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Report on Work Package D of the ETSAP Project "Integrating policy instruments into the TIMES Model"

Best Practice Examples

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1. Attributes of an ideal energy model for policy evaluation

Issue and objective

With the issue of climate change, the policy environment in which energy models are applied today has changed significantly. In addition to determining technological pathways with which certain climate goals could be reached, research concentrates on the question of what could be achieved with a specific policy instrument taking into account the conditions under which such instruments would operate, e.g. behavioural and political constraints. This raises the question of what an ideal energy model for policy evaluation would have to look like and what conventional energy system models can contribute to the issue of policy evaluation.

Solution approaches

In order to assess the suitability of energy models for policy evaluation, it is useful to draw upon a set of clear criteria. Here, the approach initiated by Jaccard et al. (2003) provides a valuable starting point. It identifies three criteria that an ideal model should comprise for the assessment of different types of policy instruments:

- **Technological explicitness:** Energy models for policy evaluation should include information on a large variety of technologies as represented by their technical and economic characteristics. This is particularly important for technology-specific measures and to evaluate the future potential of breakthrough technologies.
- **Microeconomic realism:** Energy models for policy evaluation should contain a realistic depiction of the decision-making behaviour of firms and households such that technology choice is not only based on financial cost but also on aspects like heterogeneous preferences, perception of risk, intangible cost, etc.
- **Macroeconomic completeness:** Energy models for policy evaluation should take macroeconomic feedbacks into account, since environmental policy instruments do not only affect the energy system but can have impacts on the structure and output of the entire economy which in turn are likely to entail repercussions on energy supply and demand.

Additional remarks

It has to be stressed that the representation by Jaccard et al. (2003) establishes an idealised version of an energy model for policy evaluation. In reality, data and computational limitations create a significant challenge making it difficult to combine all three criteria in one modelling approach. Consequently, the choice of the specific modelling tool should always be adapted to the research question and in most cases a combination of different model approaches will be necessary to evaluate a certain policy instrument. The set of criteria for an ideal energy model is, however, helpful as a guideline to assess the strength and drawbacks of a given model approach for policy evaluation.

2. Representing consumer behaviour in an energy system model

Issue and objective

Conventional bottom-up energy system models have often been criticized for their representation of the decision-making behaviour of different economic agents. Especially in optimization models, strong emphasis is put on financial costs as the key decision variable for technology choice. In reality, however, investment decisions by households or firms depend on a large variety of parameters which can explain why not always the most cost efficient (based on the net present value) option is chosen. Here, an important differentiation can be made between market and non-market failures (cf. Jaffe and Stavins 1994). Market failures describe all incidents in which the market mechanism does not lead to the optimal allocation of resources such that a policy intervention might be justified. In the case of energy-related investments, important examples would be information shortages, financial constraints or the owner-tenant dilemma. Non-market failures refer to all factors which are not covered by financial costs but express rational consumer behaviour, most importantly transaction costs, risk premiums for new technologies, market heterogeneity, non-economic factors (like comfort, design, etc.). In order to arrive at a realistic representation of the effects of policy instruments on the energy system, both these categories describing consumer behaviour should be taken into account.

Solution approaches

In this context, three main approaches to represent consumer behaviour in energy system models have been identified:

- A basic approach to model investment barriers has consisted for a long time in using high implicit discount rates. In addition, in some analyses the impact of policy instruments has been accounted for by lowering these rates (cf. Mundaca 2008; Božić 2007).
- A more sophisticated method has been developed for the hybrid model CIMS. To account for behavioural aspects, the calculation of the market shares of competing technologies is not only based on financial costs, but also on additional parameters: the weighted average time preference rate, a cost term representing intangible costs and a market heterogeneity parameter (cf. Jaccard 2009).
- Within the scope of the optimising energy system model SOCIO-MARKAL, the effect of awareness campaigns is modelled by introducing “virtual technologies” which include the cost of the awareness campaign and, if used, directly have an effect on the investment decision (cf. Nguene et al. 2011).

