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# ENERGY MODELS AND THE DECISION MAKING PROCESS IN THE FRG

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The energy modelling efforts and energy models developed in the FRG are described. This is followed by a critical discussion of the role which energy models have and have not played in energy policy and energy planning. Recommendations on how to improve the usefulness and impact of energy models in the decision making process are given.

## 1. INTRODUCTION

I have been involved in energy modelling for planning and policy making for about fifteen years now and I am still convinced that energy models and their proper use can contribute to better decisions in the energy policy area.

I think I should make this statement right at the beginning, because my remarks on the use of energy models for energy policy planning in the Federal Republic of Germany will be somewhat critical. Rather than describing and discussing in great detail the energy models developed in the FRG. The paper will focus to a certain extent on the problems, difficulties and failures of energy models to make their contribution to better energy policy planning.

Nevertheless the paper will start with a brief review of the history of energy modelling in the FRG.

Thereafter the question will be discussed, whether or not energy models have succesfully contributed to help solving the complex problems facing the energy planner and energy policy maker. It is intended to make clear, that despite of the tremendous progress made in the design of complex, large-scale models, energy models were by far not as successful as they could have been. It will be argued, that a new, more realistic attitude, a new orientation of the preferences of the model builder, is needed; that expectations must be redirected to what is needed and can be achieved in spite of the existing uncertainties rather than to promote and construct more sophisticated or even universal models.

An example of a successful energy model application will be given to indicate the direction of improvements required in energy models application, to make them a useful and powerful tool for energy policy planning.

## 2. ENERGY MODEL DEVELOPMENT IN THE FRG

Although the development of energy models began in the early sixties, that is well before the first oil crisis in 1973, it was the growing awareness of the energy problem originating from this event that forced an explosion in the development of energy models in the FRG.

The energy models developed in the sixties focused mainly upon the supply and demand of a single energy form or fuel like electricity, oil or natural gas. Faced with the complex problem of optimal allocation and routing of crude oil and oil products between different oil sources, refineries and demand centers the petroleum companies have developed and applied particularly large allocation models, as well as models for the refining process. Another example of a successful application of models of this sectoral type, are the models used for the analysis of electric utility operations and expansion plans. Several models using the optimization or simulation approach have been developed and are used to evaluate the optimal expansion strategy of the power plant system required to satisfy an increased electricity demand.

Both types of models mentioned above focus on the supply side, that is on the best way to satisfy an assumed fuel demand. Demand is an exogenous input to these models and is often provided by econometric demand models estimating energy or fuel demand as a function of energy prices and other determinants such as population, economic growth, etc..

A major criticism concerning the sectoral, single fuel or energy models is, that they treat the development of the sector or fuel in question as in isolation from the rest of the overall energy and economic system, thereby ignoring that there are many different ways of meeting given energy service demands such as space heat, industrial process heat, and transportations. A sectoral, single fuel model cannot describe the interfuel substitution related to changing energy prices, technological developments or environmental considerations in the different sectors of energy use.

Complying with these requirements was the main reason for the development of energy system models, describing the energy flows from different primary energy sources through various conversion and utilization processes to different end use demands.

Energy demand is usually an exogenous input to the energy supply system models. Therefore these models do not allow for demand adjustments due to higher energy prices or to changed GNP growth caused by rising energy cost and limited energy supplies.

Handling these issues requires models linking the energy sector with the rest of the economy. Consequently the next step in the model development was directed to the so-called "Energy-Economy-Models".

All of the different types of energy models mentioned so far have been developed in the FRG during the last twenty years. In addition to that, macroeconomic growth models have been extended to incorporate energy as a production factor.

After this general short glance back into the history of energy modelling in the FRG, some of the energy models developed and available in the FRG are briefly described, and it will be discussed if these models have been applied in the policy and planning area to address real problems. Thereby a distinction will be made between the following four classes of models:

- macroeconomic growth models
- energy demand models,
- energy supply system models and
- energy-economy models.

In figure 1 three macroeconomic growth models are listed. EURECA is a highly aggregated econometric model, based on a single production function for the whole economy, where energy is one of the production factors. EXPLOR is an Input-Output-model with time-dependent coefficients. The third model mentioned in this figure, which was developed by Conrad and Hildebrandt, is a dynamic Input-Output-model. The changing coefficients are determined by the changing prices of capital, labour, energy and the other sectorial inputs. None of these models has ever been applied in a real decision making process. Applications so far have been more or less an academic exercise.

