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ENOR—an energy model for Norway†

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The Energy model for Norway, ENOR, is a dynamic, multisectoral economic stimulation model to be used for long term energy analyses. Energy sectors and energy carriers are in principle treated in the same way as other sectors and economic commodities and integrated in the same general framework. The model has a two-level structure—a central coordination module ensures economic consistency, while the behaviour of each production and consumption sector is modelled in separate sector models. The model framework is thus capable of handling both engineering and economic knowledge.

1. Introduction

Energy policy discussion in Norway is almost totally focused on electricity. The obvious reason is that Norway is self-sufficient in oil and gas. The following considerations do, however, imply the need for a tool to study the future demand and supply of energy:

(1) Electricity is produced and sold in a regulated market.

(2) Decreasing returns to scale in electricity production (increasing average cost).

(3) Externalities, in the form of negative environmental impacts, in electricity production.

(4) There exist substitution possibilities between electricity and other energy carriers.

A model must therefore deal with all important energy carriers even though 'the energy problem' might be focused on just electricity.

At the time when this research project started, there existed a long-term multisectorial model for Norway called MSG. The first version of the energy model ENOR was made similar to this model for the following reasons:

(i) For some years the Ministry of Finance has been using the model extensively for preparing long-term projections for the Norwegian economy. This means that this type of model is well known to potential users of ENOR.

(ii) A multisectoral model requires an enormous amount of data including paramaters that must be estimated. By using the same type of relations in ENOR as in MSG, we could use MSG's computer programs to generate the needed data directly from the National Accounts.

(iii) Estimates of the exogenous variables can be made directly from those made for the MSG-model to make energy predictions which are consistent with other predictions made by the Ministry.

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Research on energy–economy models done in other countries served as reference for the ENOR project. Some of the more important models are as follows: the DRI interindustry transactions models (including the Hudson–Jorgenson macroeconomic and interindustry models) (Dullien *et al.* 1976); Allan Manne's ETA-model (Manne 1976); the linear programming models at Brookhaven National Laboratory, especially MARKAL (Abilock *et al.* 1979); the Swedish structural adjustment and growth model (Bergman *et al.* 1979) and some of the models for the European community (Strub 1979).

2. The theoretical framework of ENOR

The first version of ENOR has the same theoretical description of the economy as the MSG-model. The MSG originated in a book published in 1960 by Professor Leif Johansen at the University of Oslo (Johansen 1974). The Central Bureau of Statistics has made two major revisions of the MSG-model, but the main theoretical content and structure has to a great extent been preserved from the original version. The relationships in ENOR not mentioned explicitly in this paper, are equivalent to those of the *last* version of MSG, MSG-3. The type of model is briefly characterized by the following properties:

(1) Multisectoral general equilibrium growth model.

  (i) Labor and capital are assumed to be homogeneous production factors freely movable between sectors and substitutable within sectors according to Cobb–Douglas production functions.

  (ii) Fixed proportions between input and output commodities for each production sector.

  (iii) The growth of total labor force, total capital stock and technological improvements are exogenously given.

  (iv) Imports are determined by assuming fixed (or exogenously changed over time) import shares of each commodity to each sector. Exports (volume of each commodity) are determined exogenously, while export prices are assumed equal to the corresponding domestic prices (which are determined endogenously in the model).

(2) Energy sectors and energy carriers are in principle treated in the same way as other sectors and economic commodities and integrated in the same general framework.

The main endogenous and exogenous variables are shown in Fig. 1.

3. The model structure

The first version of ENOR differs in two respects from the MSG-model:

(*a*) The sector and commodity classification is changed to take proper account of ENOR's purpose. A sector should be significant from the viewpoint of either energy consumption or energy production. We have, to a certain extent, also classified sectors of major economic importance as separate sectors.
Another consideration was that the classification should be consistent with other relevant studies in Norway. In this way it is easier to implement results from these studies in ENOR.

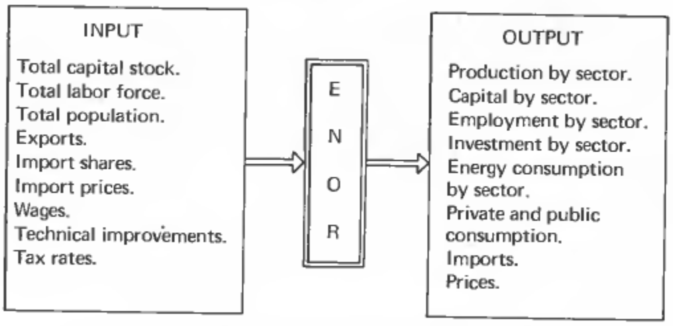

Figure 1. Exogenous and endogenous variables.