Additional remarks

Accounting for the decision-making behaviour of different economic agents in an energy system analysis can influence the evaluation of the impacts of policy instruments significantly, especially in the case of energy efficiency measures. At the same time, it has to be kept in mind that the value of a more sophisticated modelling approach depends highly on a good empirical foundation. Here, comprehensive research work is needed, especially to estimate the effects of different policy measures on behavioural parameters.

3. Increasing economic flexibility in an energy system model

Issue and objective

Energy system models are constructed by definition as partial equilibrium models such that repercussions on the rest of the economy are not taken into account. This gives rise to a number of problematic issues, especially when these models are applied for policy evaluation. First of all, by fixing the demand for energy services the flexibility of the energy system in reacting to changes in the scenario assumptions is restricted considerably because one important adjustment option, i.e. reducing demand for energy services, is disregarded. Moreover, a changing policy environment can have impacts on the structure of the economy which can be associated with significant modifications in energy demand. Finally, conventional energy system models tend to overestimate the energy saving potentials from improvements in energy efficiency since direct and indirect rebound effects are not taken into account. Hence, strategies are needed to increase the economic flexibility of energy system models.

Solution approaches

In general, it can be observed that approaches for the inclusion of macroeconomic feedbacks in bottom-up energy system models have been much more widely explored than the integration of behavioural parameters. A first step to increase the economic flexibility consists in assigning own-price elasticities to the different demand categories in the model such that the economic agents can react more flexibly to changes in the scenario assumptions. Moreover, this allows to explore direct rebound effects. However, it has to be pointed out that in order to account for all macroeconomic feedbacks, some sort of coupling with a top-down Computable General Equilibrium (CGE) model is necessary. According to Böhringer and Rutherford (2005), three different coupling strategies can be distinguished. Firstly, large-scale bottom-up and top-down models can be coupled via a soft link such that both models are still run separately but important model drivers are exchanged in an iterative process (cf. for example Schäfer and Jacoby 2006). The second approach consists in hard-linking an existing bottom-up energy system model with a reduced from representation of a CGE model (cf. for example Loulou et al. 2004). The most sophisticated strategy makes use of the possibility to specify market equilibrium models as mixed complementarity problems to create entirely integrated models containing both the detailed representation of technologies and all macroeconomic feedbacks (cf. for example Böhringer and Rutherford 2005).

Additional remarks

Using the elastic demand feature in a bottom-up energy system model constitutes a simple way of increasing economic flexibility. Furthermore, this has no significant impact on computational time. In contrast, combining energy system and CGE models proves to be much more complicated as they are based on different mathematical programming approaches (linear programming versus mixed complementarity programming). With respect to policy evaluation, it has to be pointed out that the importance of incorporating all macroeconomic feedbacks in the analysis depends strongly on the scope of the analysed instrument in terms of regional, sectoral and technological coverage.

4. Modelling emissions trading systems in an energy system model: basic approach

Issue and objective

Apart from emission taxes, emissions trading systems represent the most important market-based policy instrument that is directly aimed at emission reduction. The European Emissions Trading System (EU ETS), introduced in 2005, was the first transnational and is currently the largest greenhouse gas emissions trading system in the world. The effects of such schemes are already often taken into account in the scope of a scenario analysis with an energy system model by means of fixing a price or putting an upper bound on emissions. In order to provide a clear interpretation of the results of such an analysis, the basic mechanism of representing emissions trading systems in an energy system model needs to be understood.

