along with other regions of the World. No bottom-up model describing Switzerland has an international coverage. This is not surprising given the technological detail needed and the possibility to

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[2] In the past, some versions of European models have described Switzerland separately. This was the case of the model GEM-E3 (see Bahn and Frei, 2000), but to our knowledge these versions were not updated or maintained.

include international technology trends directly in the Swiss setting. Contrary to other models, the ETEM model is a regional bottom-up model that has been designed for modeling energy systems at a regional level. The version reported in this survey and the study using this model published in this special Issue (see Babonneau et al., 2012) describe the canton of Geneva[3].

Table 1: Typology of the Model Listed in Our Survey

	Bottom-up model	Hybrid model	Top-down model
National model	ETEM Swiss MARKAL		CEPE model CITE model GENESwIS Swissgem Switzerland
International model		MERGE-ETL	GEMINI-E3 Swissgem Worldwide

Table 2 presents the number of countries or regions and the number of sectors described by each model and indicates their temporal dimension. There is always a tradeoff between the number of regions and the number of sectors, so that the models that describe only Switzerland can dedicate more attention to the description of sectors. Another dimension that is not reported in Table 2 is the number of household groups represented by each model. Only the CEPE model, the Swissgem model family and the Swiss Markal model describe more than one household type. The Swiss Markal model represents 4 types of households. The CEPE model incorporates 14 household groups representing retired and working households in different income quantiles, and the Swissgem models also describe 14 household groups. By taking into account more than one representative household type, these models can assess the redistributive impacts of energy policies (see for example the contribution by Imhof (2012) in this Issue on the distributional outcomes of different tax regimes in the light of Post-Kyoto policies for Switzerland).

All models suppose that economic agents enjoy perfect foresight, except GEMINI-E3, which uses a recursive dynamic background, and the CEPE model, which is a static CGE model. As matters involving the energy sector are mainly

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[3] The same methodology will be applied in the coming years to other cantons.

related to medium and long term issues, the majority of the models covered by our survey can be simulated up to 2050 and sometimes beyond. The questions addressed by the contributions of this Special Issue – energy and climate policy, technical change and nuclear phase out – are all related to this medium and long term horizon.

Table 2: Regional, Sectoral and Temporal Breakdowns

	Number of regions	Number of economic sectors	Temporal dimension
ETEM	1	41	2010-2050; 5 years steps; perfect foresight
CEPE model	1	42	2005, Static model
CITE	1	12	2074; yearly steps; perfect foresight
GEMINI-E3	24	18	2001-2050; yearly steps, recursive dynamic
GENESwIS	1	31	2040, yearly steps; perfect foresight
MERGE-ETL	10	2	2010-2100; 10 years steps; perfect foresight
Swiss MARKAL	1	44	2000-2050; 5 years steps; perfect foresight
Swissgem Switzerland	1	26	2005-2100; yearly steps; perfect foresight
Swissgem Worldwide	112	22	2005-2050; yearly steps; perfect foresight

We report also the energy sources that are described by each model in Table 3, All models describe the fossil energy by distinguishing coal, oil products and natural gas. Non-fossil energy sources are in some models not describe explicitly, this is mainly the case of top-down models which describe implicitly for example renewable energies. In this case, when for example we implement a carbon tax, the models suppose that fossil energy are substituted by other inputs (namely capital, labor and other non-energy materials) that can be seen as renewable. Swissgem represents an exception by giving a detailed representation of energy sources. By nature, bottom-up models have a high degree of energy source detail with an extended description of technologies that are related to energy production and consumption, this is clearly the situation of ETEM and Swiss MARKAL.

This Special Issue is a good opportunity to address the differences between these models and to better understand how they work.

Table 3: Energy Sources Breakdowns

	ETEM	CEPE	CITE	GEMINI-E3	GENESwIS	MERGE-ETL	Swiss MARKAL	Swissgem
Coal	x	x		x	x	x	x	x
Oil	x	x	x	x	x	x	x	x
Natural Gas	x	x	x	x	x	x	x	x
Hydro	x					x	x	x
Wind	x					x	x	x
Solar	x					x	x	x
Waste	x							x
Biomass	x					x	x	x
Uranium		x				x	x	x
Geothermal							x	x
Biogas								x
Heat							x	x

3. Papers in the Special Issue

This section describes shortly the main features of the papers published in this Special Issue. We start with a methodological survey paper, introduce then the top-down models with endogenous growth effects and distributional issues between sectors and households. Next we change the direction of analysis and introduce the bottom-up models going from a regional model to a typical national model, and finally introduce an impact assessment model and a coupled model where the bottom-up models are linked to a general equilibrium model.

The first paper, by Andrea Herbst, Felipe Toro, Felix Reitze and Eberhard Jochem provides an overview of top-down and bottom-up energy modelling and an introduction to the types of models used in each approach. The overview is quite broad in scope, with some detail about illustrative models of each type. It touches also upon the third type of modelling, hybrid models, which combine parts of top-down and bottom-up. Based on their experience with the hybrid model developed in the ADAM project[4], the authors illustrate the difficulties of linking conceptually different models and what must be done to overcome them. This touches in particular on the modules that transform values of production into quantities produced, or economic into physical units.