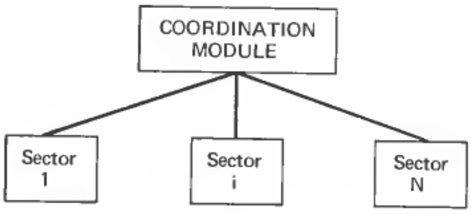

Figure 2. The ENOR model structure.

Based on the above considerations we have a classification (listed in the Appendix) with 18 production sectors and five consumption groups. The model has 19 commodities, 18 corresponding to the 18 production sectors and one 'non-competitive' import.

(*b*) The ENOR-model has a two-level structure as shown in Fig. 2.

A central coordination module is responsible for the general economic consistency of the model (i.e. market clearing). To obtain this, the central module communicates with the sector models. There is one sector model for each of the 18 production sectors, one for private consumption and one for export. The specific behaviour of a sector in regard to production and consumption of energy and non-energy commodities, are modelled in the sector models. All information to and from a sector goes through the central module via a standard interface.

The information consists of commodity flows (including the energy carriers) and prices. Labour and capital are in this respect also treated as commodities.

This technique has certain important implications. The most important feature is that the model becomes very flexible. Following certain rules for the interface, there is a large degree of freedom in describing the internal sector behaviour. The flexibility of the model can be visualized by the following characteristics:

(1) The internal sector behaviour might well differ from one sector to another. We can for instance have different production functions or different degree of detailedness. This enables us to take proper account of special knowledge for each of the sectors. Specifically, it gives us a framework where both engineering knowledge and economic knowledge can be combined.

(2) Changes in one sector model can be made without any necessary changes in other sectors.

(3) Each sector model can be developed independently of each other and implemented into ENOR at different points in time.

4. Market clearing and price consistency

In each sector of the model there is an activity variable A. When prices are fixed, input and output of commodities can be expressed as functions of this activity variable. For example, in the standard model of a production sector A is proportional to the production, while in the standard consumption sector A is proportional to the total consumption expenditure.

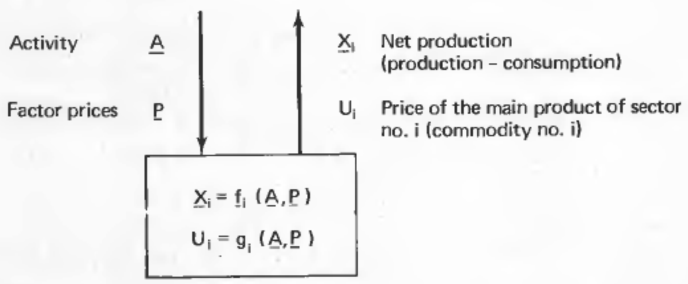

Figure 3. A generalized sector model.

Figure 3 shows the general situation for sector model number i. Input to the model consist of vectors containing all activity levels (A) and all input prices ($\boldsymbol{P}$). Based on this information, the sector model calculates the net production or consumption of each commodity (X_i) (including, as mentioned in § 3, capital and labour) and the price of its main output commodity (U_i).

The output price, U_i, is treated in the sector model as a separate variable, normally not equal to the input price for the same commodity (P_i) until the total solution is found.

The variables $\boldsymbol{A}$, $\boldsymbol{P}$, $\boldsymbol{X}_i$, and U_i constitute the 'standard interface' mentioned in § 3.

The coordination module for ENOR is responsible for clearing the market. If we let

$$\boldsymbol{X}_\mathrm{T}=\sum_{i=1}^{N} \boldsymbol{X}_i$$

$$\boldsymbol{U}=[U_i, U_2, \ldots, U_N]$$

for a system consisting of N sectors, market clearing means imposing the following restrictions:

$$\boldsymbol{X}_\mathrm{T}=0 \tag{1}$$

$$\boldsymbol{U}=\boldsymbol{P} \tag{2}$$

Equation (1) states that the sum of all sectors input equals the sum of all sectors output for each commodity, including changes in inventory. Equation (2) ensures that each commodity has the same price throughout the economy (net of taxes).

Figure 3 indicates the sector model in the form of two analytical functions. If such functions were available, they could be inserted in (1) and (2), to give a set of non-linear simultaneous equations. This is, however, not the case. The sector models are in the practical modelling constructed like numerical algorithms, capable of calculating $\boldsymbol{X}_i$ and U_i when A and $\boldsymbol{P}$ are given. The analytical form of these algorithms are never made available to the coordination module, which is responsible for clearing the market.

For this reason, a slightly modified version of the Newton–Raphson iteration technique is used in the coordination module. This technique requires the calculation of the function values and the value of the partial derivatives with respect to the activities and prices. The analytical form of the equations need not be known.