The energy demand models available in the FRG together with the methodology used are listed in figure 2. EDM is an econometric model which determines the final energy demand in industry, transportation and in the commercial and private sector. The second model is the well-known MEDEE-model, which can be characterized as a consistent accounting framework based on a disaggregated engineering process analysis of final energy demand starting from useful energy needs in different sectors. Besides these two models there do exist several other demand models of either simulation or econometric type. Although these models have been available since several years, they have not been applied by the so-called policy makers to address a relevant problem.

The energy supply system models have been in this respect somewhat more successful as can be seen from figure 3.

MARKAL, MESSAGE and EFOM are quite well-known multiperiod linear programming models dealing with the overall energy supply system. All three models have basically the same structure. They focus on the technical, economic and environmental characteristics of the energy extraction, conversion, delivery and utilization processes, that comprise the total energy system. An exogenous given useful energy demand is satisfied at minimum costs under a set of con-

| MODEL | APPROACH / METHODOLOGY | APPLICATION |
|---|---|---|
| EDM | ECONOMETRICS | — |
| MEDEE | ENGINEERING PROCESS ANALYSIS | — |
| (SEVERAL) | SIMULATION, ECONOMETRICS | — |

Figure 1 : Macroeconomic growth models

| MODEL | APPROACH / METHODOLOGY | APPLICATION |
|---|---|---|
| EURECA | ECONOMETRICS, SINGLE PRODUCTION FUNCTION | — |
| EXPLOR | INPUT-OUTPUT | — |
| CONRAD / HILDEBRANDT | DYNAMIC INPUT-OUTPUT-APPROACH WITH PRICE DEPENDENT COEFFICIENTS | — |

Figure 2 : Energy demand models

straints. The constraints involve balances for individual fuels, limits on the installation and operation of technologies as well as resource availabilities, to mention only a few.

Compared with these three models, SOPKA-E is a somewhat simpler model. It does not take into account prices of fuels and costs of conversion and end-use-technologies. It can be regarded as an accounting framework of the flow of energy from the primary energy side to the consumption of fuel by the major end-use-sectors.

The SOPKA-E model was used by the so-called Enquête-Kommission "Future Nuclear Policy" of the *Deutsche Bundestag, i.e. the German Parliament, to analyse the necessity and role of nuclear* energy in the Federal Republic of Germany. Within the work of the Enquete-Kommission the model served successfully as a framework for debate by showing the effects and consequences of different actions and policies, at least in terms of energy and fuels consumed. It should be mentioned that this was the first time, that an energy model was used directly as a tool for a complex and controversial energy policy issue by a policy making body.

Concerning the application of the other three energy supply system models listed in the table, it must be reported that until today neither the MESSAGE- nor the EFOM-model have been applied in an energy policy or energy planning process in the FRG.

On the other hand the MARKAL-model was the major tool of two important energy policy assessments.

| MODEL | APPROACH / METHODOLOGY | APPLICATION |
|---|---|---|
| SOPKA-E | SIMULATION | EVALUATION OF NUCLEAR ENERGY (DEUTSCHER BUNDESTAG) |
| MARKAL | LINEAR OPTIMIZATION | - RD&D-POLICY EVALUATION (EA)<br>- ASSESSMENT OF ALTERNATIVE FUELS FOR THE TRANSPORT SECTOR |
| MESSAGE | LINEAR OPTIMIZATION | —— |
| EFOM | LINEAR OPTIMIZATION | —— |

Figure 3 : Energy supply system models

| MODEL | APPROACH / METHODOLOGY | APPLICATION |
|---|---|---|
| LESS | INPUT-OUTPUT, SIMULATION | — |
| BONMOT | ECONOMETRIC SIMULATION, OPTIMIZATION | — |
| ZENCAP | ECONOMETRICS, INPUT-OUTPUT, OPTIMIZATION | EVALUATION OF ALTERNATIVE ENERGY FUTURES (DEUTSCHER BUNDESTAG) |

Figure 4 : Energy-economy models

One of which was in the area of energy technology assessment for R&D planning and the second one was an extensive investigation of the role of alternative fuels for the transport sector, initiated and financed by the german automobile industry.

The three models listed in figure 4 belong to the category of energy-economy-models. They were developed to model explicitly the linkages and interrelationships between the energy sector and the rest of the economy, or in other words to model the energy sector as an integral part of the economic system.