Lucas Bretschger and Roger Ramer present their CGE model, which is quite standard except for the introduction of endogenous technological change where other models generally assume autonomous energy efficiency improvement. This allows for endogenous growth. Technological change is obtained through increased capital varieties. The properties of the model and the role of endogenous technological change are tested with the staple energy policy: the carbon tax designed to reduce energy use by a substantial amount. They find that (i) the aggregate effects turn out to be moderate, (ii) all sectors in the economy continue to grow at robust positive rates, and (iii) some industries experience substantially higher, some substantially lower growth than in the benchmark scenario. Such a result was predicted in the theoretical model for low input factor substitutability. Indeed, in that case, lower energy use in production also implies lower use of other inputs, which are then diverted towards investment, which is good for growth. This effect is reinforced if the revenues of the carbon tax are used to subsidize investment.

Frank Vöhringer uses a dynamic CGE model to compare different post-Kyoto policies that reduce Swiss domestic CO_2 emissions by 20% below 1990 levels until 2020. The reference case solely uses a carbon tax on stationary sources to reach this goal, while in the counterfactuals some sectors are tax exempted but participate in the EU ETS, which amounts to linking the Swiss ETS with the EU ETS. The author experiments with different participation thresholds to the ETS and different shares of auctioned permits. He finds that exempting certain sectors shifts the burden of carbon abatement to the taxed sectors. This distortion of the abatement activities increases the cost of achieving the given abatement target. Nevertheless, the distributional consequences are far more important than the efficiency losses.

Jan Imhof addresses the equity and efficiency implications of two issues of great political relevance: (i) the CO_2 tax exemption for transportation fuels and (ii) the lump-sum recycling of CO_2 tax revenues. Most interesting is the thorough discussion of distribution effects on the basis of his empirical (CEPE) model with 14 different household types. Although he uses ‘only’ a static model, this provides room for a higher dimensionality with respect to sectors and – more

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[4] See http://www.adamproject.eu.

importantly – with respect to households. The questions addressed in this paper can very well be discussed in a comparative static manner. Imhof finds that equity is not much affected by tax exemption but that tax exemption is costly in terms of overall welfare. In contrast, the revenue recycling scheme has strong distributional impacts.

Frédéric Babonneau, Alain Haurie and Julien Thénié present their ETEM model, a bottom-up techno-economic model of the canton of Geneva. The model includes some additional technology detail on 'Smart Grid Technologies', defined in the paper to include distributed CHP, electric vehicles and intermittent renewables coupled with storage. The model is used to investigate the effect of ambitious greenhouse gas emission reduction policies (and constraints on electricity imports) on the use of conversion, smart grid and end use technologies in the housing and the transport sector. Some uncertainty analysis completes the paper. The results allow one to conclude on the role of the selected 'Smart Grid Technologies'.

Nicolas Weidmann, Ramachandran Kannan and Hal Turton use a MARKAL model of the Swiss global energy sector and a TIMES model of the electric sector. The models are not coupled, but the energy system results of MARKAL are used as inputs for dynamic electricity system simulations with TIMES. Indeed, the TIMES model can take into account variations in electricity load and supply at different times of the day and in different seasons, but it has less interaction with the rest of the energy system. Global energy services demand is exogenous, extrapolated on the basis of GDP and population growth. The scenarios are, next to a baseline, those of 20% reduction in CO_2 emissions by 2020 and 60% by 2050 under the assumption of maintenance, resp. phasing-out of nuclear generation. The comparison of the scenario results shows the energy-system costs of the ambitious climate policy targets and the extra costs when they are pursued under the additional constraint of nuclear phase-out. They are very clear and compelling: the costs of the climate targets are small, but they become substantial if nuclear power is not kept as an option.

Adrianna Marcucci and Hal Turton use a variant of the integrated assessment model MERGE to analyse technological choices for Switzerland under a stringent global climate policy with modest global energy resources; and the possible consequences of different global or regional policies. The Swiss case is developed in detail and the model allows one to take into account international spillovers on technological improvement. They simulate several scenarios under a climate change policy with different assumptions on the development of the nuclear option. The paper presents the implication and the cost of the nuclear phase out with the implementation of a climate policy.

André Sceia, Juan-Carlos Altamirano-Cabrera, Marc Vielle and Nicolas Weidmann use a multiregional multisectoral CGE model (GEMINI-E3) coupled with two MARKAL models for the residential and the transport sector. They use this hybrid model to analyse the effects of two policy scenarios on the Swiss economy: 30 and 46% overall reductions in CO_2 emissions by 2030, with the set of specific instruments discussed in the framework of the revision of the CO_2-law for the transportation and the residential sectors. The results indicate that both under moderate and under stringent regulation, the economic effects turn out to be moderate. Total deadweight losses are between 0.24% and 0.47%. These losses could be reduced further if the set of policy instruments by sector were replaced by a uniform carbon tax.

4. Concluding Remarks

This survey has shown that Switzerland hosts a significant number of economic tools dedicated to the analysis of energy and climate policies. These tools are representative of existing models in the world, in particular those that are regularly used by the Energy Modeling Forum[5].