Approximate values of the derivatives are found by checking the change in the sector response when the free variables are given small perturbations, one at a time.

Like most other general equilibrium models, ENOR is homogeneous of degree zero in prices. This degree of freedom is solved by letting the wages be determined exogenously.

5. Sector models

As mentioned in §§ 3 and 4 the hierarchical model structure gives us considerable freedom in describing the internal sector behaviour. In addition to the standard interface requirement given in § 4, the sector models must satisfy certain continuity conditions. This is to ensure that the iterations in the solution procedure converge towards the right solution. There is one type of model which in this respect might prove to be troublesome to implement as sector model in ENOR, namely linear programming models. So far we have had no trouble with the solution procedure. It does in fact converge after three to five iterations (convergence requirements: $1{\cdot}0 \times 10^{-6}$).

In the first version of ENOR all sector models were similar to the existing MSG model. We are now substituting more detailed and sophisticated models for these standard type models. In the remaining part of this section we shall give a brief outline of the standard sector models and two examples of new sector models. First, however, we will give some comments concerning the different type of sector models.

(1) As mentioned in § 1, by having the same type of relations as in MSG we could use MSG's computer programs to generate the needed data directly from the National Accounts (SNA). This includes estimating just about all parameters in the standard sector models (production and consumption sectors). The differing classifications of MSG and ENOR were no problem, since both were made up from the SNA units. In the new and more detailed sector models, however, we are no longer relying solely on data from the National Accounts. The data source might differ from sector to sector and we will make use of traditional economic time series data as well as engineering type data.

(2) The MSG, as well as the first version of ENOR, is a general equilibrium (growth) model. In some of the sector models we are about to implement, we will explicitly take into account capacity utilization less than one (100%) and restrictions on the mobility of capital. This means that the model will no longer be a 'pure' equilibrium model. We will in this paper not discuss how this in turn might change other properties of ENOR.

(3) ENOR is a model of long-term growth and the medium-term (1–5 years) dynamics of for instance investment is ignored in the standard sector models. The reason is of course the need for simplification. In the new sector models now being developed, we will implement 'lag structures' for the medium-term

changes for the cases it is deemed important. This will be the case if the medium-term changes effect the long-term growth path in a significant degree.

5.1 *Standard production sector*

The production structure of this model type involves a Cobb–Douglas function in labour and capital. We have for sector no. i:

$$A_i = B_i K_i^{\beta_i} N_i^{\gamma_i} \exp(\epsilon_i t) \tag{3}$$

where

A_i: activity level in section i,

B_i, β_i, γ_i: coefficients,

ϵ_i: coefficient in the Harrod-neutral technical improvement,

N, K: labour and capital,

t: time (all variables are time dependent).

The sector minimizes cost for given activity level, prices and production structure. The first-order conditions to this problem yield demand for labour and capital (which both are part of X_i, see Fig. 3) as functions of A_i and the price vector $\boldsymbol{P}$.

The model is run with the time steps of one year. The demand for capital K in the time period (year) t is given by the conditions above. Net investment demand in period t is calculated by K_t–K_{t-1}, i.e. by subtracting last periods capital stock (K_{t-1}) from the desired capital stock this period (K_t). This relationship between investment and capital is the major dynamic property of the model.

Depreciation is given by fixed depreciation coefficients for each capital good to each sector. Gross investment in time period t is accordingly determined once we have solved for K_t. This gross investment demand is in each sector separated into demand for the specific ENOR commodities and as such listed in this sector's commodity requirements (in X_i).

Input to and output from production is determined by fixed proportions:

$$X_{ji}^{-} = \lambda_{ji}^{-} A_i \tag{4}$$

$$X_{ji}^{+} = \lambda_{ji}^{+} A_i \tag{5}$$

where

X_{ji}^{-} (X_{ji}^{+}) is input (output) of commodity j to sector i (in time period t)

$\lambda_{ji}^{-}, \lambda_{ji}^{+}$ are the input and output coefficients. These can be changed over time to reflect technological change.

Equations (4) and (5) plus the demand for labour, capital and gross investment mentioned above, yield sector no. i's net demand, X_i, as a function of A_i and $\boldsymbol{P}$. Thus the above expressions form the contents of the functions f_i (A, $\boldsymbol{P}$) in Fig. 3. As can be seen from eqns. (3)–(5), activities of other sectors have no influence on X_i in f_i. The same goes for the function g_i in Fig. 3. This property will also be valid for most of the new sectors we are introducing. The solution procedure takes this into account ensuring the lowest possible computer costs.

The value of U_i is equal to unit cost, i.e. income = expenditure. The definition of 'cost' is here somewhat modified in each sector to take due account of taxes, subsidies, profits, etc.