LESS contains a set of various models representing the economy, the energy demand and energy supply system. While LESS is a pure simulation model, the BONMOT-model uses an optimization approach in its energy supply part. Unlike these two models which consist of a set of basically independent models, the ZENCAP-model is an integrated model, which treats the interactions between energy and the economy within a single network of equations. Different methodologies like econometrics, Input-Output and optimization are used. Only the ZENCAP-model has been used by an Enquete-Kommission of the german parliament to evaluate four alternative energy futures, characterized by a consumption of non-renewable energy between 300 to 800 MTCE in the year 2030.

## 3. ENERGY MODELS AND ENERGY POLICY PLANNING

This is where the development and application of energy models stands today. I believe that the energy modelling community can look back upon a tremendously fast development over the last ten years. Great advances can be reported, such as:

- the development of models for many different issues in the energy policy and planning area
- the availability of large scale models of the entire energy system as well as of models that describe the interaction between the energy sector and the rest of the economy,
- the availability of improved data bases and modelling techniques, as well as extremely powerful computers and modelling software.

But are these advances sufficient?

Is it not so,
- that most of the energy policy decisions and the strategic decisions in the energy industry are not based on the outcome of an energy modelling analysis,
- that energy modellers do not have much to offer when complex real world problems require a quick answer,
- that the treatment of uncertainty, which has in the last years become the major issue in the planning process, is still unsatisfactory from the decision-making point of view?

So what did the energy modellers do wrong? Nothing so far. They developed a variety of efficient and powerful models in a reasonable short time. Methodological improvements are still possible, but as useful energy models are available yet, the attitudes of the energy modelling community must be shifted from the development of new and more detailed models to the application of the models to help to solve the problems the decision makers are confronted with.

The appreciation of energy models by the so-called decision makers is characterized by ups and downs. The initial phase of suspicion and skepticism that was based on ignorance was followed by a phase of overconfidence and high expectations. During that time the models, especially computer models were viewed to be able to provide answers to any question; to be not a tool for making up our minds, but the answer itself. As it turned out that the predictive and forecasting power of the various energy models was not sufficient to be of empirical value in the light of events, overconfidence turned into disillusionment. Since some years we are in the phase of disillusionment. What is at stake now, is to overcome the present distrust and to regain credibility. Otherwise the danger is great that energy models will never contribute to better decisions in energy policy and energy industry.

It's necessary that models and modellers adopt a more issue-oriented approach and that expectations on both sides are reduced to what can be provided by an energy models analysis in spite.

Figure 5 shows the primary energy forecasts for the Federal Republic of Germany, which were published in the period from 1955 to 1972.

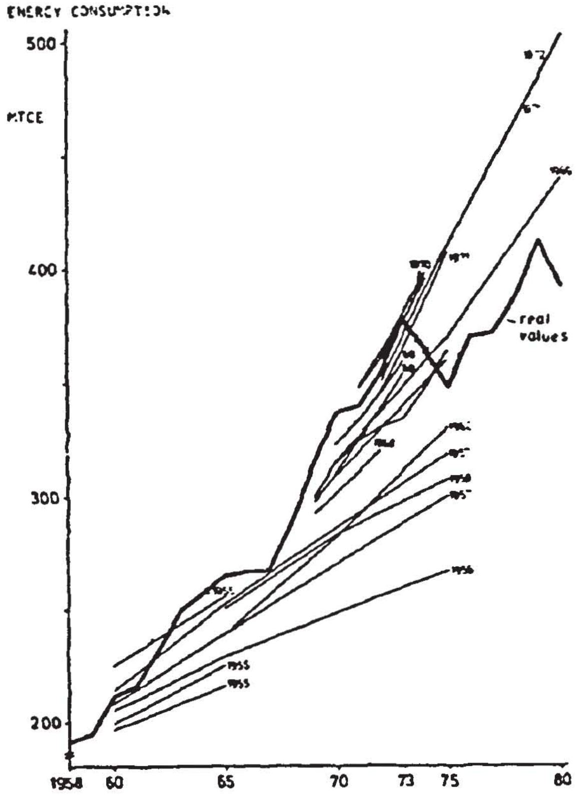


Figure 5 : Primary energy forecasts for the FRG in the period from 1955 to 1972

Compared with the actual development, all forecasts turned out to be wrong. The increase of the primary energy consumption was underestimated by the forecasts of the 50's and 60's.

