

A SURVEY OF DUTCH
INTEGRATED ENERGY - ENVIRONMENTAL -
ECONOMIC POLICY MODELS

Peter Nijkamp, editor

Researchmemorandum 1980-9

Oct. 1980

Papers to be presented at
the IEEE-Conference on
Cybernetics and Society,
Cambridge, (Mass.), October 1980



Contents

P. Nijkamp,	A Preface to Integrated Energy - Environmental - Economic Analysis.	1
J.W. Antzen and L.C. Braat,	An Integrated Environmental Model for Regional Policy Analysis.	4
P. Lesuis, F. Muller and P. Nijkamp,	An Interregional Policy Model for Energy-Environmental Management.	9
W. Hafkamp and P. Nijkamp,	National-Regional Interdependencies in Integra- ted Economic-Environmental-Energy Models.	13
R. Bannink, C. Broekhof and P. Nijkamp,	A Programming Approach as a Design for Economic Development Policy.	18
P. Nijkamp and P. Rietveld,	Multilevel Multiregional and Multiobjective Po- licy Models for Environmental and Energy Manage- ment.	25

A preface to Integrated Energy-Environmental-Economic Analysis

Peter Nijkamp

Integrated policy analysis aims at providing tools for harmonizing conflicts among individuals, groups, goals of interests in society. Harmonized planning strategies for a diversified system require methods for the resolution of conflicts arising from the interdependence between the components of the system at hand. Hence, integrated policy methods should try to identify feasible states of a system such that these states reflect a meaningful compromise between different policy options.

The seventies have been marked by a drastic change in the attention from social scientists as well as from engineers. Environmental problems (pollution, decline in quality of life, exhaustion of energy and other natural resources, etc.) have come to the fore. Moreover, in political sciences much attention has been oriented to conflictual equity problems (unequal distribution of welfare, unequal burden from environmental deterioration, unbalanced supply of energy sources, etc.). The abundance of our affluent society seems to be accompanied by a new scarcity; lack of clean air, lack of energy and raw materials, lack of an equitable distribution of welfare constituents both within and between nations, etc.

The economic and technological development of most industrial societies demonstrate a conflictual trend: any further increase in material economic growth evokes a counter-effect which neutralizes - or at least affects - the original economic progress. This 'law of conservation of disaster', which has its roots in the first and second law of thermodynamics, deserves a profound attention from economists, regional scientists and engineers.

Given the recent experiences in many countries and in light of the above-mentioned remarks, a research agenda for the analysis of integrated energy-environmental-economic development patterns should include the following items:

- A study of the impacts of (realized or expected) changes in the energy sector (for example, price increases, decline in oil supply) on the spatial distribution of activities and vice versa. The sensitivity of location and settlement patterns as well as of their associated transportation- and mobility patterns deserves a closer analysis. The impacts of shifts in land use and in urban space (for example, the design of energy saving cities and transportation networks or the creation of satellite cities) upon energy consumption are fairly unknown as well.

- A thorough investigation of the differences in regional energy efficiency.
Such a comparative study requires a closer look at the physical conditions of the regions concerned, the differences in technological conditions (different kinds of energy sources, possibilities of interfuel substitution, etc.) and the sectoral composition of production and final demand of the regional system at hand. Only an integrated analysis of these determinants may explain interregional energy efficiencies.
- An analysis of feasible regional policy and decision areas. In respect to this, the use of policy scenarios (for example, alternative strategies of covering the need for energy resources, alternative solutions for tackling sudden shocks in oil supply, etc.) may be a meaningful vehicle. This can also be combined with simulation models for exogenous international developments.
- A study of the interactions between regional production, energy consumption, pollution and spatial allocation of activities. In this case a multidimensional approach is necessary to assess the tradeoffs among conflicting items. Such a multidimensional policy analysis is a prerequisite for arriving at a balanced selective development, in which economic options and regional objectives are brought into harmony with ecological principles regarding environmental management. In this way one may also obtain an integrated view of impacts of oil price increases, of input substitution and of alternative technologies. Sudden shocks (for example, catastrophe -theoretic types of perturbations) can also be studied in this framework.
- A careful examination of the distributional impacts of energy problems for the spatial system at hand. Equity problems may emerge among others through shifts in regional accessibilities as a consequence of an energy saving physical planning, through different spatial impacts of energy policies (for example, spatial differences in the rate structure of electricity) or through incapability of some regions to pay the higher energy costs. There is a fair chance that the energy problem will worsen the equity situation in detriment to lagging regions.
- The construction of an accurate and up-to-date information system on environmental impacts of production, consumption, mobility and energy use. In this respect, spatially disaggregated models are a prerequisite for arriving at balanced policy decisions aiming at coherent and effective solutions.

- The construction of integrated land use - environmental quality models so as to incorporate physical planning models in environmental models. In respect to this, environmental impact statements, technological impact statements and urban impact statements may become meaningful vehicles. Parallel to this development one should also make an attempt at linking such models and statements to policy evaluation methods. The recently developed multi-criteria models open many perspectives for a better integration of diverse components and interests in our complex society.

It has to be admitted that the successive items of this agenda cannot immediately be realized in an adequate manner. Many research efforts have to be made in order to reach a mature analysis of integrated energy-environmental-economic policy problems.

AN INTEGRATED ENVIRONMENTAL MODEL FOR REGIONAL POLICY ANALYSIS

J.W.Arntzen & L.C.Braat
Institute for Environmental Studies
Free University, Amsterdam
Postbus 7161, Amsterdam, The Netherlands

Summary

An integrated environmental model is being developed to provide regional planners and policy-makers with a device for multidisciplinary assessment of effects of regional policy. At first a model, for a specific plan and region is developed and subsequently it is generalized to become applicable to a wider scope of plans and regions. At present economic, demographic and ecological aspects and urban and regional facilities are integrated in a spatial framework. Energy aspects are partly included while health and social well-being are not represented in the model yet. In this paper a general outline of the model and the present state of development are described.

Introduction

Environmental problems have been studied most often in a monodisciplinary fashion. Many facts and insights regarding various aspects of these problems have been obtained in that way. However, the relationships between aspects of the problems, which are often fundamental to the solutions, are often neglected. In order to provide policy-makers with comprehensive environmental analyses, integration of monodisciplinary studies is imperative. The usefulness of models in analyzing complex problems has been widely recognized. By nature multidisciplinary environmental analysis is complex which suggests the application of models. In this paper the multidisciplinary approach is exemplified in an integrated environmental model. In the past ten years integrated environmental studies have been initiated by both scientific institutions, environmental action groups and several departments and agencies in administrations of various countries.¹

At the Free University of Amsterdam cooperation between the Institute for Environmental Studies and the Department of Economics has resulted in two theoretical papers regarding environmental modeling² and subsequently in a research project for which funding has been provided by the National Physical Planning Agency.³

This project, which started in January 1979, aims to develop a regional integrated environmental model which should function as a device for assessment of economic, social and ecological effects of regional policy. To build a general model, which can be used for various types of policy-analysis and in different regions, a specific model is built first. In the present setup demographic, economic and ecological aspects and urban and regional facilities are integrated within a spatial framework. Several aspects of regional environmental problems have been excluded from analysis in this approach. Health and social wellbeing of the human population are not yet included in the model, due to lack of research capacity. An integrated environmental model may be used to assess effects of regional policy in general, but also more specifically to put Environmental Impact Statements in a regional perspective and to analyze long term feedback effects of particular economic and social activities.

Structure of the model

In environmental problems both quantitative and qualitative aspects are of importance. The latter ones are

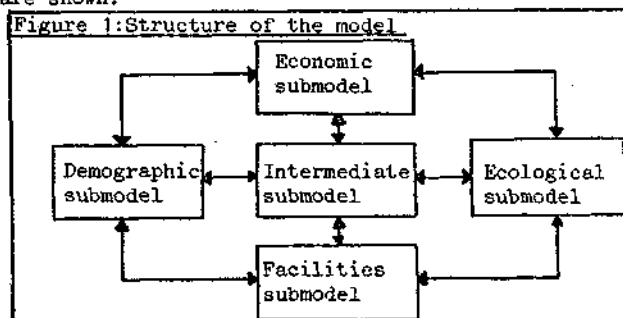
often not encompassed in models. In the model that is presented here, qualitative variables are explicitly included.

In the present state of development the Integrated Environmental Model (IEM) consists of five submodels. A demographic submodel generates size and composition of the population of the region. The demand for, the use and the capacity of facilities for social and economic activities are brought together in a facilities submodel. The economic cycle between demand and supply proves to be hardly quantifiable at a regional scale because of lack of data about consumption and regional leakages (import to and export from the region). The economic submodel therefore concentrates on the supply side, the production of goods and services.

The components and processes of the natural environment are described in the ecological submodel. This submodel contains several sets of variables, each set representing a different ecological system (e.g. marine, freshwater and various terrestrial ecosystems). Some relations between the natural environment and human society are described and analyzed in this submodel by the concept of functions of the natural environment. This concept is defined as "the supply of means for human use"⁴. The word supply includes both the actual and the potential supply of means.

The performance levels of the functions offer a measure of the relations between ecological systems and economic and social systems.

The fifth submodel does not consist of a set of related variables, but of an aggregate of procedures, formulas and data sets (e.g. maps). In this submodel three aspects of space are described: surface area, location and distance. This intermediate submodel functions as a device to integrate spatial aspects into the interactions between variables of the other submodels. In figure 1 the submodels and the major relationships within the Integrated Environmental Model are shown.



To construct a generally applicable model two steps have been distinguished. First a model is developed, based on a particular plan for a specific region in the Netherlands involving changes in population, economy, facilities, land use pattern and ecological systems.

Secondly, the specific model that results is generalized to become applicable to other regional plans and other regions. Therefore the potential for generalization of databanks, variables, equations and methodology is considered in making choices for the development of the specific model.

Integration is the basic characteristic of the study. Variables for the submodels have been selected according to the following criteria: relation to the plan,

relevance for regional planning, availability of data and function in the structure of the (sub)model. Subsequently, equations are specified, which describe the relations between the variables. Not all relationships can be fitted in mathematical equations. Those cases, where dose-effect relationships are not quantitatively known and where subjective factors are important, like in the perception of the attractiveness of an area to live work or recreate in, are described in qualitative terms.

A particular feature of this study is that it aims to integrate existing data, rather than rely on extensive field work. Many problems are met in attempting to integrate data from different sources and collected for different objectives. Because the model aims to be a policy-analysis device, accessibility of the model for the policy-maker and for the public has high priority. This and the subjective and qualitative aspects embodied in the model suggest to develop an interactive model. Decisions about details of policy, priorities and boundary conditions are therefore chosen to be part of the analysis.

The model is being developed for the regional scale, which in the Netherlands averages about 1000 km². This scale has been selected because it is widely used by planners and policy-makers and because it offers a possibility to integrate economic, demographic and ecological data. This compromise scale requires disaggregation of economic data (usually available at the national or provincial level), aggregation of demographic (available at the local level) and ecological data (available at local and sub-local level). The time period for which the effects of a regional plan are analyzed in the Integrated Environmental Model is another compromise. The period chosen (10-15 years) is a compromise between accuracy of the output of the model and relevance for the planners and policy makers.