An evident drawback in this sector model is that the demand for energy is independent of relative prices. For the most important sectors, this weak point will be eliminated by making completely new sector models. The remaining sectors will simply be changed by making new relations instead of (4) for j = electricity, oil, coal. This is already done for the commercial and public services. The assumption in those sectors is that 'utilized energy' for heating purposes (including machinery and lighting) is a function of the capital stock and degree-days. Through cost minimizing behaviour the sector determines how this energy demand is met by electricity and fuel oil. The resulting demand functions for electricity and oil are consequently dependent on relative prices. The implicit direct price elasticities in the relations used in ENOR are in the range of $-0{\cdot}2$ to $-0{\cdot}4$ for electricity and $-0{\cdot}6$ to $-0{\cdot}8$ for oil.

Of the alternatives to the chosen production structure indicated by (3)–(5) above, we most seriously looked into the macroeconomic model system of Data Resources Inc. long term interindustry transactions model (Dullien 1976). By forming price possibility frontiers (in 'translog' form (Dullien 1976)) they have a system where all input coefficients (like λ_{ji}^- in (4)) are endogenously determined as functions of relative prices. The main reasons why we did not try to formulate a similar type of production structure in ENOR were the following:

(1) The data requirement for estimating all parameters were considered too large. The same goes for the actual estimation work which would have been necessary.

(2) We will try to take into account government policies which do not work through the market prices, as well as those that do. Formulations similar to Hudson and Jorgenson's can only analyse policies working through the market mechanism.

5.2 *Standard consumption sector*

As shown in the Appendix, private consumption in ENOR is divided into five consumption groups. Within each of these groups, there are fixed proportions between the 19 ENOR commodities. For each consumption group is specified a demand function with relative prices and total consumption expenditure as explanatory variables.

The level and composition of private consumption are endogenously determined within the total model framework in such a way that full capacity utilization is ensured.

The income (or rather expenditure) elasticities are exogenous and in general assumed to be constants. The exception is for consumption group no. 3, private car, where the elasticity is decreased over time. The price elasticities are calculated and updated for each time step (i.e. each year) following Frisch's 'complete scheme' formulae (Frisch 1959).

The outline of the sector model for private consumption given above, shows that it is of a traditional econometric type. Later in this section we will give a brief discussion on how this model will interact with a technological based submodel for house heating. Analogous to the standard production sectors it is possible to make minor changes in this model too. Examples of such changes are experiments with alternative estimates on the price and 'income' elasticities of the energy carriers.

5.3 *The Electricity production sector*

Modelling this sector it is important to bear in mind some characteristics of the Norwegian electricity generation system:

(i) Electricity is up to now based 100% on hydropower.

(ii) Production and distribution is controlled by public authorities.

(iii) Significant increases in marginal cost of electricity generation is expected due to increasing cost of the remaining hydropower.

(iv) There exists price discrimination in the sector.

(v) The pricing of electricity is to a great extent determined by the public authorities. The price level is hotly debated—should it be based on marginal cost or average cost?

From the above considerations we have chosen the structure outlined below. The sector is divided into three subactivities:

(A) Electricity generation by hydropower.

(B) Electricity generation by thermal power.

(C) Distribution of electricity (including transmission).

Inputs to the sector model are:

(i) prices; and

(ii) gross demand for firm power measured in GWh/year. This is a vector, i.e. it consists of the gross demand from each sector.

The chosen activity index is gross production of firm power. Firm power is used due to the hydropower based system in Norway. Since the rainfall over the year has obvious stochastic qualities, so has the potential electricity production. To take proper account of this, two steps have been taken:

(i) Deliveries to and from the other Scandinavian countries.

(ii) Electricity is sold at different prices depending on the safety of delivery (the probability of being delivered at the time asked).

It suffices here to note that electricity in general is handled as being either firm power or occasional power.

To ensure that the above features of the Norwegian electricity sector is handled in a proper way in ENOR, we have relied upon existing models at the Norwegian Research Institute of Electricity Supply and Norwegian Water Resources and Electricity Board (NWE). These institutions have comprehensive technological models that calculate the optimal production structure over time. Main input variables are the prices of the energy carriers in question and data for the remaining hydropower sites. Using results from these model runs we are able to specify as functions of demand for firm power:

(i) mean energy production from hydro (subactivity, A);
(ii) capacity of thermal power plants (subactivity, B);
(iii) firm power from hydro and thermal;
(iv) occasional power; and
(v) exports and imports of electricity. (6)

To make sure the production structure given by (6) is the optimal electrical production system within an ENOR scenario the assumptions made in the other models must be compatible with assumptions and results from the ENOR scenario.