Solution approaches

As emissions trading systems constitute quantity-based mechanisms, the basic approach for their integration into an energy system model is comparatively straightforward. By putting a user constraint on the maximum amount of emission allowed in the entire trading region in a certain time period both defining features of such a cap and trade system are accounted for. The dual variable of the user constraint representing the cap equals the marginal costs of the last (most expensive) unit of emission abated to fulfil the constraint. It can be therefore interpreted as the certificate price that would arise in the trading system under the modelled conditions. Moreover, it directly affects the generation cost of plants using fossil fuels. The second fundamental feature, the trading mechanism, is already implicitly included in an optimising energy system model. The linear optimization approach ensures that the most cost efficient way of fulfilling the cap is realized – as it would be the case when emission allowances can be traded between emitters.

Additional remarks

It is evident that the basic approach for the representation of emissions trading systems in energy system models is relatively easy to implement. Challenges may arise, however, when trying to depict the actual features of a specific trading scheme as realistically as possible. Here it becomes obvious that the design of real-world tradable permit systems can deviate substantially from the idealised and abstract representation in theoretical literature. Special attention needs to be paid particularly with regards to the regional (cf. the following Best Practice Example) and sectoral coverage, the mechanism for the allocation of emission certificates and the linking with other emissions trading systems or the Clean Development and Joint Implementation mechanisms.

5. Modelling supranational emissions trading schemes in a national energy system model

Issue and objective

When designing an emissions trading system, one of the aims is to cover a comparatively large region such that the advantages in terms of cost efficiency are fully exploited. In energy system analyses, where due to the complexity of representing the entire energy system often models with national or limited regional scope are applied, this gives rise to the problem that in many cases the modelled region does not coincide with the trading region. So far, this issue has usually been addressed in two manners: either by setting a fixed emission reduction path for the respective country or by integrating fixed certificate prices into the model. In the first case, the drawback consists in the fact that the emission trade with the remaining trading region is neglected, while in the second case the influence of changing national framework conditions on the certificate price is ignored. Hence, the aim consists in developing a modelling approach that makes it possible to determine both the emission reduction in the modelled region and the emission certificate price endogenously.

Solution approaches

The basic idea of the approach suggested here is to incorporate the emission reduction options of the entire trading region into the national model. To do so, an additional process is introduced which contains the emissions of all participating countries outside of the modelled region which would arise if no tradable allowance system was in place and therefore no reduction measures would be undertaken. This procedure makes it possible to put a cap on total emissions in the trading region. While the emission mitigation in the model region is still based on the explicit modelling of technologies within the reference energy system, the reduction options in the remaining regions are added to the model with the help of an abatement cost curve. This is modelled as a step function containing the emission reduction potentials in the rest of the trading region at different certificate price levels. The comprehensive data needed for this cost curve can either be obtained by an extensive literature research, by conducting a quantitative model analysis at global scale or by aggregating the results from several national model analyses. Through the optimization approach, the most cost efficient manner of fulfilling the cap on emissions is determined such that the marginal abatement costs for the modelled region and the remaining region are approximated and a uniform certificate price for the whole system emerges.

Additional remarks

When using an abatement cost curve to represent the reduction potentials in the remaining trading region, one has to keep in mind that one specific cost curve represents the reduction potentials under a specific set of scenario assumptions. If it is assumed that the framework conditions in the remaining trading region change, the cost curve needs to be adjusted. Moreover, the interaction between the emission reduction targets and the cross-border exchange of electricity has to be considered such that electricity imports should be restricted or bound to the steps in the cost curve. This modelling approach could also be applied to include credits from CDM or JI projects into a model with limited regional scope.

6. Modelling feed-in tariffs systems for renewable electricity in an energy system model

Issue and objective

Fixed feed-in tariffs (FIT) or premiums are currently the dominant policy instrument for the promotion of renewable electricity in Europe (cf. de Jager et al. 2011). Thus, the expansion of the various renewable sources in electricity generation depends strongly on the tariff level and structure of such systems. So far, in energy system analyses the effects of FIT systems have usually only been taken into account in an indirect manner by exogenously setting the future amounts of renewable electricity generation. This, however, strongly reduces the flexibility of the model. The aim is therefore to develop a modelling approach for the explicit representation of FIT systems in energy system models, such that renewable electricity generation is part of the optimization process and all effects of the FIT system are determined endogenously.