The plan

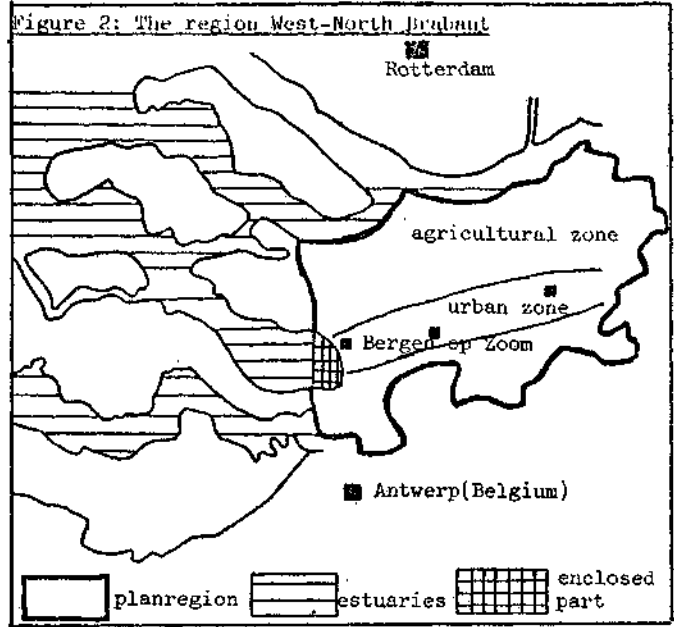
The specific model is being developed for a region in the southwestern part of the Netherlands in which an urban development plan is located. This plan is an example of the national policy to protect open space in the landscape and concentrate urban development in selected urban areas. The main element of the plan is the construction of 10,000 houses within a period of 10 years in a polder, located in the eastern part of an estuary adjacent to the city of Bergen op Zoom (see figure 2).

Part of the estuary is enclosed by dikes and here ca. 300 ha. is to be drained to become a polder. Directly related to the plan are an increase of industrial production capacity, allocation of part of the houses to immigrants (from the Rotterdam region), construction of recreational facilities and increase of energy use and other utilities.

The region

The region West-Brabant is quite diverse, both as to the artificial and the natural environment. Agricultural land use dominates the region (71.7%). Natural areas cover about 12,000 ha. (ca. 10%) while urban areas (including industrial plants and roads) occupy ca. 18% of the total surface. The population has been increasing at 16.8‰ (in 1976), but this is mostly due to immigration from the Rotterdam region. The unemployment rate is somewhat higher than the national average.

The water quality in the region varies from good in the smaller creeks and rivers to very bad close to the industrialized areas. The air quality is strongly influenced by the extensive industry in Antwerp (Belgium) and Rotterdam.



The submodels

The construction of the model has been started with the selection of the variables for each of the submodels. The criteria for selection have been mentioned above. In the demographic submodel population is classified by age and sex. This submodel operating at the municipal scale, generates forecasts of the size and composition of the populations for any aggregate of municipalities. These forecasts are used for the economic submodel (labor market) and the facilities submodel. The latter submodel contains those facilities which are of particular interest to the natural environment of the region. This study is not concerned with aspects of the natural environment in urban areas (e.g. parks).

Therefore urban facilities are aggregated into one category. Other categories include facilities for water resources, waste disposal, recreation and energy. Several aspects of the facilities are distinguished in this submodel: 1) household demand and use, 2) total demand and use (including demand and use of industry, generated in the economic submodel) and 3) supply capacity and related surface area. In the economic submodel the bottom up approach is used. Production functions are specified for nine production sectors. However, for adequate analysis of pollution, resource use (water and energy) and production of waste, a more detailed classification is needed. Whenever necessary, a standard classification up to 300 sectors can be applied. The development of employment in the region is described by a policy scenario (for the plan-situation) and a trend-scenario (for the reference situation). In the ecological submodel the enclosed estuarine system has been modeled first, because this system is most directly affected by the plan. Aspects of water quality, vegetation and fauna are used as indicators of changes in the system. Feedback relations exist via the appreciation of the condition of the system by recreationists and indirectly with the local economy (expenditures by recreationists). Feedback relations exist also through a set of standards for air and water quality and nature conservation objectives. These relations require that the qualitative aspects of the system are described too. In the intermediate submodel surface areas of land use systems are registered and a land use map is designed based on these data.

The surface areas of variables in the other submodels are aggregated in the intermediate submodel per land use system. Changes in surface area and location, which are forecasted by the model, are either allocated by the policy-maker or by the analyst according to an explicit set of standards and rules of dominance for land use systems.

Another aspect of space, distance, is important in determining the concentrations of pollutants in air and water. In general, concentrations decrease with distance, which implies that estimates of air and water quality and effects on organisms must take account of the distance factor. Various models describing and predicting diffusing of pollutants are tested for inclusion in the integrated environmental model.⁵ At present this part of the model is not elaborated yet.

Variables and equations

The variables that have been selected so far are listed in table 1. Two major groups are distinguished: endogenous and exogenous variables. The first category contains those variables that are explained within the model, while variables of the second group are not influenced by other variables of the model.

Table 1: Variables and relation of the model

Exogenous variables

Net migration
Net commuters
Production of houses
Surface area (s.a.) of houses
Watersupply capacity
S.a. watersupply capacity
Waste processing capacity
S.a. waste processing capacity
Electricity production capacity
Electricity distribution capacity
S.a. electricity capacity
Recreational facilities
S.a. recreational facilities
Sewage treatment capacity
S.a. sewage treatment capacity
Investment
Employment
Regional leakages
S.a. aquatic ecosystems
S.a. terrestrial ecosystems
Watervolume
Phosphate-input en -output
Salinity-input and -output
Groundwaterinput
Migration of animal species

Endogenous variables

Dependent variables	Explanatory variables	Characteristics
Population size	Pop.size,migration	A D F
Labor force	Population size	A D F
Labor supply	Labor force,commuters	A D G
Demand for houses	Population size	B D F
Stock of houses	Stock of h.,production of houses	A D G
S.a. houses	Stock of houses	A D F
Wateruse households	Population size	B D F
Wateruse,total	Wateruse households and industries	B D G
Supply groundwater	Groundwaterstock,-input	B D G
Waste households	Population size	B D F
Waste,total	Waste households and industries	B D G
Electricityuse house-holds	Population size	B D F
Electricityuse,total	Electr.use households and industries	B D G

Table 1 continued

Dependent variables	Explanatory variables	Characteristics
Effluent households	Population size	B D F
Air pollution househ.	Population size	B D F
Recreationists	Population size	B D F
Recreation density	Recreationists,recr. facilities and areas	B D F
Traffic	Pop.size,prod.volume	B C
Production volume	Laborsupply,investment	B D E
Value added	Production volume	A D F
S.a. production	Employment	A D F
Air pollution industries	Production/Employment	A D F
Effluent industries	Production/Employment	A D F
Wateruse	"	A D F
Electr.use	"	A D F
Unemployment	Laborsupply,employment	B D F
Consumption	Pop.size,value added	B/A D?E
Phosphate-concentration	Input Ph.,watervolume	A D F
Salinity	Input S,watervol.,output S	A D F
Biomass aquatic vegetation	Biomass aq.veg.,conc. P,s.a. aq.ecosystem, recreation density	B D E
Biomass terrestrial vegetation	Biomass terr. veg., groundwaterlevel,s.a. terr.ecosystem,recr. density	B D E
Biomass aquatic fauna	Biomass aq.fauna,water vol.,biomass aq.veg., recreation density	B D E
Biomass birds	Biomass birds,biomass aq.fauna and veg., recreation density	B D E
Species composition aq.vegetation	Salinity,conc.P,recr. density,migration of species	B C
Species composition terr.vegetation	Groundwaterlevel,recr. density,migration spec.	B C
Species composition aq.fauna	Salinity,spec.compos. aq.veg.,migration spec.	B C
Species composition birds	Spec.compos.aq. and terr. veget.,spec.comp. aq.fauna	B C
Groundwater stock	Groundwater stock,in-put groundwater,output	B D E
Urban land use	s.a. houses,s.a. recr. facilities	B D G
Infrastructural l.u.	traffic	B D G
Industrial land use	s.a. production	B D G
Public facilities land use	s.a.:sanitary landfill,electricity capacity, sewage treatment,incineration	B D G
Resource extracting land use	s.a. groundwater extr.	B D G
Agricultural land use	Agricultural product.	B D G
L.u.aq.ecosystems	s.a. aq.ecosystems	B D G
L.u.terr.ecosystems	s.a. terr.ecosystems	B D G
Total land use	Urban l.u.,Infrastructural,Industrial,Public facilities,Resource extr.,Agric.,Aq.ecosyst. Terr.ecosystems.	A D G

A=relations between variables of one submodel

B=relations between variables of different submodels

C=qualitative relations

D=quantitative relations

E=behavioral equations ($Y=f(x_1, \dots, x_n, a_1, \dots, a_n)$; $a_1, \dots, a_n$ has to be estimated)

F=definition ($Y=f(x_1, \dots, x_n, a_1, \dots, a_n)$; $a_1, \dots, a_n \neq 1$)

G=identity ($Y=f(x_1, \dots, x_n, a_1, \dots, a_n)$; $a_1, \dots, a_n = 1$)

s.a. = surface area

The integrative character of the model is mainly determined by the variables in each submodel which are related with variables of other submodels. Integration of the monodisciplinary submodels is actually effectuated by those equations and descriptive relationships, in which variables of different submodels are related to each other. In fact, the interactions between the economic, social, demographic, ecological and facilities structure of the region form one of the criteria for selection of variables. The submodels also contain variables which are only related with variables in the same submodel. These variables are selected either for internal consistency of the model, for descriptive or for indicator functions. The availability and quality of the data determine to a large extent whether a relation can be translated into a mathematical equation or has to be described in qualitative terms. The endogenous variables in table 1 are listed with their respective explanatory variables. The relationships are presented in a descriptive way and characterized as to type of equation by which they may be described. Since the model is being designed for policy-analysis, special attention is paid to variables, which describe components, processes and activities which can be controlled by policy-makers. In the present study this attention is focused on those aspects of the region which are within the realm of regional planning agencies. The information presented in table 1 is illustrated in the next section in the analysis of effects of the plan.

Analysis of the effects of the plan

The major elements of the plan have been mentioned above. The effects of the plan are assessed in comparison with a reference situation for the region. In this reference situation the polder is not constructed the extra 10,000 houses not built etc.

The analysis starts with the introduction of the changed initial values of the variables involved. Next, simulations with the model equations are carried out. Since simulations with the model have not been executed yet, the effects are indicated in a descriptive way.