Losses in the transmission lines and in the distribution network are functions of electricity consumption (firm power) by sector.

From the above variables, the sector model is capable of calculating its net consumption of all commodities (including labour and capital, i.e. X_i:

(1) Demand for capital.

This is a compound function of three non-linear parts corresponding to the three subactivities in the sector:

A: the capacity in subactivity *A*,

B: the capacity in subactivity *B*,

C: total losses in subactivity *C*.

The function is specified by data from NWE which gives the capital costs of specific hydro and thermal power projects.

A typical scenario shows, as expected, rapidly increasing capital requirements per unit electricity produced. The resulting marginal cost curve will have a shape like that in Fig. 4.

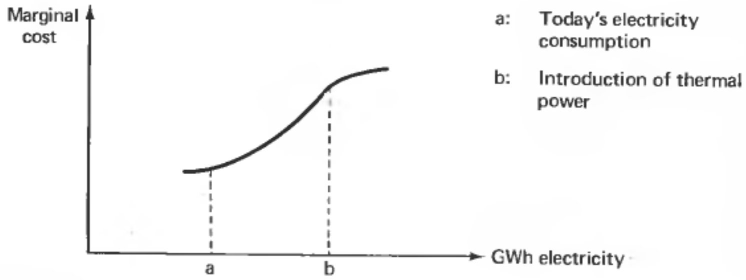

Figure 4. Marginal cost in the electricity production sector in Norway.

After having solved for the sector's demand for (real) capital, net investment and depreciation are determined in the same way as in the standard sector model. (The coefficients being specified for each subactivity.)

(2) Demand for commodities for production (including all energy carriers and labour): input functions analogous to (4) are specified for all commodities for each of the three subactivities. They depend on

(i) the capacity in *A*,

(ii) the production in *B*,

(iii) the losses in *C*.

(3) Net output of firm power is calculated as:

gross production – losses – internal use of electricity.

(4) Occasional power is distributed to the sectors according to fixed coefficients. In most sectors this power is used as a substitute for fuel oil.

Due to specific energy policy issues in Norway, ENOR has three alternatives for computing the electricity price (i.e. this sector's U_i):

(i) exogenously determined,

(ii) price = average cost,

(iii) price = marginal cost.

In all cases the specific price of electricity paid by a sector will vary according to taxes, distribution cost, and price discrimination.

5.4. *House heating*

The model outlined below is a submodel and will be part of the description of private consumption.

The main purpose of such a model is to determine the use of different energy carriers for heating the total stock of residential houses in Norway. In addition the demand for investments in heating technology and insulation is determined. New technologies are taken into account.

The interaction with the rest of ENOR is shown in Fig. 5.

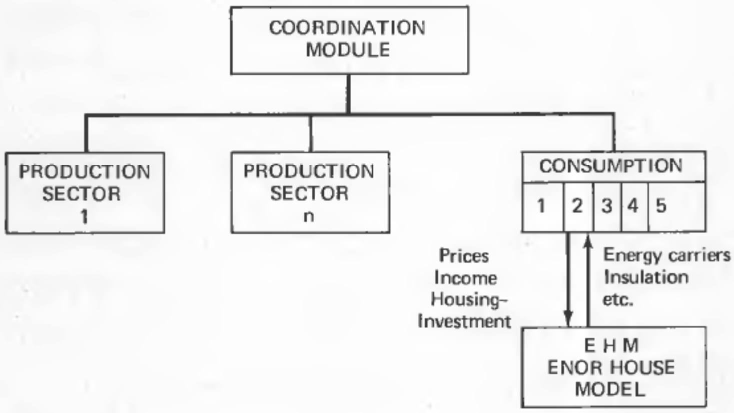

Figure 5. Interaction between ENOR and ENOR's house heating model (EHM).

The figure shows that inputs to the submodel (EHM) are prices, income (or total consumption expenditure) and investment in housing. Given these inputs, the EHM model calculates the use of each energy carrier and commodities for insulation, heating equipment, etc. These data are then given back to ENOR to update the relevant input coefficients (which for all practical purposes will be those for consumption group 2 (housing, electric appliances, and space heating). Through this interaction the submodel EHM should be within the same consistent framework as the rest of ENOR.

The EHM model itself is similar to a model developed at Oak Ridge National Laboratory (Hirst *et al.* 1977). The main difference is that ENOR has modelled the technologies in greater detail (including new heating technologies), and instead treated economical parameters (price and income elasticities) more superficially.

Figure 6 gives the main structure of the EHM submodel.