Solution approaches

The modelling approach is split up into two steps: the modelling of the generation side (i.e. the tariffs) and the modelling of the demand side (i.e. the FIT surcharge):

- **The generation side:** In the first step, the feed-in tariffs are explicitly integrated into the model with the help of the model parameters which represent subsidies. In the case of technology-specific schemes, attention should be paid that the complexity of the system is accounted for, i.e. that a large variety of renewable technologies is included in the model. Moreover, to provide a realistic representation, the special characteristics of a given system should be considered, e.g. limitations in the payment period, annual degression rates, etc.
- **The demand side:** Usually, the additional costs of the FIT system are financed by a levy on retail electricity prices (the FIT surcharge). The level of this surcharge depends on the expansion of renewable electricity, i.e. on the model results. Therefore, subsequent to the first model run, where only the tariffs are implemented, the FIT surcharge is calculated and integrated into the model framework (as additional costs on final electricity demand). Afterwards, an iterative process of several model runs is needed to adjust FIT payments and the FIT surcharge to one another.

Additional remarks

For price-based measures, like FIT systems, the modelling approach is comparatively complex. Moreover, the model itself should fulfil certain requirements to allow for a realistic representation of the impacts of the feed-in tariffs, most importantly: include a broad range of renewable technologies, apply a high time resolution, use price-elastic demands to adequately capture the effects on electricity consumption, take into account other system effects that a strong expansion of renewable electricity entails (e.g. on the electricity grid or the need for storage capacities).

7. Modelling quantity-based support schemes for renewable electricity in an energy system model

Issue and objective

Quantity-based mechanisms for the promotion of renewable electricity, most importantly tradable green certificate (TGC) schemes and tendering procedures, are currently only applied by a few countries in Europe, while they are more prevalent in U.S. states (cf. Schmalensee 2011). From a theoretical point of view, they offer a number of advantages, like target accuracy, competition between renewable producers, market-based pricing as well as cost efficiency (in the case of technology-neutral schemes). As it was the case with feed-in tariffs, it is crucial to represent the functionality of such quantity-based support systems in a correct and realistic manner in energy system models in order to be able to evaluate the long-term impacts on energy supply and demand, compare different types of support schemes for renewable electricity and explore the interactions with other types of policy instruments.

Solution approaches

Since TGC schemes and tendering procedures address the quantity of renewable electricity generation rather than its price, the modelling approach for the explicit representation of such schemes is much more straightforward than in the case of feed-in tariff systems. Target values for relative shares or absolute amounts of renewable energies in electricity generation can be easily introduced into the model with the help of user-defined constraints. As it would be the case in the trading system for green certificates or under the tendering procedure, in the optimization process the cheapest generation options to fulfil the quota are chosen. The shadow price of such a user constraint is equivalent to the difference between the generation costs of the technologies covered by the quota and the market price for electricity and can therefore be interpreted as the certificate or auction price. In that manner, both technology-neutral (one user constraint) and -specific (separate constraint for each renewable source) systems can be modelled.

Additional remarks

In this context, an important difference between using relative and absolute bounds to model the expansion of renewable electricity needs to be highlighted. In the case of a relative constraint, the shadow price directly impacts electricity generation costs and therefore also electricity prices in the model. Hence, the additional costs on the demand side are already accounted for. In contrast, when generation from renewable energies is forced into the model by specifying absolute minimum quantities, the shadow price can be interpreted as the required subsidy (from outside of the energy system) to make the respective technology competitive. Thus, in this case end-user electricity prices are not affected. If the costs of the support system are financed by a levy on retail electricity prices, an additional cost term on final electricity demand has to be integrated into the model, as it was the case for feed-in tariffs.