Every model has its strengths and weaknesses. For specific research or policy questions it is fine to use stylized models that just emphasize the features that are necessary to address those questions. Thus for instance, a simple model able to turn on and off some form of endogenous technical progress can provide insights about the importance of that feature. On the other hand, if the goal is to simulate large-scale policies that will certainly have important impacts on the whole economy, it is necessary to have adequate macroeconomic equations and to embed Switzerland in the international context. If the goal is to simulate modest policies that are tailored to specific energy sources or sectors, a technology-rich representation of energy generation and its use is required. Finally, if the goal is to simulate large-scale policy programs that develop over time and differentiate between energy sources and sectors, all of the above is needed, which implies coupling bottom-up and top-down models. With the risk of creating monster models, the results of which no one is able to comprehend.

Some features of the real world are under-represented in all models. Uncertainty is one of them, because it is extremely difficult to solve stochastic models in a coherent way. This poses also questions about the representation of agents'

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[5] See http://emf.stanford.edu.

preferences and anticipations (myopia, time-inconsistency, etc.). As important as uncertainty in individual decision making is uncertainty about policies and their adoption (more on this below). Endogenous growth is another property of the real world, certainly important for the long-term effects of policies (in particular but not only RD&D policy), which is seldom represented in large simulation models. It requires much more computation time and creates the risk of multiple equilibria. In addition, the data are often missing for calibration. Finally, these models assume all too often perfect markets, while the real world is riddled with market imperfections: markets that are missing or not perfectly competitive, heterogeneous firms that do not maximize their profit (especially in the public sector), spillovers and externalities that do not translate into costs and incomes, etc. This is particularly important for the energy markets because the public sector plays such an important role on that market, next to be composed of a small number of big players, and because electricity is such a complex good (more on this below). It is also particularly important on these markets because policies are often designed precisely to overcome market imperfections.

We are here at the edge of general modeling research. Until the community has come up with practical solutions, it might be preferable to use models with uncertainty or endogenous growth, which are necessarily drastically simplified regarding sectoral and regional disaggregation, when simulating policies for which these are really central features, e.g. innovation policies.

As regards energy modeling in particular, the highly complex and increasingly important electricity market is still often represented in an over-simplified manner. To do it right, output should be differentiated by season, day of the week and even hour; variable pricing should be allowed for; the particular equilibrium between supply and demand cannot be driven simply by price adjustments; and the volatility of some sources (renewables) and the speed with which the output of other sources can be adjusted ought to be taken into account.

In the discussion at the workshop, potential users of such simulations were also given a chance to express their wishes. Among them is the wish for long-term forecasting. Of course, these models are not designed for forecasting. They postulate a baseline based on other people's forecasts of long-term growth rates, population dynamics and exogenous technical progress; then they simulate deviations from that baseline. In effect, when building a complete baseline based on a few parameters, they actually generate forecasts for magnitudes such as energy production and consumption. If these models are endowed with constraints on resources and technologies, they 'bend' the baseline to fit those constraints. They thereby produce in effect predictions of important variables over time horizons that are much longer than those of the regular business-cycle forecasters. Usually modelers are quite discrete about those predictions, as they feel that the simulated deviations from the baseline are much more robust to modeling assumptions than the baseline itself. In fact, there are not many better long-term forecasts around, so modelers should not be too shy about their own predictions. This is increasingly done when modelers compare their baselines before they set up a multi-model policy simulation exercise (e.g. in the context of the Energy Modeling Forum).

The discussion with the potential users of these simulations also showed that the easy times when they wanted to know the effects of a 5 ct/kWh energy tax are gone. Today's policies are much more subtle and reactive to environmental and economic development. The clients of policy simulations want to know what gradually increasing tax rate, differentiated by climate impacts of the energy sources, will allow meeting a given consumption target at a distant horizon. Or they ask for the economic costs of replacing in the optimal fashion a given source of energy (coal, imported oil, nuclear power plant). They even need guidance about the meaning of 'optimal', since there are many ways in which the effects of a policy can be measured. They also ask for regional impacts of regional policies, which implies downscaling the models in a fashion that the data seldom allow for and for which modelers need plausible sub-models of interregional trade and migration.

The requirements for sensitivity analyses are also growing. No longer is it sufficient to double and divide by two some elasticities. Modelers are asked to test the sensitivity of their results to the baseline, i.e. to diverse growth rates, dates for peak oil, outcomes of international negotiations, paces of technological development and deployment, etc. Simulating a range of scenarios takes preeminence over standard sensitivity analysis. An alternative is multi-model simulations. Still, all of this complicates considerably the interpretation and communication of results.

In the face of these demands, actually facilitating them, computing power is growing fast and the data are also improving. Thus, every modeling group can continuously improve its tool along these lines, learning from one another and from parallel efforts in the rest of the world. It is still often the lack of data that holds them back, which gives particular value to the work that is done by different federal offices and research teams to improve the data base. This important contribution to the modeling work is possibly too little acknowledged in this Special Issue.

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