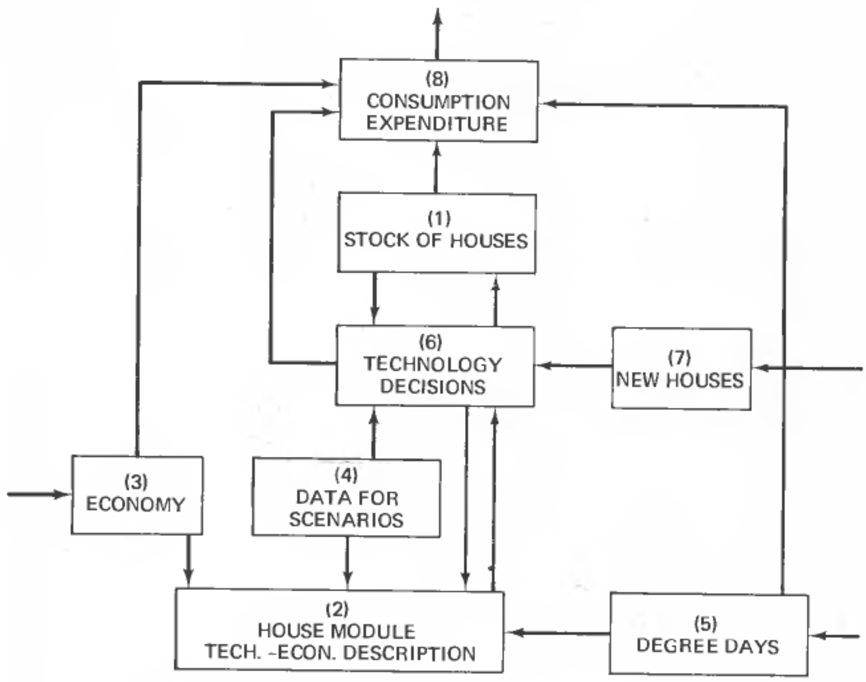

Figure 6. The ENOR house heating model (EHM).

Module 1 keeps track of the number of residential houses and apartments in Norway. The houses are grouped into categories depending on two characteristics:

(i) type of house (one-family house, apartment building, etc.);

(ii) heating technology.

For each category, the number of houses and estimates of relevant parameters are known.

A 'house module' (module (2)) calculates total costs for heating a house with given parameters. Inputs here are economically based data (3), special exogenous variables (4), and a composite relation between the indoor temperature and the degree days (5). Module 6 determines the heating technology in new (7) or modernized houses. This can either be done on the basis of economic optimality or based on exogenous 'scenario data' (from (4)). An example would be imposing a scenario restriction such as all new one-family houses after 1985 must have solar panels.

Consumption of each of the energy carriers can be calculated in module (8) using information obtained from (1) and (5). The same goes for investment in insulation and heating equipment derived from (2) and (6).

To conclude this brief description of the house heating submodel of ENOR, we want to emphasize certain aspects.

(1) Identification of substitution possibilities in the energy demand.

(i) Short-term substitution possibilities. These are limited to those houses that have a heating technology based on more than one energy carrier. In Norway this is a much greater proportion of the total number of houses than in most other countries (about 60%).

(ii) Long-term substitution possibilities. In the long run the degrees of freedom will increase and the choice of heating technology (and degree of insulation) will be dependent on actual and anticipated relative prices.

(2) The 'indoor temperature' is an exogenously determined variable in the sub-model and is essential for calculating the level of energy use in houses. The relationship between this temperature and economic parameters like income and energy price is now being estimated.

6. Applications of the ENOR model

The simulation properties of ENOR have been treated in a rather informal way. First we made use of the fact that the first version of ENOR was similar to MSG and that the performance of MSG had been tested over several years (Johansen 1974). Our short cut was to test ENOR's simulations with those of MSG. The results showed a difference in predicted value of for instance GNP of about 1% in the year 2000 (see Kjølberg (1980 a) for details). It was supposed that this difference for the most part could be explained by the differing sector and commodity classifications of MSG and ENOR.

Another kind of test on the simulation properties is made 'automatically' by the fact that ENOR's (and MSG's) base year is 1975. Evaluating the model performance for the years 1975–79, we must take into account that the economy probably has not been on its equilibrium growth path in all these years.

Developing new sector models in ENOR makes it necessary to keep on examining the simulation properties of the whole system. This becomes increasingly important as sector models not following the traditional 'free competition' assumptions are being implemented.

In the rest of this paper, we will give a brief description of two case studies done with ENOR in 1979–80.

6.1. *Energy forecasting*

ENOR is not yet a fully developed energy model. The description of the model structure, however, makes it clear that the model can be run before all of the sector models have their final form. Thus, from April to August 1979 ENOR has been used extensively to make projections of the energy demand up to the year 2000 for the Ministry of Petroleum and Energy. This work is documented by Kjølberg (1980 a).