8. Representing regulatory instruments in the buildings sector in an energy system model

Issue and objective

Command-and-control instruments have for a long time played a dominant role in environmental policy and are still applied today in various sectors and for a variety of purposes. The buildings sector exhibits a huge potential for comparatively cost efficient emission mitigation options, but at the same time significant investment barriers need to be overcome. Therefore, regulatory measures are usually implemented for new buildings and existing ones undergoing major renovation in the form of mandatory efficiency standards or minimum renewable shares for heating and cooling. In theory, modelling regulatory instruments in quantitative energy models is relatively straightforward as any obligatory measure can be integrated with the help of bounds and user constraints. However, special attention needs to be paid to the high level of detail and the flexibility (by offering various alternative options to fulfil the requirements) that these regulations usually contain.

Solution approaches

In the case of modelling obligatory efficiency standards in the buildings sector, in a first step it needs to be ensured that a detailed building typology covering both the housing stock and the expected construction activity of new buildings is incorporated in the model. Moreover, as the requirements generally only apply to refurbished existing buildings a reasonable assumption on the annual refurbishment rate has to be set. The easiest way to integrate minimum efficiency standards into the model consists then in incorporating them exogenously into the heating demand projections of the different building types (based on the specific heating requirement per unit of building volume or area to be heated). Alternatively, an endogenous approach can be chosen in which the various efficiency measures are represented by saving processes which are forced into the model with the help of lower bounds or user constraints. This method has the advantage that the additional investment costs are directly accounted for in the model.

When modelling regulations on the minimum use of renewable energies for heating and cooling it has to be kept in mind that such instruments usually offer a large variety of choices (in the form of different renewable technologies) to comply with the obligations. This flexibility needs to be accounted for in the model. Thus, first of all it has to be made sure that all these options are included and that they are made obligatory for the affected building categories. The technology choice could then be left to the optimization approach. However, this is likely to lead to highly unrealistic results as only the criteria of cost efficiency is applied resulting in a concentration on only one heating technology type per building category. Hence, the modelling approach is complemented by adding realistic lower and upper market shares for each technology option.

Additional remarks

When developing modelling approaches for the representation of regulatory instruments in the buildings sector in an energy system model, particular challenges arise due to high complexity of these measures. Thus, the extent to which such instruments are modelled endogenously with a high level of detail or are represented by reasonable exogenous assumptions always also depends on the type of model that is used.

9. Representing financial incentive measures in the buildings sector in an energy system model

Issue and objective

Financial incentive measures, like investment grants, soft loans or tax reliefs, are usually implemented as complementary measures to reduce investment barriers or to facilitate the market introduction of new and innovative technologies. In the buildings sector, such instruments are often provided for voluntary measures that go beyond the mandatory requirements established by command-and-control policies. The special challenge in modelling financial incentives in energy system models consists in incorporating the decision-making behaviour of different economic agents as the use of subsidy schemes does not only depend on cost efficiency but is influenced by various economic and non-economic factors. Thus, modelling approaches that reflect a realistic development of such instruments and are therefore suitable to assess their impacts on the energy system are needed.

Solution approaches

Energy system models usually contain different types of subsidy parameters such that the necessary foundation for the modelling of financial incentive measures is given. In general, various approaches can be chosen to integrate such measures which vary in complexity and rely either more strongly on exogenous assumptions or the actual endogenous incorporation of the financial incentives. In a first step, it has to be made sure that all the options that are subsidized are represented correctly in the model. In the case of thermal insulation measures, this can be achieved with the help of saving processes.

For the representation of investment grants two different approaches have been identified. The first one consists of exogenously estimating the future effects of the grant programme (based, if possible, on historical data) and then integrating these impacts in a fixed manner with the help of user constraints into the model. As an alternative, the investment subsidies can be inserted directly into the model by means of adding an additional (virtual) process which contains the subsidy parameter. The decision whether, to what extent and for which technologies the investment grants are used is then left to the optimization calculus. If the budget of the support programme is limited, an additional user constraint on the total investment volume or the grant budget needs to be included.