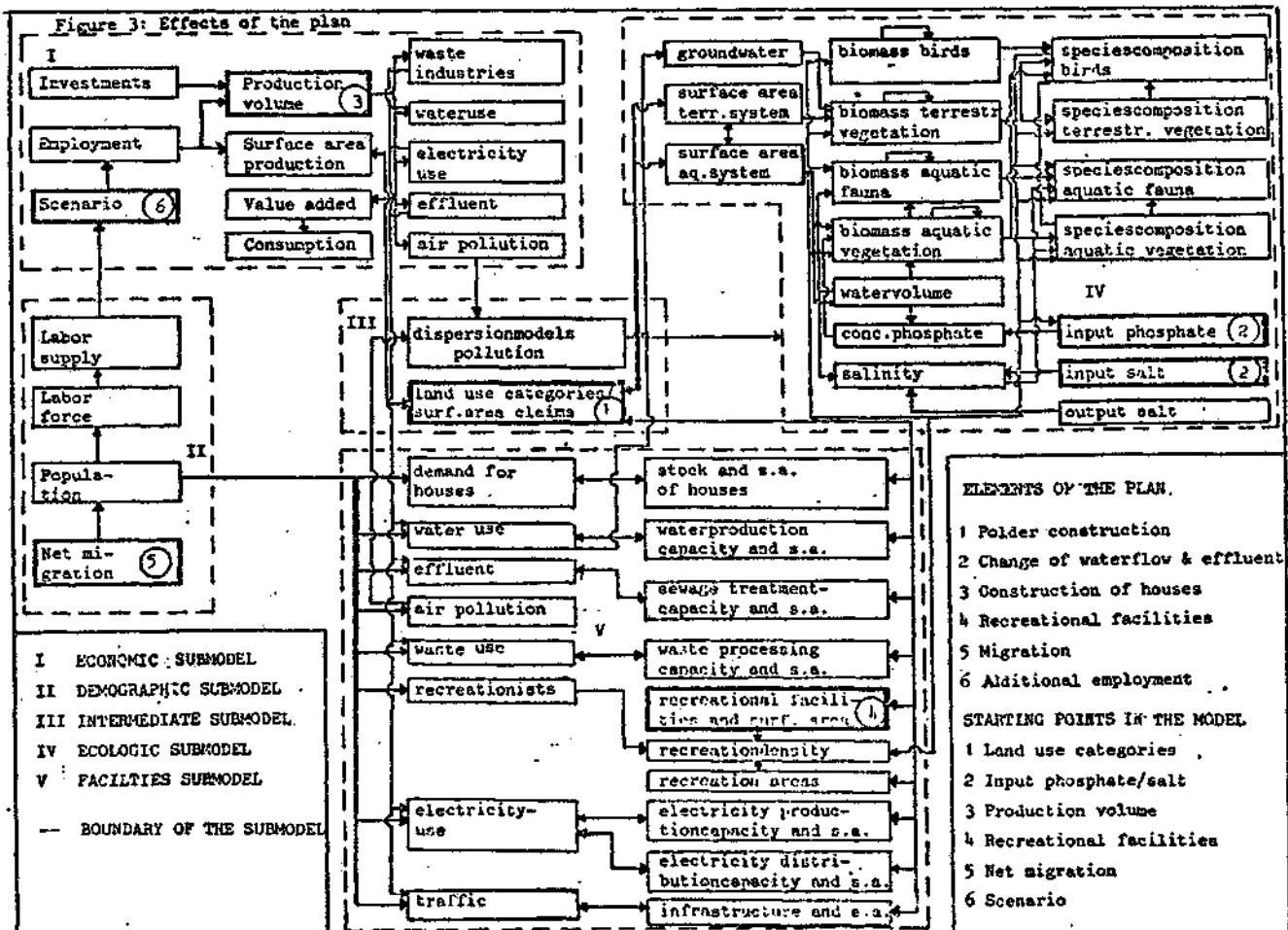
In figure 3 a diagram of the affected variables is presented, which is based on table 1. The starting points of the various elements of the plan in the model are indicated. The following effects can be traced:

1. Effects of the polder

The construction of the polder leads to changes in land use (intermediate submodel) and in the surface area of the aquatic and terrestrial systems of the enclosed part of the estuary. Consequently water volume, salinity and phosphate concentrations are affected, which in turn influence biomass and species composition of the ecosystems. Next to these changes in ecological variables, changes in variables of other submodels are caused by this land use alteration. The polder and adjacent urban lake (between the polder and the old city) are classified as urban land use, which causes a change in that category. The enclosed part of the estuary then consists of a polder, an urban and a "natural" lake. The latter one may function as a recreational area, with potential increase of disturbance of developing aquatic and terrestrial vegetation and animal species and pollution of the water. Altogether the amenity of the landscape and constituting systems is altered.

2. Effects of changes in waterflow and inputs of effluent

The construction of the polder allows for a diversion of polder and city effluents from the natural lake to the urban lake. Also, the water level of the natural lake can be regulated with an input of urban lake water instead of water from the adjacent part of the estuary, which is more polluted and has a higher salinity.



Consequently the natural lake will be desalinated faster than without the creation of the polder and the urban lake. Moreover the lake will be less polluted. This may result in a greater attractiveness of the natural lake for wildlife and recreational purposes.

3. Effects of the construction of houses in the polder
The construction of houses results in extra activity in the building and construction sector (economic production) and in an increase of the stock of houses (facilities submodel). No direct change in land use is registered since the polder has already been designated as urban aldn use. Additional urban facilities can be located inside the city of Bergen op Zoom. The surface area necessary for these facilities is included in the surface area of houses.

4. Effects of recreational facilities

Construction of the facilities leads to effects comparable to the construction of the houses, but additionally a change in land use is caused by this element of the plan (terrestrial ecosystems become urban land use). The facilities may stimulate recreational activities and change the pattern of recreation and the recreation density in the region. Ecological effects have been described above (see 1. effects of the polder), a local economic effect is the increase of expenditures by recreationists and the increases of employment.

5. Effects of migration

According to the plan approximately 20,000 immigrants will enter Bergen op Zoom. A direct effects is the increase in the population of the region. Indirect effects are: an extra demand for houses (largely satisfied by the increase in supply of houses (see 3)) increase of air and water pollution by households, extra demand for water (with effects on the ground-water stock and ecological systems dependent on it), extra garbage en sewage, increase of recreational activities and of the labor force.

6. Effects of additional employment

According to the plan the increase of the labor force is met by an equal increase of regional employment ("policy scenario"). The latter presupposes an expansion of production capacity, production and surface area of production. When the area which is presently allocated to industrial land use, is no longer sufficient a reallocation of space may become necessary (depending on political priorities) involving changes in other land use systems (accounted for the intermediate submodel). Other effects of additional employment are those related to the increase in production volume (water and energy use, air and water pollution). To analyze these effects on a regional scale, a detailed classification of the production sectors has to be used. Emission of pollutants and resource extraction cause effects which via the intermediate submodel are described in the ecological submodel, while in case of water production for industrial use, water processing facilities (facilities submodel) are involved too.

Perspectives

In this paper a general outline and the present state of development of the Integrated Environmental Model have been summarized. It is obvious that the framework presented here needs to be elaborated before the model becomes operational in environmental policy analysis. Three different sets of activities are distinguished in completing and operationalizing the model. First, the relations must be specified and tested. Step by step submodels need to be linked to each other and finally simulations with the entire model have to be carried out. However some submodels are incomplete yet, as to variables, relations and connections with other submodels. For instance a dispersion model for pollution must be incorporated in the intermediate submodel

In addition other ecosystems, which are indirectly affected, have to be described in the ecological submodel. Next, the specific model which is developed in the first stage of the study must be generalized. By comparing the structure of other regions with the structure of the West-Brabant region, the degree of generality of the model can be assessed and adaptations for general applicability determined.

Another aspect of generalization is the applicability of the model to different types of plans. The degree of generality of the specific model will be determined by an inventory of the components, processes and activities which are directly affected by the various plans. The third stage concerns the further elaboration and addition of aspects of the environmental problems and of the regional structure, which for various reasons have not been incorporated in the model yet. For example, environmental aspects of energy production, distribution and consumption have been included only partly in the model. However, it can be expanded within the present framework.

Social and health aspects may be added to the present set of submodels, when research capacity and funding become available.

Finally, it is the authors' feeling that the integration of different disciplines involved in environmental problems, is possible. We encountered many problems and experienced a lot of the communication problems between the different fields of research. Nevertheless, we hope that our contribution is of value for tackling environmental problems in the way it should be done, viz. multi-disciplinary.

Acknowledgements

The authors wish to thank everyone who has contributed to the study and in particular the National Physical Planning Agency for making it possible in the first place. We also like to thank Mrs. B.L.A. Jessurun, who did most of the typing in the study.

References

- 1 Heinzmann, J., 1980, A complex regional strategy needs a complex regional analysis. Inst. of Geography and Geoecology of the Ac. of Sc. of the German Democratic Republic.
- Rijn, H.T.U. van, 1976/77, Geïntegreerd milieuonderzoek: een onderzoek naar de beleving van het ruimtelijk milieu in het Rijnmondgebied. Openbaar Lichaam Rijnm.
- Thoss, R., 1978, Regional environmental Information Systems. Paper for the Int. Symp. on Regional Dimensions of Environmental Policy, Berlin.
- 2 Nijkamp, P. & J.B. Opschoor, 1977, Naar een geïntegreerd Milieumodel? Verk. Inst. voor Milieuvraagstukken, A-18, Vrije Universiteit, Amsterdam
- Arntzen, J.W., P. Nijkamp, J.B. Opschoor, 1978, Geïntegreerde Milieumodellen, wenselijk en mogelijk? ESB, 5-7-1978
- 3 Arntzen, J.W., L.C. Braat, L. Hordijk, S.W.F. van der Ploeg, 1979, Geïntegreerd Milieumodel, een theoretisch kader voor het toetsen van ruimtelijke plannen. IvM publicaties, 79-5.
- Arntzen, J.W., L.C. Braat, J.P. Hettelingh, 1980, GMM, progress report to the Nat. Physical Planning Agency.
- 4 Braat, L.C., S.W.F. van der Ploeg, F. Bouma, Functions of the natural environment, an economic-ecological analysis, IvM publicatie, 79-9.
- 5 Janssen, L.A.M., 1979, Rekensysteem Luchtverontreiniging II; TNO-CMP 79/1, Delft.

1. Summary¹⁾

This paper is devoted to *spatial* aspects of *integrated energy-economic-environmental* interactions, so that *policy conflicts within and between regions* can be analyzed in greater detail. The aim of the study is to provide a comprehensive systematic analysis of energy and pollution aspects of a spatial economic system interconnected by means of an integrated input-output model.

2. Interregional Input-Output Models, Energy and Pollution

In a rather simple way, a regional input-output model may be represented^{8,13} as:

$$(I - T^r) \underline{x}^r = \underline{y}^r, \quad (1)$$

with $\underline{x}^r$ a vector of gross production in region r *), T^r a matrix of regional input-output coefficients of region r , $\underline{y}^r$ a vector of final demand for regional products out of region r , and I a unit matrix.

In a complete interregional input-output model the trade relationships between the regions should be explicitly specified. For two regions, k and l , the following interregional input-output model may be proposed:

$$\begin{bmatrix} I - T^k & -M^k_l \\ -M^l_k & I - T^l \end{bmatrix} \begin{bmatrix} \underline{x}^k \\ \underline{x}^l \end{bmatrix} = \begin{bmatrix} \underline{y}^k \\ \underline{y}^l \end{bmatrix}, \quad (2)$$

where M^k_l denotes the matrix of input-output coefficients of intermediate products imported by region l and delivered by region k .

In system (2) the trade relationships between regions k and l are described by M^k_l and M^l_k , so fixed import coefficients are assumed. If, however, the export of intermediate products from region k to region l depends on the demand in region l as well as on the share of region k in total national production, the following relationship may be assumed:

$$a_{jl}^{ik} = \rho^{ik} a_{jl}^i, \quad (3)$$

with a_{jl}^{ik} a coefficient of intermediaries delivered by sector i in region k to sector j in region l , ρ^{ik} a production share of region k in total

national production of sector i , and a_{jl}^i a coefficient of intermediate demand by sector j in region l for national commodities produced by sector i .

On the basis of (3) the system for the two regions k and l can easily be rewritten.