We will here show three scenarios from the work done for the Ministry. Since the runs were made in the middle of 1979 they should not be interpreted as forecasts of today. The scenarios are chosen to indicate the possible range of the energy demand in the year 2000. The three cases have the following main assumptions:

I. *High growth scenario*

The growth rate of the gross national product (GNP) is 3·0% p.a. in the time period 1975–2000, while private consumption (Cp) has a growth rate of 2·1%. The electricity prices are assumed to increase with 1·7% p.a. and oil prices with 3·1% p.a. from 1979 to 2000. All growth rates are in constant kroner.

II. *Low growth scenario*

The growth rates of GNP and Cp are here 2·5% and 1·6% respectively. The price assumption for electricity is as in I, while oil prices are supposed to increase 4·7% p.a.

The input coefficients of the energy carriers (see eqn. (4)) in industrial sectors are changed over time following the historical trends. They are the same for I and II and show totally a certain switch from oil to electricity. All other input–output coefficients are kept constant.

III. *Energy conservation scenario*

In this scenario we implement reduction in the energy coefficients in the industrial sectors. Data for these changes are taken from a Parliamentary report on energy conservation (St. meld. no. 42, 1978–79). The economic growth in this scenario is the same as in II, the same goes for the growth rate of the oil price (4·7%). The electricity price is, however, assumed to increase 2·8% p.a. from 1979 to 2000.

The main results are shown in the Table.

The energy use in the following sectors are not included in the Table.

(i) electricity supply, including distribution and transmission losses (sector 5);
(ii) ocean transport (sector 16); and
(iii) crude petroleum and natural gas production (sector 17).

Since these calculations are not meant to be unconditional forecasts, we will not get into any deep discussion as to the magnitude of these numbers. Just for the point of record we will make three comments:

(1) Even though all of the alternatives show a significant growth rate of the energy demand, it is in all cases (and for both oil and electricity) lower than the growth rate of GNP.
(2) The energy demand varies to a great extent according to different economic growth assumptions (I and II) and to energy conservation assumptions (II and III).
(3) The growth rate of energy demand differs between sectors. This is particularly the case in the low growth alternatives (II and III).

6.2. *Labour market analyses*

Developing the ENOR great concern has been taken to ensure flexibility and the possibility of doing different experiments with the model. The model was never meant to be 'just' an energy forecasting model. Below we will give a brief outline of an analysis made with ENOR which has nothing to do with energy systems. It serves as an indication of the broad area of use.

In § 5.1 we gave a brief outline of the standard production sector model. We have a Cobb–Douglas production function (3) in two production factors, labour (N) and real capital (K). In a project with the Norwegian Institute for Studies in Research and Higher Education, we have experimented with the use of different production functions. In these experiments the labour has been divided into three categories according to education. The purposes of this project were:

(1) to develop better methods for forecasting the long-term development in the markets for different categories of labour;
(2) to test how much the existing macroeconomic models will gain in realism by dividing the production factor labour into three; and
(3) to test ENOR's flexibility with respect to different assumptions about the production structure.

Sectors	1977[1]		2000					
			I		II		III	
	TWh Electricity	PJ Oil	TWh Electricity	PJ Oil	TWh Electricity	PJ Oil	TWh Electricity	PJ Oil
Private households	20·2	83·0	27·0	123·0	23·0	102·0	22.9	104·3
Private and Public Services ENOR no. 14, 15, 18	9·3	88·9	22·7	164·0	21·0	141·3	19·9	147·5
Energy intensive industry ENOR no. 6, 9, 10	25·5	26·6	54·9[2]	72·8	41·8[2]	52·7	33·7[2]	55·9
Other sectors ENOR no. 1–4, 7, 8, 11–13	10·5	114·0	21·2	197·5	15·9	159·1	13·2	167·0
Sum	65·5	312·5	125·8	557·3	101·7	455·1	89·7	474·7
Sum, excluding 6, 9, 10	40·0	285·9	70·9	484·5	59·9	402·4	56·0	418·8

[1] Source: Ressursregnskap for energi 1977 (Resource accounts for Energy 1977) Statistisk Sentralbyrå.
[2] Electricity supply to energy intensive industry (6, 9, 10) is decided directly by the Parliament. The numbers in the table are taken directly from model runs and should not be interpreted as forecasts.

Table 1. Net end use of electricity and fuel oil.