In the case of soft loans, the same differentiation between an approach based on an exogenous impact estimation and a more endogenous method can be observed. However, the endogenous approach is not as straightforward as for investment grant programmes, as low-interest loans do not directly lower the actual investment costs. Instead, the financing costs are reduced which can be expressed in the model by applying lower discount rates to the supported investments. The size of the impact on discount rates is difficult to verify empirically such that a sensitivity analysis with a range of different discount rates is advisable.

Additional remarks

The future impacts of financial incentive measures on the energy system are particularly difficult to predict as their use is influenced by the decision-making behaviour of households and firms. Hence, before integrating the effects into an energy system model, a good empirical foundation is required. With regards to the modelling approach, in general the right balance between fixing assumptions exogenously and representing the measures in an endogenous manner needs to be found depending on the type of model that is applied.

10. Literature

Böhringer and Rutherford 2005 Böhringer, Ch.; Rutherford, T.: Integrating Bottom-Up into Top-Down: A Mixed Complementarity Approach. ZEW Discussion Paper No. 05-28, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim, 2005.

Božić 2007 Božić, Helena: Optimization of Energy Consumption and Energy Efficiency Measures with MARKAL Model. Paper for the International Conference on Clean Electrical Power (ICCEP), 21-23 May 2007, Capri, Italy.

de Jager et al. 2011 de Jager, D.; Klessmann, C.; Stricker, E.; Winkel, T.; de Visser, E.; Koper, M.; Ragwitz, M.; Held, A.; Resch, G.; Busch, S.; Panzer, C.; Gazzo, A.; Roulleau, T.; Gousseland, P.; Henriet, M.; Bouillé, A.: Financing Renewable Energy in the European Energy Market. Final report by order of the European Commission, DG Energy. Utrecht, 2011.

Jaccard 2009 Jaccard, Mark: Combining top down and bottom up in energy economy models. In: Evans, J. (ed.); Hunt, L. (ed.): International Handbook on the Economics of Energy. Cheltenham, UK, Northampton, MA, USA: Edward Elgar, 2009: 311-331.

Jaccard et al. 2003 Jaccard, M.; Nyboer, N.; Bataille, C.; Sadownik, B.: Modeling the cost of climate policy: distinguishing between alternative cost definitions and long-run cost dynamics. In: The Energy Journal, Vol. 24 (2003), No. 1: 49-73.

Jaffe and Stavins 1994 Jaffe, A.; Stavins, R.: The energy-efficiency gap - What does it mean?. In: Energy Policy, Vol. 22 (1994), Issue 10: 804-810.

Loulou et al. 2004 Loulou, R.; Goldstein, G.; Noble, K.: Documentation for the MARKAL Family of Models, Part II: MARKAL-MACRO. Energy Technology Systems Analysis Programme, International Energy Agency (IEA), Paris, October 2004.

Mundaca 2008 Mundaca, Luis: Markets for energy efficiency: Exploring the implications of an EU-wide 'Tradable White Certificate' scheme. In: Energy Economics, Vol. 30 (2008), Issue 6: 3016-3043.

Nguene et al. 2011 Nguene, G.; Fragnière, E.; Kanala, R.; Lavigne, D.; Moresino, F.: SOCIO-MARKAL: Integrating energy consumption behavioral changes in the technological optimization framework. In: Energy for Sustainable Development, Volume 15 (2011), Issue 1: 73-83.

Schäfer and Jacoby 2006 Schäfer, A.; Jacoby, H.D.: Experiments with a Hybrid CGE-MARKAL Model. In: The Energy Journal, Special Issue on Hybrid Modelling of Energy-Environment Policies: Reconciling Bottom-up and Top-down, 2006: 171-177.

Schmalensee 2011 Schmalensee, Richard: Evaluating Policies to Increase the Generation of Electricity from Renewable Energy. Working Papers 1108, Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research, May 2011.