A well-known limitation of the input-output approach is that the technical coefficients are assumed to be constant. This implies that each sector has only one average technique at its disposal. In practice, however, very often a choice can be made out of different processes, implying substitution between different inputs. In an interregional framework also import substitution between different regions might be considered. Both kinds of substitutions are dealt with in section 3.

Energy

The integration of energy within the input-output system is straightforward. In a national input-output system the partitioning of $\underline{x}$, $\underline{f}$ and A leads to:⁸

$$\begin{bmatrix} \underline{x}^n \\ \underline{x}^e \end{bmatrix} - \begin{bmatrix} A_n^n & A_n^e \\ A_e^n & A_e^e \end{bmatrix} \begin{bmatrix} \underline{x}^n \\ \underline{x}^e \end{bmatrix} = \begin{bmatrix} \underline{y}^n \\ \underline{y}^e \end{bmatrix} \quad (4)$$

In this system, the indices n and e denote the non-energy and the energy sectors, respectively. The outputs of the energy industries may well be expressed in energy units, and also the energy system itself is representing an input-output system. This extension can be included in systems (2) and (3) in a straightforward manner. In system (4) fixed energy coefficients have been assumed. If different processes of energy production and energy consumption are available, however, energy coefficients may change whenever changes in relative prices occur. The possibilities of energy substitution are dealt with in section 3.

Pollution

The integration of environmental pollution within the input-output system can be established by defining fixed pollution coefficients with regard to total pollution^{10,12}. In the present study, however, we are especially interested in the amount of pollution caused by energy consumption. Clearly, emission rates are not always the same for all sectors, even if energy consumption would be the same. If $v_p^{i,jr}$ is the emission of pollutant p caused by the consumption of energy from sector i in sector j in region r , we obtain:⁸

$$v_p^{i,jr} = q_p^{i,j} (a_{jr}^i x_{jr}^i + m_{jr}^i) \quad (5)$$

1) This paper is a condensed version of a more extensive article published by Lesuis et al.⁹

*) In the article we adopt the convention of denoting regions and sectors from which products originate (as outputs) by superscripts, and regions and sectors which use products (as inputs) by subscripts.

In this equation the emission of pollutant p is related to total energy inputs, both originating from the country itself ($a_{jr}^i x_{jr}^i$, the demand including energy imports from other regions, see (3)) and from abroad (m_{jr}^i); $q_p^{i,j}$ is called the emission factor, i.e. the emission rate per unit of consumption of energy source i in sector j . Let v_p^{er} and v_p^{nr} be row vectors of emissions per unit of product resulting from other sources than energy consumption, caused by energy sectors and non-energy sectors, respectively. Then total pollution becomes (supposed we also pay attention to pollution caused by final demand f):

$$v_p^r = i' \left[\begin{matrix} v_p^{i,jr} \\ v_p^{nr} \end{matrix} \right] + \left[\begin{matrix} x_{jr}^{nr} \\ x_{jr}^{er} \end{matrix} \right] + \left[\begin{matrix} v_{nr}^{f} \\ v_{er}^{f} \end{matrix} \right] \left[\begin{matrix} f^{nr} \\ f^{er} \end{matrix} \right] \quad (6)$$

As to the final demand sector, a distinction is made between pollution caused by energy consumption (row vector v_p^{er}) and pollution from other sources (row vector v_p^{nr}). In the system above the emission coefficients remain constant. Apart from abatement techniques a reduction in emission may be obtained via substitution processes induced by relative energy prices (as will be discussed hereafter).

3. A Translog Model for Price Effects and Technology Shifts

The choice of inputs to produce a certain amount of output based on input substitution and technology changes can be treated by incorporating input coefficients in models of producer behaviour as endogenous variables, dependent on relative prices⁶. In a multiregional framework complexity is increased, however, by including interregional trade possibilities or regional differences between production costs (including environmental factors). Then the competition between regions may cause a specialization of regions and give rise to a specific regional input structure.

In this section producer behaviour will be analyzed on the basis of duality relationships between the production function and the (unit) cost function by using a translog approximation as developed by Christensen et al.¹. By logarithmic differentiation of the unit cost function with respect to factor prices, a system of relative factor demand relationships is derived, which contains the optimum cost shares necessary to produce a given output at minimum cost. Computation of own price, substitution elasticities and input-output coefficients is straightforward⁸. The translog functional form is quite general, since it provides a second-order Taylor expansion of any arbitrary twice differentiable cost function.

The interregional input-output model from section 2 is consistent with the following regional translog price possibility frontiers for each sector s and region r :

$$\ln p^{sr} = \ln \alpha_{sr}^0 + \sum_{ik} \alpha_{sr}^{ik} \ln p^{ik} + \frac{1}{2} \sum_{ikjl} \alpha_{sr}^{ikjl} \ln p^{ik} \ln p^{jl} \quad (7)$$

where p^{sr} output price of sector s in region r , $s = 1, \dots, I$; $r = 1, \dots, K+1$, with K the number of regions and $p^{s(K+1)}$ representing prices of imports from abroad.

By differentiating logarithmically with respect to prices and by applying Shephard's lemma¹⁷, the value shares of the inputs from each sector i and region k in the total inputs in sector s in region r can be derived:

$$s_{sr}^{ik} = \alpha_{sr}^{ik} + \sum_{jl} \alpha_{sr}^{ikjl} \ln p^{jl} \quad \forall s, r, i, k \quad (8)$$

where the following conditions are valid:

$$\alpha_{sr}^{ikjl} = \alpha_{sr}^{jlik} \quad \forall s, r, i, k, j, l \quad (9)$$

and:

$$\sum_{ik} \alpha_{sr}^{ik} = 1 \quad \forall s, r \quad (10)$$

$$\sum_{ik} \alpha_{sr}^{ikjl} = 0 \quad \forall s, r, j, l$$

Equations (8) form a system of regional factor-input demand equations. This system can be conceived of as an interregional input-output model. The derivation of these shares will be discussed later, but first some simplifications will be made. We will assume a limited information input-output system, so that (a) the regions of origin k of the inputs remain unspecified, (b) no separate account of the import shares is given, and (c) a regional sector obtains inputs at prices p_r^i within the region r , irrespectively of the region of origin k of the inputs. These prices can be considered as region-specific averages $f_r^i (p^{i1} \dots p^{iK})$ of p^{ik} , $k=1, \dots, K$. This approach leads to a reduction of the number of variables in the specification of the price possibility frontier. A second simplification is to assume that the regional production structure is weakly separable in major categories such as material, energy, capital and labour⁶. This is consistent with the partitioning of the input-output table in section 2. As is shown by Fuss⁵, this implies a two-stage optimization procedure of (a) the individual inputs of each category and (b) each aggregate input.

This leads to the specification of the following system of equations for the materials sub-model in region r :

$$\ln PM_{sr} = \ln \beta_{sr}^0 + \sum_{i=1}^M \beta_{sr}^i \ln p_r^i + \frac{1}{2} \sum_{i=1}^M \sum_{j=1}^M \beta_{sr}^{ij} \ln p_r^i \ln p_r^j \quad \forall s, r \quad (11)$$

with PM_{sr} an aggregate materials-input price for sector s in region r , p_r^i an output price of materials or non-energy sector i in region r , $i=1, \dots, M$ with M the number of materials sectors.

Application of the same procedure as used in system (7)-(10) leads to a similar specification of the value share equations of individual materials input in total materials input in sector s in region r . The same holds true for the sub-model for energy inputs.

The average input prices for energy and materials, together with exogenous prices of labour and capital services (assumed already to be aggregates) determine regional output prices, which can also be derived from a translog model. Given the resulting share equations and the corresponding restrictions (cf. equations (8)-(10)), all prices can be solved.

The national production of sector s may be allocated to regions according to a similar translog price possibility frontier with its corresponding share equations and restrictions. Such regional sector shares implicitly include interregional trade relationships in the optimization procedure. This causes no difficulties in analyzing energy and pollution problems, as long as traded products have the same pollution characteristics as corresponding non-traded product. In this case national pollution coefficients may be assumed.

So far, the solution of the model consists of the simultaneous determination of the pattern of economic interactions which result from a given specification of the economic environment. The behaviour of the energy sectors is one component of the determination, and the simulated performance of the energy sectors also includes its interrelationships with the rest of the economic system.

Given the projections of the temporal evolution of the vectors of final demand and prices of the primary inputs together with prices of imports from abroad, the projections of a future development for sectors and regions can be made. This development can be judged by a policy-maker to find a balance between divergent objectives, such as employment, energy use, environmental quality and economic growth, which may be conflicting in nature. This will be discussed in the next section.

4. A Multiregional Multiobjective Policy System

There is a growing awareness of the existence and relevance of spillover effects, both between economic subjects and between regions. A simultaneous consideration of all relevant policy objectives (implying a *multidimensional* objective profile) and of all relevant regional decision units (implying a *multiregional* profile) complicates the traditional decision and programming methods. Therefore, a new formal approach based on a *generalized multiobjective programming* framework has to be devised, such that the interdependencies among the various elements of the policy structure are reflected.

The conflict between regions emerges from the existence of spillover effects in an open spatial system (for example, interregional input-output linkages, diffusion of pollution, transportation), while the conflict between objective functions emerges from intraregional interactions such that the achievement of a high value of the one objective involves a low value of a competing objective. The latter type of conflict is studied in the field of multiobjective programming^{2,3,7,13}.

The existence of competing regions can formally be described by the same multiobjective approach. Suppose that the integrated energy-economic-environmental structure of region 1 can be described by means of the following model:

$$\underline{x}_1 = f(\underline{x}_1, \underline{x}_2, \underline{e}_1) \quad (12)$$

where $\underline{x}_r$ is a set of relevant variables for region r , $r = 1, 2$ (for example, sectoral production levels, employment, emission of pollution, energy consumption, etc.), and where $\underline{e}_1$ represents a set of exogenous variables.

Clearly an analogous model can be constructed for region 2. The interregional input-output model discussed in sections 2 and 3 can be regarded as a further specification of such a model.

In addition to the structural relationships incorporated in (12), a set of regional side-conditions (technical, economic, environmental, institutional) may be assumed. Together with (12) the feasible area of $\underline{x}_1$ may be represented by K_1 :

$$\underline{x}_1 \in K_1 \quad (13)$$

Then the following multiregional multiobjective programming problem for the spatial system as a whole can be assumed:

$$\begin{aligned} \max l_1(\underline{x}_1) & \quad \max l_2(\underline{x}_2) \\ \max s_1(\underline{x}_1) & \quad \max s_2(\underline{x}_2) \\ \max u_1(\underline{x}_1) & \quad \max u_2(\underline{x}_2) \\ \text{subject to: } \underline{x}_1 \in K_1, \underline{x}_2 \in K_2. \end{aligned} \quad (14)$$

In the present paper the assumption will be made that the spatial system as a whole aims at achieving a maximum value for the three successive objective functions, while next on the basis of a compromise solution the regional authorities aim at achieving the most favourable outcome for the region at hand. This approach will be based on an interactive learning procedure, so that the centrally coordinated decisions have to take account of the regional priorities, while on the other hand the regional options are co-determined by national priorities (see for a formal exposition of multilevel multiobjective programming Nijkamp and Rietveld¹⁵).