The project is documented in an IFA Work Report (Kjølberg 1980 b) and in a forthcoming report from The Norwegian Research Council for Science and the Humanities. The production functions used in the experiments were the following:

(1) Cobb–Douglas function

$$A_i = B_i K_i^{\beta_i} N_{1i}^{\gamma_{1i}} N_{2i}^{\gamma_{2i}} N_{3i}^{\gamma_{3i}} \exp(\epsilon_i t) \quad (7)$$

where

$$\gamma_{1i} + \gamma_{2i} + \gamma_{3i} = \gamma_i \text{ from eqn. (3)}$$

(2) Cobb–Douglas/constant elasticity of substitution (CES)

$$A_i = B_i L_i^{\gamma_i} K_i^{\beta_i} \exp(\epsilon_i t) \quad (8)$$

where

$$L_i = (\alpha_{1i} N_{1i}^{-\rho_i} + \alpha_{2i} N_{2i}^{-\rho_i} + \alpha_{3i} N_{3i}^{-\rho_i})^{-1/\rho_i} \quad (9)$$

(3) Double CES-function

$$A_i = B_i[\lambda_i L_i^{-\mu_i} - (1-\lambda) T_i^{-\mu_i}]^{-1/\mu_i} \exp(\epsilon_i t) \quad (10)$$

where

$$L_i = (\xi_i N_{1i}^{-\theta_i} + (1-\xi_i) N_{2i}^{-\theta_i})^{-1/\theta_i} \quad (11)$$

$$T_i = (\phi_i N_{3i}^{-\tau_i} + (1-\phi_i) K_i^{-\tau_i})^{-1/\tau_i}) \quad (12)$$

The different production functions were mainly chosen in order to test different assumptions about the substitution possibilities (among the production factors). This possibility can be measured by the elasticity of substitution (σ). Given the assumptions in ENOR, this σ shows the percentage change in the ratio between the production factors when the factor price ratio changes with 1%. σ may differ within one production function for different pairs of production factors. This is the case for both (8) and (9) and (10)–(12), while in (7) (as in all Cobb–Douglas functions) the σ is equal to 1·0. In (8) and (9) the elasticity of substitution between any pair of labour inputs is $1/(1+\rho_i)$, while it is more complicated for any pair of capital and labour. In (10)–(12) we have

$$\sigma \text{ between } N_1 \text{ and } N_2 = \frac{1}{1+\theta_i}$$

$$\sigma \text{ between } N_3 \text{ and } K = \frac{1}{1+\tau_i}$$

The quantitative assumptions and results in the analyses will not be given here. Some qualitative conclusions can, however, be drawn.

(1) Problems in the market for the higher educated labour force might come into effect if the supply of this type of labour continues along historical trends. Adjustment through changes in the relative wage structure might not be enough unless the elasticity of substitution is significantly greater than 1·0. More empirical (econometrical) research is needed about the actual size of σ in different sectors, before any quantitative conclusions can be drawn with some certainty.

(2) Introducing a division in the labour force where the different categories have different (marginal) productivities, means implementing an *endogenous* factor of productivity growth (in addition to the exogenous Harrod-neutral technical improvement factor, ϵ).
The results from this analyses with ENOR indicates that former estimates of the exogenous growth rate (ϵ) have been too high, i.e. there is not enough transition in the labour force from lower to higher productivity categories. This transition is of course dependent on both the development of the relative wage structure and of the substitution possibilities between the labour categories.

(3) From a technical point of view, these experiments were highly successful. The changes in the production structure were easy to implement in ENOR and there was no problems with the solution procedure.

7. Conclusions and further research

The main advantage with ENOR is it's flexibility. Within the same structural framework, the model can be anything from a 'plain' econometrical multisectoral model to a comprehensive engineering economic model. This feature makes it well suited as a tool in energy analyses.

In the remaining work on ENOR, we will focus on the following aspects:

(*a*) Integration of engineering and economic variables within each sector model.

(*b*) Explicit treatment of the energy demand's price sensitivity in each sector.

(*c*) A further look at some of the main assumptions in the model, especially imposing limited mobility of the real capital.

Appendix

Sector classification

(1) Agriculture and manufacturing of agricultural products
(2) Fishing, hunting and processing of fish
(3) Forestry and manufacture of wood products and paper and pulp
(4) Coal mining
(5) Electricity supply
(6) Manufacture of industrial chemicals
(7) Petroleum refining, and manufacture of products of petroleum and oil
(8) Manufacture of mineral products
(9) Manufacture of non-ferrous metals
(10) Manufacture of iron, steel and ferroalloys
(11) Manufacture of fabricated metal products, machinery and equipment
(12) Other manufacturing industries
(13) Construction
(14) Commercial services
(15) Domestic transport
(16) Ocean transport
(17) Crude petroleum and natural gas production, pipeline transport
(18) Public services

Consumption groups

(1) Food, beverages and tobacco

(2) Housing, electric appliances and space heating

(3) Private car

(4) Public transportation

(5) Other commodities and services

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