The primary energy forecasts published after the first oil crises in 1973 are illustrated in figure 6. The figures for the primary energy consumption of the year 2000 differ by about a factor of two. Without going into further details, this figures demonstrate that their success in forecasting the energy future will be not greater than that of the earlier forecasts in the 50's and 60's.

To state the point more clearly, from the past experience we can conclude, that we can not expect any precise forecasts of the future, even if we employ very detailed and sophisticated models. The main reason for this is that the development of the main factors determining future energy demand and supply, such as the economic growth rates or the price of crude oil, to mention only two, are to a great extent

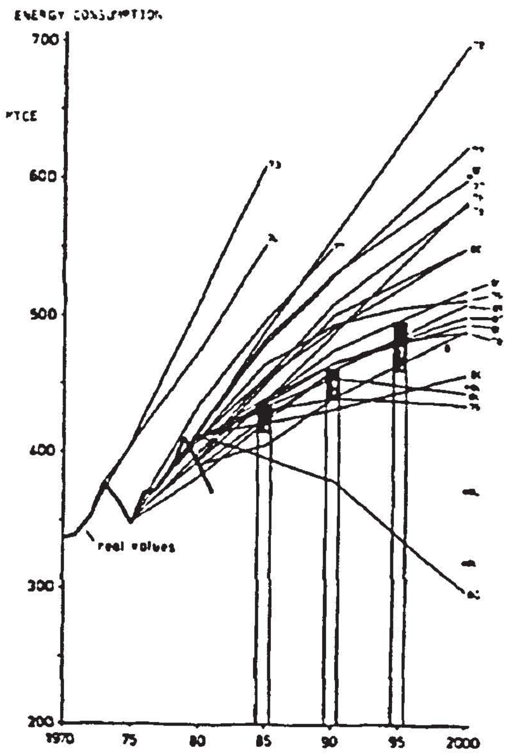


Figure 6 : Primary energy forecasts for the FRG in the period from 1973 to 1983

uncertain. In recent years, for example opinions about the future oil price development have changed dramatically during relatively short periods of time.

The range of long term oil price estimates published since 1973 is from $15 to $150 per barrel. And a recent analysis of the International Energy Workshop (IEW) about the oil price estimates used in the most up-to-date long-term energy projections throughout the world showed, that the individual oil price estimates for the year 2000 differ by factor of four.

Some energy modellers and energy analysts have reacted to the increased uncertainty by generating several scenarios with different assumptions about the uncertain factors. Concerning the world oil prices, uncertainty is usually reflected by assuming two or three annual growth rates, low, moderate and high. The usual recommendation to the decision maker then is: We'll give you the results under these scenarios and you make your own choice. But where does this leave the decision maker? It seems to me that this kind of analysis is not very helpful to him. If it is not possible to be more precise about the oil price factors, then at least he should be provided with the information how this uncertain factors influence his near-term decisions, or with an indication of those near-term decisions that are insensitive to the development of uncertain determinants.

For the use of energy models this does mean, rather than asking what the energy demand in some future year will be, or what the contribution of different supply options in the year 2000 will be, the appropriate question is, what must an energy policy look like, if it has to be robust and flexible enough to cope with the uncertainties that lie ahead?

If energy models are to aid in decision making, then it cannot be a meaningful aim to try to forecast the future development of the energy system. However carefully the forecast is made, the inherent uncertainty lying in the future cannot be removed. Rather the task consists in identifying with the help of the energy model and after explicit consideration of the uncertainties, what I would like to call "robust" decision steps. These are those steps relevant to the near future, that give the best possible guarantee, that the path chosen will not have been regretted at a much later point of time.

This different view of how to use energy models to provide useful information to the decision making process is a prerequisite to regain credibility and promote a more fruitful interaction between the decison makers and the model builders.

## 4. ROBUST DECISIONS - A CASE STUDY

In the following very briefly some results of an energy model application are explained, which was directed to identify "robust" decisions, in spite of the existing uncertainties.

The energy model study was financed by the german automobile industry and its main objective was to analyse the role of alternative fuels in the transportation sector in connection with the development of the overall energy system. The central model used was MARKAL, a dynamic linear programming model, which was mentioned above.

To capture in the analysis the uncertainties of the major determining factors three different scenarios were designed and three different oil price developments were assumed. The average annual growth rate of the GDP for example varied between 2,2 % and 3,7 % in the different scenarios.