The interactive approach used in the present article is based on a series of successive steps. These steps will briefly be discussed:

(a) The first step implies a (centralized) optimization of the three regionally aggregated objective functions:

$$\begin{aligned} \max l &= l_1 + l_2 \\ \max s &= s_1 + s_2 \\ \max u &= u_1 + u_2 \\ \text{subject to } \underline{x} \in K \end{aligned} \quad (15)$$

The optimal solutions of each separate optimization of the three objective functions of (15) are denoted by (l_1^0, l_2^0) , (s_1^0, s_2^0) and (u_1^0, u_2^0) , while the optimal values of the corresponding argument variables are denoted by $(\underline{x}_1^l, \underline{x}_2^l)$, $(\underline{x}_1^s, \underline{x}_2^s)$ and $(\underline{x}_1^u, \underline{x}_2^u)$ respectively.

(b) The compromise solution between the three aggregate objective functions can be found by constructing a so-called pay-off matrix $P^{4,14}$. Such a pay-off matrix reflects the losses in a certain objective, when a competing objective is maximized. A compromise between such conflicting objectives can be achieved by means of equilibrium notions from game theory. There are several ways to identify such an equilibrium point from a pay-off matrix P .

The elements on the main diagonal of P represent the so-called *ideal points*, i.e. the solutions of model (15). The off-diagonal elements represent the values of a certain objective function, when the optimal argument variables corresponding to the maximum of another objective function from model (15) are substituted into

this function. Consequently, P shows the sacrifices in other objectives when a certain extreme option (the maximum of only one objective function) is achieved. Clearly, any meaningful compromise between these extreme options should fall in the range of the row minima and row maxima of P.

It should be noted that the pay-off matrix can be divided into regional components, so that the diagonal blocks of P reflect again the intraregional conflicts, and the off-diagonal blocks the interregional conflicts. Then the diagonal elements in the off-diagonal blocks are related to conflicts between the same set of objective functions in different regions.

There are various ways to calculate a compromise solution from the pay-off matrix P, for example, by calculating the vector of weights λ of the successive objective functions for which all extreme solutions of P are valued equally⁴.

(c) The regional compromise solutions (l_1^* , s_1^* , u_1^*) and (l_2^* , s_2^* , u_2^*) are provided to regions 1 and 2 as a frame reference. These regions have to judge whether or not they are satisfied with the initial compromise solution. When a region deems a certain compromise unacceptable, this compromise solution should reach a higher value. The set of objective functions which are regarded as unsatisfactory are denoted by S_1 and S_2 , respectively. Thus, step (c) can be regarded as the specification of decentralized priorities regarding the achievement of objectives.

(d) The decentralized priorities of step (c) can be incorporated as constraints in the next phase of the interactive program. These constraints can be formalized as:

$$\begin{aligned} l_1 &\geq l_1^* & l_2 &\geq l_2^* \\ s_1 &\geq s_1^* & s_2 &\geq s_2^* \\ u_1 &\geq u_1^* & u_2 &\geq u_2^* \\ \text{if } l_1, s_1 \text{ or } u_1 &\in S_1 & \text{if } l_2, s_2 \text{ or } u_2 &\in S_2 \end{aligned} \quad (16)$$

These constraints can now be included in the first step of the second run of the interactive process in which the central policy solution is calculated [see also (15)]:

$$\begin{aligned} \max l &= l_1 + l_2 \\ \max s &= s_1 + s_2 \\ \max u &= u_1 + u_2 \\ \text{subject to: } x &\in K \\ &\text{and condition (16)} \end{aligned} \quad (17)$$

Then the procedure can be repeated, until a convergent solution is obtained (see for a convergence proof Fandel⁴ and Rietveld¹⁶). This ultimate compromise solution can be regarded as an equilibrium solution between the diverging options of conflicting objectives and conflicting regional interests.

5. Conclusion

The approach described in the previous sections has been applied to an interregional input-output model for the Netherlands⁹. The provisional results obtained so far demonstrate the operational character of the abovementioned analysis. Both the translog model and the multiobjective model based on some meaningful policy scenario's provide meaningful results.

References

- [1] Christensen, L.R., D.W. Jorgenson and L.J. Lau, 1973, Transcendental Logarithmic Production Frontiers, *Review of Economics and Statistics*, LV, pp. 28-46
- [2] Cohon, J.L., 1978, *Multiobjective Programming and Planning* (Academic Press, New York)
- [3] Delft, A. van, and P. Nijkamp, 1977, *Multicriteria Analysis and Regional Decision-Making* (Martinus Nijhoff, Boston/The Hague)
- [4] Fandel, G., 1972, *Optimale Entscheidung bei mehrfacher Zielsetzung* (Springer, Berlin)
- [5] Fuss, M.A., 1977, The Demand for Energy in Canadian Manufacturing, *Journal of Econometrics*, vol. 5, pp. 86-116
- [6] Hudson, E.A. and D.W. Jorgenson, 1976, Tax Policy and Energy Conservation, in: D.W. Jorgenson (ed.), *Econometric Studies of U.S. Energy Policy* (North-Holland Publ. Co., Amsterdam), pp. 9-94
- [7] Keeney, R.L. and H. Raiffa, 1976, *Decision Analysis with Multiple Conflicting Objectives* (Wiley, New York)
- [8] Lesuis, P.J.J., F. Muller and P. Nijkamp, 1980^a, Operational Methods for Strategic Environmental and Energy Policies, in: T.R. Lakshmanan and P. Nijkamp (eds.), *Environmental-Energy-Economic Interactions* (Martinus Nijhoff, Boston/The Hague), pp. 40-73
- [9] Lesuis, P.J.J., F. Muller and P. Nijkamp, 1980^b, An Interregional Policy Model for Energy-Economic-Environmental Interactions, *Regional Science and Urban Economics*, vol. 10, nr. 3 (forthcoming)
- [10] Muller, F., 1973, An Operational Mathematical Programming Model for the Planning of Economic Activities in Relation to the Environment, *Socio-Economic Planning Sciences*, VII, pp. 123-38
- [11] Muller, F., 1979, *Energy and Environment in Interregional Input-Output Models* (Martinus Nijhoff, London/The Hague/Boston)
- [12] Nijkamp, P., 1977, *Theory and Application of Environmental Economics* (North-Holland Publ. Co., Amsterdam)
- [13] Nijkamp, P., 1979, *Multidimensional Spatial Data and Decision Analysis* (Wiley, New York)
- [14] Nijkamp, P. and P. Rietveld, 1976, Multiobjective Programming Models, *Regional Science and Urban Economics*, vol. 7, pp. 253-74
- [15] Nijkamp, P. and P. Rietveld, 1980, Multiobjective Multilevel Programming in a Multiregional System, in: P. Nijkamp and J. Spronk (eds.), *Multicriteria Analysis: Practical Methods* (Gower Publ. Co., London) (forthcoming)
- [16] Rietveld, P., 1980, *Multiple Objective Decision-Making and Regional Planning* (North-Holland Publ. Co., Amsterdam)
- [17] Shephard, R.W., 1953, *Cost and Production Functions* (Princeton University Press, Princeton)

NATIONAL-REGIONAL INTERDEPENDENCIES IN INTEGRATED ECONOMIC-ENVIRONMENTAL-ENERGY MODELS

Wim Hafkamp, University of Amsterdam
Peter Nijkamp, Free University, Amsterdam

Department of Economics
Jodenbreestraat 23
1011 NH Amsterdam

Summary

In the paper, a detailed description of an integrated economic-environmental-energy model, which is under construction, is given. The model focusses on (regional) income, labour opportunities and environmental quality and, indirectly, on energy use. It has been designed according to a procedure set out by the authors in earlier work; it is an operational translation of a purely conceptual model of a society with production, employment and environmental pollution. The model consists of three interdependent submodels, which are a result of projecting reality on three layers: an economic, a social and an environmental layer. It is called the Triple-Layer-Model. National-regional interdependencies play an important role in the econic submodel.

1. Introduction

The call for abatement of air pollution has been rising during the last decade. On the one hand, this is caused by the recently growing awareness of the dangers of air pollutants for human health and the biotic environment in general; for instance, the negative effects of acid rains on the natural environment have been shown to be tremendous. On the other hand, this is caused by substitution processes in the energy sector; for instance, availability of natural gas in the Netherlands urges energy users to switch back to oil or even to coal. The Maximum Acceptable Concentrations of air pollutants have been set increasingly lower over the last decade. In that case, any further increase of emissions of air pollutants - due to a forced shift to more polluting fuel types and/or a general increase in the demand for energy - is a serious problem.

In the Netherlands, authorities are increasingly becoming aware of the fact that the emission of among others sulphur dioxide and nitrogen oxides has to be reduced substantially. Therefore, the Dutch government has recently started working on a series of concrete environmental quality measures. The seriousness of environmental problems has led the authorities to edict measures in a policy atmosphere, even before a thorough study of the economic consequences of these measures had been completed. In this paper, an attempt at providing a background study will be presented.

The present paper will provide a framework for estimating the effects of anti-pollution measures and regional economic policy measures on the emission and immission of some important categories of air pollution, regional income, and regional and sectoral employment. The growing scarcity of important fuel types such as oil and natural gas will also be an essential element in this paper.

The method of analysis being used here has been described in Hafkamp and Nijkamp (1979a) and Hafkamp (1979). This method consists of two phases:

1. The construction of a conceptual model on the basis of problem definition, experience and scientific background.
2. The deduction of an operational model from the conceptual model and available data.

The necessity of constructing a conceptual model is argued in Hafkamp and Nijkamp (1979a). A conceptual model is constructed there, while a brief outline of an operational model is also given there. Here we will elaborate on the operational model. In section 2 of this paper we shall present the design and the structure of a so-called Triple-Layer-Model (TLM). In section 3 we shall deal with the separate submodels and their interrelations in a more detailed way. Section 4 is devoted to operationalising the model and simulating a decision-making process with various policy options. Some conclusions and future research lines will be given in section 5.

2. Design of a Triple-Layer-Model

In this section, a model of a society with production, employment and pollution will be presented. This will be done by projecting reality on three surfaces associated with three interrelated submodels, respectively:

- E: a national-regional economic model
- L: a regional, sectoral employment model
- P: a pollution model, against the background of energy availability.

Together the three submodels form the Triple-Layer-Model (TLM). The model is not entirely new in all its components. Part of the economic model is based on the so-called SECMON-model of the Dutch economy by Driehuis (1979). The SECMON-model is a large simulation model of the Dutch economy (including four production sectors). We shall regionalise the model into five regions and disaggregate it into 11 sectors. This makes the model itself a multi-level model in which national-regional interdependencies reflect the relations between the two levels of the model. Models like this have been developed in France, Belgium and The Netherlands. For France, the REGINA-model (see Courbis(1979)) describes a three-level system which aims at optimizing regional employment conditions by a policy of regional investment planning. For the Netherlands, the REM-model (see Van Delft and Van Hamel (1978)) does the same for a two-level structure in a less detailed manner. For Belgium, there is the RENA-model (see De Corel, Thys-Clement and Van Rompuy(1973)). A detailed methodological comparison between these models is made by Hordijk and Nijkamp(1980), where also a set of criteria is formulated, which a national-regional model has to fulfil.

The labour market model describes employment (supply and demand) in the regions and sectors. The demand for labour is analysed through the production structure; gross production, capacity and capacity use in capital intensive sectors as well as import substitution are important elements here. The supply of labour is analysed through wages, prices and income developments and further with given demographic data. This submodel is mainly related to demand for labour, because anti-pollution measures and stimulation of employment are often regarded as contradictory options (though this is not necessarily the case).

The pollution model contains a description of emission and diffusion of (air) pollutants. Introduction of anti-pollution technology takes place in this model. It should be noted however, that we cannot limit ourselves to only pollution aspects as such. A major part of the air pollution is caused by combustion of so-called fossil fuels. Therefore, it is necessary to take into account the availability of several types of energy, its use in the production and consumption sector as well as its environmental repercussions.

The three blockdiagrams in Fig. 1 can best be seen as parallel planes hanging over each other; inter-layer relations are indicated by vertical arrows then, whereas intra-layer relations are indicated by horizontal arrows.

3. Submodels of the Triple-Layer-Model

In this section we present the design of the TLM. Variables and relations of Fig. 1 are further specified here. Every submodel is presented separately. Firstly, the variables and relations within the submodels are treated, while next the interdependencies between the submodels will be dealt with.

3.1. The Regional-National Economic Model.

The submodel is based on the regional input-output tables for the 11 Dutch provinces for 1970, published by the Central Bureau of Statistics (CBS). Behavioral equations and the blocks associated with the government and social insurances stem from the SECMON-model and are regionalised (if necessary).

The production block is based on the above mentioned input-output tables. For this purpose the 11 Dutch provinces are aggregated to 5 regions. The sectors are aggregated toward 11 sectors. Figures for 1970 are updated for the year 1975 (in a later phase the actual input-output tables for 1975 will be published by the Dutch CBS). The following equations will be used to calculate final demand at a sectoral and regional level:

- Consumption (private): The value of total private consumption is calculated for every region via regional wage and non-wage income. Regional expenditure patterns are assumed to be equal.
- Investments (by firms): The level of the investments by firms is determined by various factors such as wages, non-wage income, prices, capacity variables and monetary variables. A distinction is made between investments in buildings and investments in equipment. For agriculture and the capital extensive service sectors it is assumed that all investments are delivered by the construction sector of the same region. In the manufacturing sectors and the capital intensive service sectors investments are delivered by the construction sector according to a constant ratio.
- Government expenditure: Material government consumption is mainly considered as exogenous (e.g., military expenditures, and other categories of government consumption). An example of an endogenous material government consumption is the public expenditure which strongly depends on the number of government employees.

Government investments are composed of two categories. Investments in road construction and water control are assumed to be endogenous (depending upon investments in housing and the interest rate), while other investments are assumed to be exogenous.

- Exports: Detailed information on interregional imports and exports by sector is not available. Only national exports - the most important category - are analysed in the model. They are assumed to depend upon the volume of world trade and the relative prices of Dutch exports.
- Imports: A distinction is made between: (1) final products and (2) raw material/ manufacturing inputs. Category 2 is subdivided into: (a) competitive and (b) non-competitive imports. The volume of category 2 imports depends on the level of gross production, while the volume of category 2a also depends on the relative price level.

Production capacity is calculated for the manufacturing industries and for the capital-intensive service sectors. Growth of production capacity is determined by the investment rate in equipment.

Wages and prices are calculated at a sectoral level, but not at a regional level. Regional differences of wages and prices are so small that they may be neglected. Contract wages in the manufacturing industries are established in negotiations between employers and employees. Influencing factors are: expected consumer prices, specific sectoral circumstances and compensations for tax rise and social insurance premiums. Producers' prices are determined by other producers' prices, wage costs per unit of product, prices of imported inputs, capacity rate and capital costs.

Taxes consist of endogenous tax variables such as indirect taxes minus subsidies (such as TVA), company taxes, income taxes and exogenous tax variables such as revenues from natural gas resources and other non-tax incomes. Non-material government expenditure are wages, interest payments and income payments to individuals and firms.

The monetary sector is described at a national level. The most important variables are here money creation (by the government and by firms) and the interest rate. These variables have an influence on sectoral investments and production capacities.

In this economic submodel, there are bottom-up relations as well as top-down relations. Bottom-up relations are especially relevant for consumption, prices, wages, investments, exports and imports. Top-down relations relate in particular to government expenditures and the monetary sector, but also to the total level of private investments. Variables like gross production, imports, exports and prices of several types of goods are also elements in the other two sub-models.

3.2. The Labour Market Model.

Labour demand in regions and sectors is analysed in the labour market model. For the time being, we consider the supply side given. Demand for labour is assumed to depend mainly on gross production in regions and sectors. Besides, there are other important factors such as quantity of working hours, capacity rate and labour-saving technological progress.

3.3. The Pollution Model.

This submodel deals with three phenomena:

1. Emission of air pollutants caused by:
 - a. combustion of fossil fuels
 - b. process emissions, etc.
2. Concentration of air pollutants

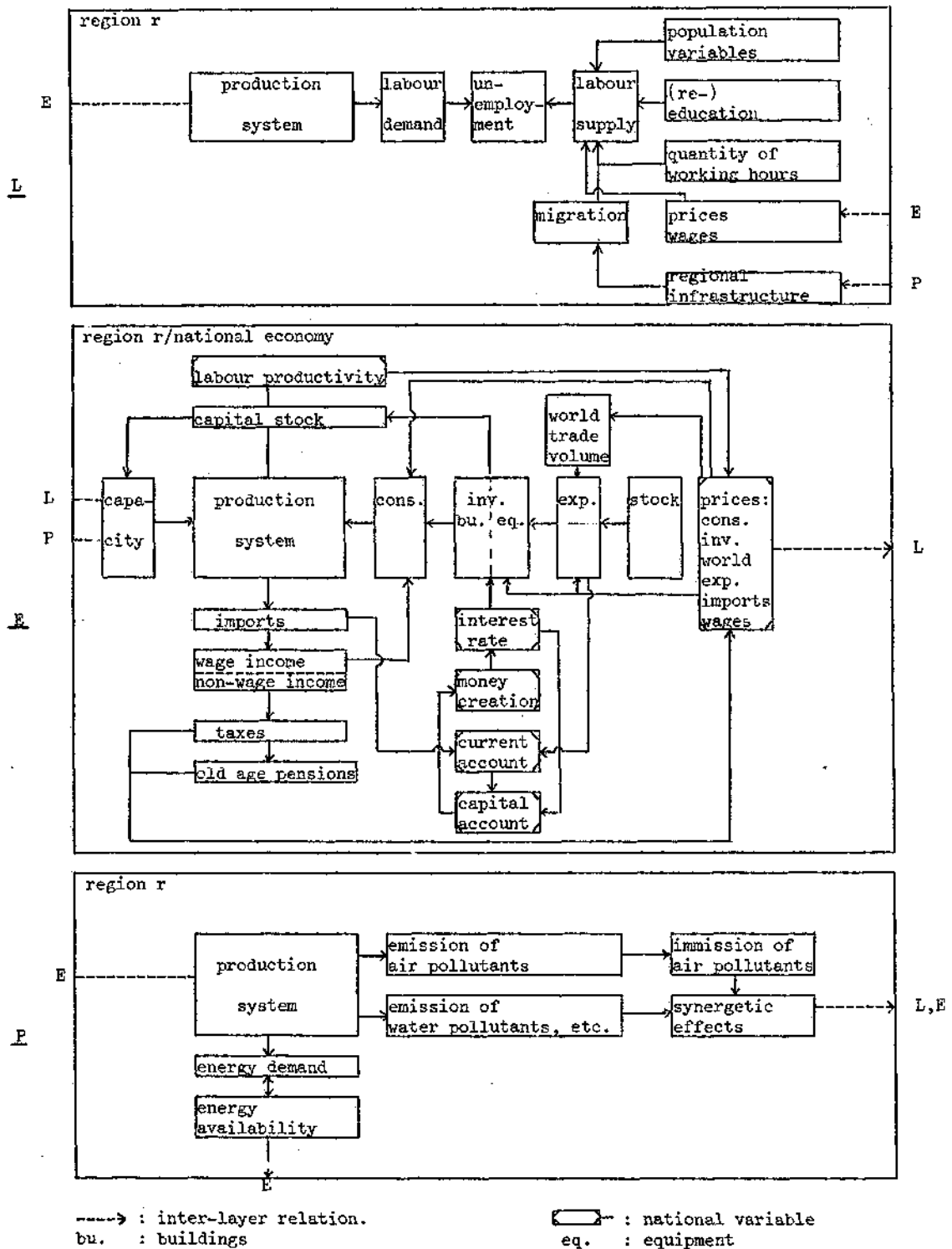


Fig. 1: Structure of Triple-Layer-Model

3. Reduction of emission by:

- a. saving energy, selective growth, etc.
- b. alternative choices of energy sources
- c. anti-pollution technology

Pollution of water and soil is not taken into account here. Also no attention is paid to the phenomenon of synergetic effects. This means that any anti-air-pollution program has to be accompanied by other programs through which the natural environment is protected on other aspects than air pollution. In general, a substitution of one type of pollution by another one has to be prevented in pollution management programs. Not all types of air pollution will be studied in this section. We limit ourselves to three important categories: sulphur dioxide, nitrogenoxides and dust particles.

Emission of air pollutants is subdivided into two categories (see 1a and 1b above). Process emissions make up less than 10% of the weight of total emissions of air pollution. Therefore, we deal only with combustion emissions. Gross production and production technique determine the quantity of various kinds of fuel to be used. Then the emission of air pollutants can be calculated through a vector of emission coefficients (See Institute for Environmental Studies (1978)). Special points of interest are the integration of production and demand for electricity as well as pollution by traffic.

Diffusion of air pollution is important, because over the last decade the maximum acceptable concentration of SO_2 was more and more surpassed in several places in the Netherlands. It has to be added that also emissions from German and Belgian industrial areas influence the concentration of air pollutants in some parts of the Netherlands, pending on the weather conditions. The diffusion of air pollutants depends on many factors (inter alia place, time, quantity and height of emission and weather conditions). Diffusion models can be constructed analytically (see among others Muller (1979) and Coupé (1975)) or empirically. If an empirical approach is chosen, one has to obtain emission data over a certain period at several sources in an area as well as immission data from a number of places in the whole area where the emissions influence the concentration of air pollutants. For the moment there is no such model for the Netherlands. We use a diffusion model by Coupé (1975).

In the beginning of this section, anti-pollution measures have been subdivided into three categories. Here it becomes clear that there is an important correspondence between the energy problem and the pollution problem. Much research has already been done in the field of purification of fluegases and clean combustion methods (see among others Pearse and Seaman (1975) and Zinn and Lesso (1978)). In our submodel a number of abatement techniques is introduced to reduce emission to a fraction of its original level (10% to 90%). The necessary investments and other costs are integrated into the economic system via an additional sector. The way these programs are financed will be treated in section 4.

The choice of energy source also has an important influence on the emission of air pollutants. For example: SO_2 emissions in the Netherlands decreased drastically after a large-scale introduction of natural gas, but since a switch back to coal or oil may take place a drastic increase may occur. Especially the shift of electricity producers from natural gas to oil, coal or nuclear energy and the further exploration and introduction of alternative energy sources (solar energy, wind, etc.) are of great importance to environmental quality.

Besides these measures, there are other means to influ-

ence air-pollution via energy use. Selective growth is a good example of this, where the growth in sectors which cause little pollution due to a small energy use is favoured. Another important aspect in western countries is the effect of a decreasing population, which also leads to a relatively decreasing demand for energy. Also, there is a call for an "energy tax" in the Netherlands, which may cause a general decrease of the demand for energy over all sectors. Any type of energy conservation (insulation, etc.) leads to a decreasing energy use and thereby to a decreasing emission of air pollution.