Figure 7 shows the different crude oil price developments assumed in the analysis. In the "high" case the crude oil price increases to about 110 $/bbl in the year 2010 after being stable until the late eighties, while in the "decrease" case it drops to about 70 % of the

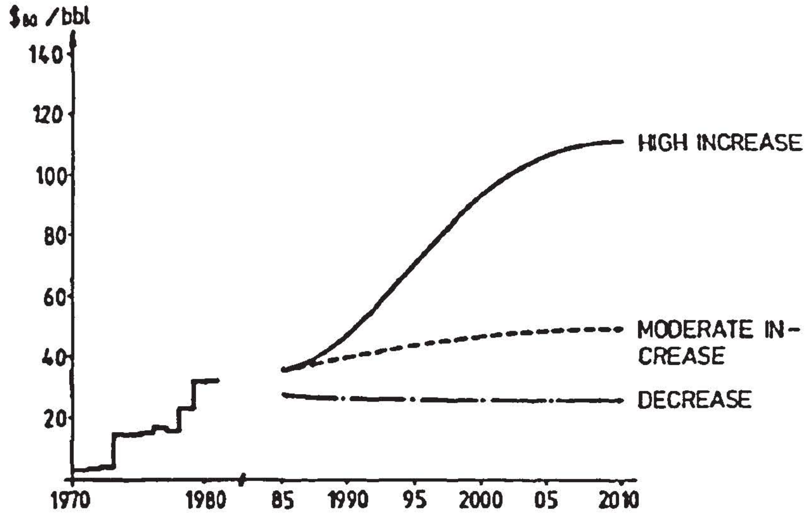


Figure 7 : Alternative oil price developments

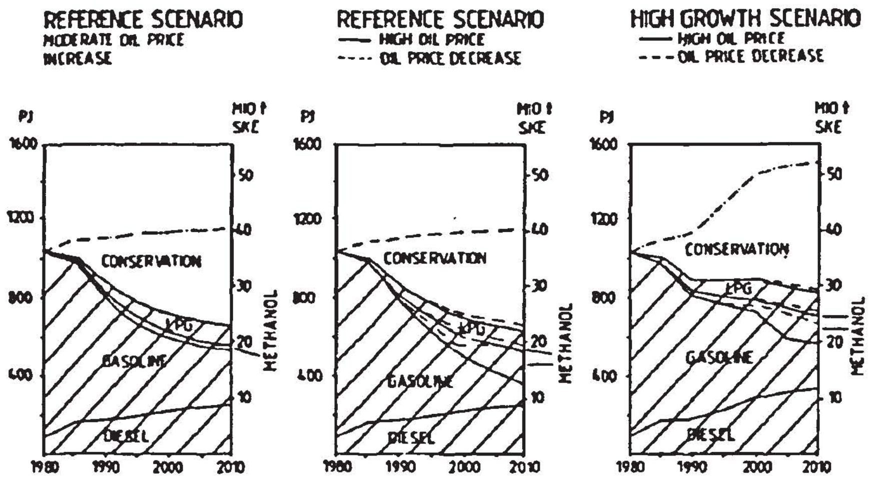


Figure 8 : Energy consumption of cars by fuel

1982 level. The moderate oil price increase case assumes a long-term rise of about 50 %. These oil price developments reflect the possible range of this uncertain factor. Of course, there have been made other input assumptions, which cannot be discussed here.

Figure 8 summarizes some of the major findings. It shows the energy consumption of cars by fuel type in two scenarios and for different oil price developments.

In all cases the energy consumed is decreasing, due to energy conservation measures. Better fuel efficiency by improved combustion and car-designs reduces the fuel consumption by about 45 % in all scenarios.

The second important developments are the structural changes in the fuels consumed. In all cases, that means regardless of high or low oil prices, the market share of gasoline is decreasing dramatically and gasoline is substituted by diesel. These robust trends can only be explained with developments in the domestic and commercial sector, which are strongly interlinked with the structural changes in the fuel consumption of the transport sector. Some of these interrelationships are discussed later.

The prospects of methanol as a car fuel are not as clear as in the case of gasoline and diesel. Whether methanol has a chance to substitute gasoline depends on the oil price development. Only in the case of high oil prices methanol produced from coal becomes economically competitive with the oil-derived fuels. Nevertheless it turned out by the analysis that methanol is the only alternative fuel, that under certain conditions can become an alternative to gasoline. Ethanol, compressed natural gas, hydrogen and electricity on the other side do not have any promising prospects. Figure 9 shows for the reference scenario the typical time-dependent structural change in the car population by fuel type, for the reference scenario and the high oil prices.