4. Simulation, Data Base and Decision making.

The model as a whole is a simulation model. It does not provide us with an adequate explanation of society and human behaviour. The model is not appropriate to make reliable predictions for the nearby future. The data base for this model is relatively small; clearly, information should be available at a much more disaggregated level. A number of SECOMON equations have a low R^2 , while not all coefficients differ significantly from zero (at .95 level). Simulations with the model are characterised more by an optimisation approach than by a scenario-approach, although there are certain elements of a scenario approach present in the model. Within an optimisation approach, the value of one or more goal variables has to be optimised, given a set of systems constraints and policy options. Within a scenario approach the consequences of alternative policy options for the system are studied. In our case the goal variables are (regional) income, environmental quality and labour opportunities. In this study a multiple-objective, multi-decisionmaker (MOMD) problem has to be solved. Elements of a scenario-approach are also present, because a decisionmaking procedure can start from different viewpoints. Especially, financing anti-pollution measures is an important issue here. A broader discussion of tax/subsidy schemes and redistribution principles (polluters pay, pollutee pay, etc.) is given in Hafkamp and Nijkamp (1979a, 1979b). The MOMD problem at hand contains partly conflicting interests. Earlier studies have shown that there is rather a conflict between income and environmental quality than a conflict between energy and environmental quality (see Nijkamp (1980)). This is clear, because the improvement of environmental quality can often be seen as an economic (public) good.

5. Conclusions.

The conclusions of this paper are in a way preliminary, because the actual construction of the model has not yet been completed. The model however, may be a valuable contribution to the current scenario models of energy economic systems and national-regional models. It is an ambitious attempt to construct an integrated regional-economic-environmental-energy model, which may include both an optimisation structure and a scenario structure. In this respect this model can be used as an important tool for comprehensive policy analysis.

References

- Corel, L. de, F. Thys-Clement and P. van Rompuy, RENA - Een Econometrisch Model voor het Plan 1976-1980, Planbureau Brussel, 1973.
- Coupé, B., Regional Economic Structure and Environmental Pollution, Stenfert Kroese, Leiden, 1977.
- Courbis, R., The Regina Model - A Regional-National Model for French Planning, in Regional Science and Urban Economics, Vol. 9, pp. 117-139., North-Holland, 1979.
- Delft, A. van and B. van Hamel, Operationeel Onderzoek en Regionaal Beleid, in Regionaal Beleid, P. Nijkamp and C. Verhage (eds.), Stenfert Kroese, Leiden/Antwerpen, 1978, pp.123-156.
- Driehuis, W., Een Sectoraal Model t.b.v. de Analyse van de Nederlandse Economie, University of Amsterdam (mimeographed), 1979.
- Hafkamp, W., Elements of Science Policy in Environmental Economics, University of Amsterdam (mimeographed), 1979.
- Hafkamp, W. and P. Nijkamp, Dilemma's in Environmental Economics; Environmental Models Revisited, in Canadian Journal of Regional Science, Volume 11, no. 2, pp. 1-21, Institute of Public Affairs, Halifax Canada, 1979a.
- Hafkamp, W. and P. Nijkamp, An Integrated Interregional Model for Economic-Environmental Policy, in Economic-Environmental-Energy Interactions, T. R. Lakshmanan and P. Nijkamp (Eds.), Martinus Nijhoff, Boston, 1979b.
- Hordijk, L. and P. Nijkamp, Integrated Approaches to Regional Development Models, Free University (mimeographed), Amsterdam, 1980.
- Institute for Environmental Studies, Milieuverontreiniging en Productiestructuur in Nederland, Amsterdam, 1978.
- Muller, F., Energy and Environment in Interregional Input-Outputmodels, Martinus Nijhoff, Boston/The Hague/London, 1979.
- Nijkamp, P., Environmental Policy Analysis, John Wiley & Sons, Chichester/New York, 1980
- Pearse, J. and M. Seaman, Economic Consequences of NO_x and Odour Abatement, Interim Report for the Ministry of Health and Environmental Control, The Hague, 1975.
- Zinn, C.D. and W.G. Lesso, Putting the Economics in Best Available Control Technology or Pollutants in the Air and Dollars to the Wind, Interfaces, vol. 9, No. 1, The Institute of Management Sciences, 1978
-

A PROGRAMMING APPROACH AS A DESIGN FOR ECONOMIC DEVELOPMENT POLICY

Robert Bannink, Cees Broekhof and Peter Nijkamp

Economic Institute Tilburg, the Netherlands

1. Introduction

The formulation of economic policy needs information from various fields. Without denying the importance of other auxiliary disciplines, we will concentrate ourselves mainly on an economic analysis in this preparative study. Economic policy analyses are usually based on econometric models describing equilibrium growth (e.g., based on vintage production structures). An analysis of the changing input values of these models provides the expert with more insight into reactions from medium- to long-term forces on these changes. By trial and error procedures one may try to identify those changes which are in close agreement with the policy-makers evaluation.

As each major problem requires its own specific model (e.g., in terms of employment, energy, pollution etc.), it is an important responsibility for policy-makers to translate the insights regarding key elements of problems - obtained by studying such models - into a consistent policy.

In the present paper an alternative approach based on programming techniques will be presented.

The reasons why we prefer models using these techniques are:

- . they can start from any historical set of data independently of the existence of an equilibrium or a disequilibrium situation on the commodity, labour or money market.
- . they can easily - at least in a conceptual sense - integrate several relevant aspects of policy-making such as a trade-off analysis.
- . they can describe both a disequilibrium and a equilibrium path.
- . they focus much attention on the definition and relevance of policy objective functions.
- . they allow the description of a multiple goal-setting, caused by the participation of different groups in policy-making.
- . they focus the attention on the importance of specific restrictions in relation to the simultaneous effects of all other restrictions.

This paper is a new one in a series of reports on this project, which started in 1975 with a paper at the ISI-conference in Warsaw (September 1975). The structure of the paper and the models described therein reflect our efforts to describe the essence of our thoughts, rather than their historical development, statistical difficulties or computational results. In section 2 we will describe the core of the economic structure. In section 3 we will introduce pollution and energy. In section 4 the balance of payments will be considered. In section 5 the public sector will be described. In section 6 we reconsider policy objective functions and conclude this paper.

2. The core of the model

The core of the model is based on the idea that production is realized in production sectors by means of a combination of primary inputs, labour and capital goods; this structure can be described by an extended Input-Output-model. This model is called extended, because traditional I-O-models omit capacity limits.

A second aspect of the core model is its circularity: the consumption sector earns its income from these production activities and decides to spend its income to consumption or savings.

A third aspect is the dynamic structure reflecting the autonomous progress of technology, which can be included in the economy by investments.

The final aspect is the set of policy objective functions which are related among others to decisions to produce and to invest in the planning period.

2.1. Production functions

For production sector i , there is a production function in which the production depends inter alia on the year of investment of each capacity used. This structure is described by the following equations:

$$(1) \quad QP(i, t) = \sum_{\tau=t-l}^{t-1} QP(i, t, \tau),$$

where production of sector i in year t equals the sum of the production of that sector in period t produced by using the productive investments installed in year τ . Technical life time is defined by l . Construction of capacity is assumed to take 1 year.

$$(2) \quad QP(i, t, \tau) \leq \frac{FINV(i, \tau)}{PINV(\tau) * \kappa(i, \tau)}$$

Production capacity is smaller than or equal to the value of investment divided by its price and marginal capital-output ratio.

$$(3) \quad QLAB(s, i, t, \tau) = \alpha(s, i, \tau) * QP(i, t, \tau)$$

Labour is subdivided into categories, denoted by the index s . Each category has an investment-specific productivity, denoted by its reciprocal value $\alpha(s, i, \tau)$. This parameter has an exogenous temporal evolution;

$$(4) \quad \alpha(s, i, \tau) = A_{s,i} [\exp B_{s,i} * \tau]$$

where $A_{s,i}$ and $B_{s,i}$ are input parameters reflecting the progress in technologic know-how.

$$(5) \quad \begin{aligned} \text{FREV}(i, t, \tau) &= P(i, t) * QP(i, t, \tau) \\ &- \sum_s W(s, t) * QLAB(s, i, t, \tau) \\ &- \sum_j P(j, t) * \beta_{ji} * QP(j, t, \tau) \geq 0 \end{aligned}$$

The gross profit from employing a time-specific capacity for production has to be positive. New variables in this equation are:

$P(i, t)$, denoting the prices of products from branch i in year t ;

$W(s, t)$, denoting the wage rate for labour capacity s in year t ;

β_{ji} , denoting the input-output coefficients of intermediate production of sector j needed to produce one unit of production in sector i .

Contrary to the commonly used models, the price and wage variables are given input parameters in order to maintain a linear model. However, a reaction of labour income on profits is taken into consideration in equation (7).

2.2. Investments

At the outset of the planning period, capacity is given for each sector of industry by the historical investment series. Since the model is solved for all periods within the planning period simultaneously, the future demand for each sector of industry is known (see equation 11).

The amount of investments, needed to adjust capacity to this demand, has to satisfy a pay-back criterion, commonly used in industry:

$$(6) \quad \text{FINV}(i, t) \leq \sum_{\tau=t+1}^{t+T_i} \text{FREV}(i, \tau, t)$$

where T_i = (critical) value of the pay-back period in branch i .

Adjustment of production capacity to demand is not the only reason for investments: as soon as profit is an element in the objective function, investments can be made to raise profitability by using relatively more recent equipment, thus raising labour productivity and thereby reducing the wage costs.

Common economic theory describes a wage rate reaction to this policy, but wage rates and prices have to be treated as exogenous variables in this model to keep its linear structure.

We employ the following equation to reflect the wage reaction on a rising profitability:

$$(7) \text{FSUR}(i, t) =$$

$$\sum_{t'=t-T_1}^{t-1} \lambda(t, t') \left[\sum_{\tau=t'+1}^{t'+T_1} \text{FREV}(i, \tau, t') - \text{FINV}(i, t') \right]$$

The expression in brackets is the slack in equation (6), the surplus profit in relation to the minimum profit level needed to invest. The $\lambda(t, t')$'s are a series of distributed-lag parameters, only depending on the difference between t and t' and adding up to a value equal or less than unity. The amount $\text{FSUR}(i, t)$ is then the total effect in period t of all these shares in surplus profits realized by investments before t . This quantity is as well a part of labour income as normal wages are.

By this formulation we avoid to turn down hardly profitable sectors of industry into submarginal profitable ones. Only the timing of earning the surplus profit and paying the related wage quota can differ slightly. A third restriction on investments is that the financial means have to be available. These financial means can be provided by the initial capital, enlarged during the planning period by retained profits. These funds can - for each sector i - be enlarged by borrowing savings from consumers, but in that case a maximum ratio between capital growth from retained profits and from new savings has to be taken into account (see equation (9)):

$$(8) \sum_{\tau=t_0}^t \text{FINV}(i, \tau) \leq \text{CAP}(i, t_0)$$

$$+ \sum_{\tau=t_0}^{t-1} \left\{ \sum_{\tau'} \text{FREV}(i, \tau, \tau') - \text{FSUR}(i, \tau) \right\} \\ + \sum_{\tau=t_0}^{t-1} \text{SAV}(i, \tau)$$

$$(9) \sum_{\tau=t_0}^t \text{SAV}(i, \tau) \leq \phi(i) \sum_{\tau=t_0}^t \left\{ \sum_{\tau'} \text{FREV}(i, \tau, \tau') - \text{FSUR}(i, \tau) \right\}$$

$$(10) \sum_i \text{SAV}(i, t) \leq \text{FSAV}(t),$$

where $\text{FSAV}(t)$ are total consumer savings in period t .