At the beginning, gasoline is substituted by M 3, a mixture of gasoline and 3 % methanol, later M 15 is the dominant fuel, which in the 90'th is substituted partly by pure methanol (M 100). As already mentioned the number of diesel-driven cars is in all scenarios steadily increasing, to about 30 % at the end of the time horizon.

As it was mentioned already, the developments in the transportation sector are strongly interlinked with the developments in the refinery and private sector. The increased use of diesel as fuel in the transport sector goes along with a decreasing consumption of light distillate oil in the private and commercial sector. Both developments in these end-use-sector have a strong impact on the refineries, as can be seen from table 1.

The crude oil input is decreasing in all cases, even in the case of decreasing oil prices. But what seems to be more important is that in all scenarios a development back to a simple distillation refinery takes place. There seems to be no need for an increase in conversion capacity, like cathalytic or hydrocracker. This result, which is robust, is quite the opposite of the present strategy of the german oil companies, which is to increase their conversion capacity.

It is hoped that the brief explanations of some results of this model analysis have shown, that it is possible to identify so-called robust decisions, even if the range of uncertainty of important factors is quite large. Hopefully it could have been shown that this kind of model analysis is able to provide useful and important informations to the decision making process, under explicit consideration of the uncertainty, and that this has little or nothing to do with forecasting the energy future.

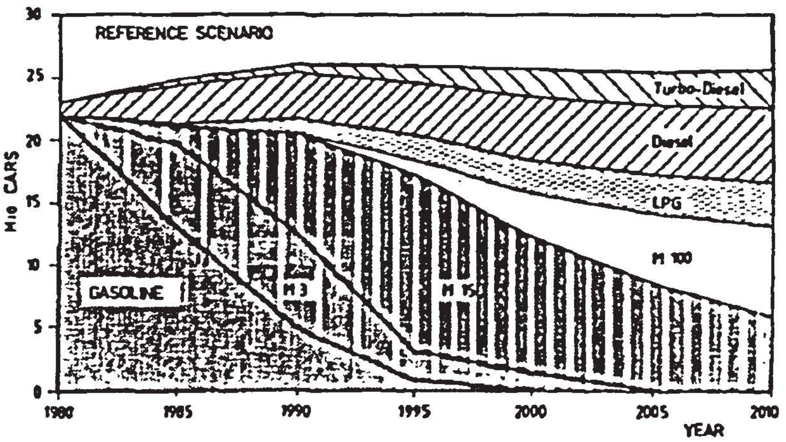


Figure 9 : Development of car population by fuels used

| | | 1980 | 2000 | 2010 |
|---|---|---|---|---|
| REFERENCE-SCENARIO | CRUDE OIL INPUT | 103 | 78 | 73 |
| | CAT. CRACKER | 8 | - | - |
| | HYDROCRACKER | 2 | 1 | - |
| | THERM. CRACKER | 12 | 11 | 11 |
| REFERENCE-SCENARIO HIGH OIL PRICE | CRUDE OIL INPUT | 103 | 66 | 57 |
| | CAT. CRACKER | 8 | 5 | - |
| | HYDROCRACKER | 2 | - | - |
| | THERM. CRACKER | 12 | - | - |
| REFERENCE-SCENARIO OIL PRICE DECREASE | CRUDE OIL INPUT | 103 | 76 | 79 |
| | CAT. CRACKER | 8 | - | - |
| | HYDROCRACKER | 2 | - | - |
| | THERM. CRACKER | 12 | 12 | 14 |

Table 1 : Refinery input and output of conversion plants

Models in general, and energy models in particular should not be viewed as tools that will predict the future more accurately. But with models we may be able to understand better the interdependence and influence of various factors, both those that are within our control and those that are not. In a planning environment characterized by major uncertainties, models can reflect the importance of those uncertainties to the decisions at stake.

Making use of these potential benefits of energy models requires, that they are viewed by both the energy modellers and the decision makers as tools for developing insights, rather than for forecasting numbers. The message is straight forward: Models are vital for energy policy analysis, yet their use and usefulness is conditional to the ability of the modellers to address the right questions.

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