Some final remarks have to be made before concluding this subsection.

In equation (6) a correction has to be made for the last years of the planning period to avoid disturbing horizon effects. We have chosen a factor $\frac{t}{T-t}$ for $T-t < T_1$ where T is the last period before the planning horizon. In that case the summation limit is T .

In equation (8) the summations in the right-hand side are only relevant for t -values larger than t_0 , the first planning period.

In an earlier version of this paper the equations (9)-(10) were omitted.

2.3. Demand

The final demand for consumption goods is given by the Keynesian consumption function:

$$(11) \text{FDEM}(i, t) = \text{CO}(i) + \text{MC}(i, t) * \text{FINC}(t),$$

where $\text{MC}(i, t)$ is the marginal consumption rate and where $\sum_i \text{MC}(i, t) < 1$ is the aggregate marginal consumption rate.

Income is defined by:

$$(12) \text{FINC}(t) = \sum_{s, i, \tau} W(s, \tau) * \text{QLAB}(s, i, t, \tau) + \sum_i \text{FSUR}(i, t)$$

The final demand for capital goods is given by adding up all planned investments $\text{FINV}(i, t)$ over i . The result of this summation is supposed to be stored in $\text{FDEM}(i, t)$ for i referring to capital producing industry, where $\text{CO}(i)$ and $\text{MC}(i, t)$ for that industry are zero.

Now we reach a second deviation from traditional equilibrium models, which is even more fundamental than the first one which led us to the definition of $\text{FSUR}(i, t)$. The restriction on production by capacity and profitability can cause a shortage in supply as compared with demand. Given the exogenously determined wage rates and product prices, the producers can even decide to stop production. Another reason can be found in the restrictions on investment funds leading to undercapacity and consequently to a shortage in supply. The non-negative gap between supply and demand is supposed to be delivered by external suppliers. The size of this external supply is a signal for the user of this model to consider whether changes in the parameters are needed or not.

$$(13) \sum_T QP(i,t,T) * P(i,t) + FIMP(i,t) =$$

$$\sum_j P(i,t) * \beta_{ij} * \sum_T QP(j,t,T) + FDEM(i,t)$$

2.4. Labour market

In this model the labour market is not a market in the ordinary sense, where equilibrium is found between supply and demand, but a reservoir. For each category of labour, no more can be used than is available, while available labour is an exogenous variable.

$$(14) \sum_{i,T} QLAB(s,i,t,T) \leq LAB(s,t)$$

This formulation supposes a perfect mobility between sectors of industry within each labour category and perfect immobility between categories.

2.5. Capital market

There is also for the capital market just a minor function conceptualized in this model. For the productive use of savings we defined already equation (10). Here we have to define the amount of savings:

$$(15) FINC(t) + FCI(t) = \sum_{i \in C} FDEM(i,t) + FSAV(t)$$

This equation defines savings as the balance between income and consumption. There are two variables concerned with savings:

FSAV for positive savings and FCI for negative savings; their product has to be zero. Technically, we take account of the latter remark by giving FCI an unfavourable coefficient in the goal function, which exceeds the sensible range of shadow prices of FSAV. The quantity FCI is external just as FIMP.

Of course, the model could be enlarged by interest from savings, in which case an exogenous price variable $R(t)$ has to be defined and additional terms have to be included in the right hand side of equation (12) and/of equation (5). The formulation of the discharges of the debt and the availability of new investments cause slightly more complications, but the importance of this part is - in this phase of the study - considered to be too small to pay more attention to it. As soon as monetary aspects are introduced, this has to be elaborated of course.

2.6. Objective functions

The preceding subsections described the structural relations within our core model. The objectives which are pursued are still to be described. They are of course dependent on the primary purposes for which the model will be used. We can imagine the following priorities and their related objective functions:

- a. the aim of economic growth within the given parameter values leads to the goal function:

$$(16.1) \text{Max} \left\{ \sum_{i,t,T} \text{FREV}(i,t,T) - \sum_{i,t} \text{FSUR}(i,t) - \sum_{i,t} \text{FINV}(i,t) \right\}$$

which implies the maximization of retained profits payable to share holders.

- b. the aim to get a maximum labour income leads to:

$$(16.2) \text{Max} \sum_t \text{FINC}(t)$$

- c. the aim of a maximum employment leads to:

$$(16.3) \text{Max} \sum_{s,i,t,T} QLAB(s,i,t,T)$$

or, weighted with wage rates:

$$(16.4) \text{Max} \sum_{s,i,t,T} W(s,t) * QLAB(s,i,t,T)$$

- d. Finally, we may also assume a kind of decision game between actors in the model, for example, producers and consumers, each with their own goal function. Owing to the fact that the model is strictly linear, the game-theoretic approach can easily be applied to the model. This subject will be reported in a forthcoming paper. Here we restrict ourselves to a simple goal function or a linear combination of two simple alternative goal functions.

3. Introduction of pollution and energy

The preceding section has described a programming reformulation of the main features of an economic model. Recently, these features have been adjusted to new problems: pollution and energy.

3.1. Pollution

For the pollution problem we can define one (or more, if detailed description of this aspect is needed) row of coefficients in the primary input sectors of the Input-Output-relations:

$$(17) \quad QSO2(i,t) = S(i,t) * \sum_t QP(i,t,\tau)$$

where $QSO2(i,t)$ denotes the amount of pollution caused by production. The coefficients $S(i,t)$ may be assumed to obey the trend

$$(18) \quad S(i,t) = SO(i) \exp(C_i \cdot t),$$

$SO(i)$ and C_i being parameter values.

The same holds for pollution by consumers:

$$(17') \quad QSO2(c,t) = S(c,t) \sum_{i \in C} FDEM(i,t)$$

with a time trend (18') for $S(c,t)$ analogous to (18).

This amount of pollution can be reduced by using special facilities: purifying investments. They provide the capacity for purifying activities reducing the primary level of pollution:

$$(19) \quad QO2(i,t,\tau) \leq \frac{FPI(i,\tau)}{PINV(\tau) * \lambda(i,\tau)}, \quad t - \tau < T_s$$

where the index i denotes sectors of industry and the consumption sector, $QO2(i,t,\tau)$ the amount of pollution reduced by purifying activities in sector i in period t using purifying investments of period τ which have a technical lifetime of T_s .

These investments, however, affect the funds for productive investments, so that the left hand side of restriction (8) has to be adjusted with an analogous summation of $FPI(i,\tau)$ where the index i is referring to sectors of production.

The restrictions which society puts on pollution can be described by the right hand side of (20):

$$(20) \quad \sum_i \left[QSO2(i,t) - \sum_{\tau} QO2(i,t,\tau) \right] \leq SO2(t)$$

3.2. Energy

We can include energy consumption either in the way as we formulated the use of labour - via year-of-investment dependent coefficients - or as we did with pollution - via year-of-production dependent coefficients. We have chosen here for the first approach (cf. equation (3) and (4)):

$$(21) \quad QEN(i,t,\tau) = Y(i,t) * QP(i,t,\tau),$$

$i \in \text{production} + \text{consumption}$

where

$$(22) \quad Y(i,\tau) = E_i \exp F_i \cdot \tau$$

When more attention has to be paid to the energy problem, equation (21)-(22) can be subdivided into more categories of energy.

Now the problem arises whether we have to continue with writing down corrective measures as we did with pollution (cf. equation (19)) or whether we have to assume that the use of energy does not leave possibilities for energy saving activities. Assuming that energy saving activities are possible, the best way to formulate the effect of investments in that direction should be via an influence on equation (22), but that again violates the linearity of the model. Finally, we have decided to use a formulation analogous to equation (19):

$$(23) \quad QES(i,t,\tau) \leq \frac{FEI(i,\tau)}{PINV(\tau) * \delta(i,\tau)},$$

where the same consequences as mentioned for FPI hold for equations (8) and (15) with reference to FEI .

Finally we formulate the impacts of purifying activities on energy consumption and of energy saving on pollution:

$$(24) \quad QEP(i,t) = EP(i) * \sum_{\tau} QES(i,t,\tau)$$

$$(25) \quad QPE(i,t) = PE(i) * \sum_{\tau} QO2(i,t,\tau)$$

where in both equations the symbol i refers to sectors of production and the consumption sector.

Consequently, the left hand side of equation (21) has to be adjusted within the brackets by either $+ QEP(i,t)$ or $- QPE(i,t)$, the sign depending on the influence as-

sumed: saving energy can have polluting effects or purifying effects. The influences can be made explicit, when the model is extended with one or more energy production equations. This is one of the future research directions.

Finally, society is assumed to set a restriction on the total use of energy

$$(26) \sum_i \left[\sum_{\tau} QEN(i, t, \tau) + QPE(i, t) - \sum_{\tau} QES(i, t, \tau) \right] \leq EN(t)$$

4. Balance of payments

As mentioned before - cf. our remarks preceding equation (13) - we cannot formulate a programming model which guarantees an equilibrium with the outside world. Nevertheless, it is worthwhile to define some relationships reflecting the balance of trade:

4.1. Imports

Primary imports can be easily defined for sectors of industry:

$$(27) FIM(i, t) = PI(i, t) * \beta_{i, k} * \sum_{\tau} QP(i, t, \tau)$$

where $PI(i, t)$ are import prices related to the import structure of sector i and $\beta_{i, k}$ technical coefficients. The same holds for autonomous imports of consumption:

$$(28) FIM(i, t) = \varepsilon(i, t) * FDEM(i, t)$$

This relationship reduces the demand for home-produced goods with the same quantity at the right hand side of equation (13).

Besides these technological and behavioural effects, we have mentioned already the induced imports $FIMP(i, t)$ in equation (13).

One aspect influencing imports and exports has to be paid attention to, viz. the interpretation of $FSUR$ (cf. equation (7)).

So far we have not made any difference whether we considered $FSUR$ as payment in money to the consumption sector or as a real payment by lowering prices. In the first interpretation, the effect is purely national, but in the second interpretation the effect influences autonomous imports of consumption (equation (28)) as well as the demand for exports.

So we define parameters $\psi(i, t)$ within the range 0 to 1 denoting the fraction of $FSUR(i, t)$ paid in real terms.

The effect on autonomous imports of consumption goods leads to a change of (28) into:

$$(28') FIM(i, t) = \varepsilon(i, t) * FDEM(i, t) -$$

$$- \bar{\varepsilon}(i, t) * \psi(i, t) * FSUR(i, t)$$

4.2. Exports

Demand for exports is mainly autonomous, which - for this model focussing on a national economy - is the same as exogenous. The price elasticity for exports may be supposed to exceed 1 (in absolute value); so we get

$$(29) FEX(i, t) = FEXO(i, t) + PEL(i) * \psi(i, t) * FSUR(i, t)$$

where $PEL(i)$ denotes the final effect of demand for exports on the relative importance of lowering prices. The amounts of $FEX(i, t)$ have to be added to the right hand side of (13).

4.3. Capital accounts

The part of (dis-)savings which are not used (provided) within the national economy are, by definition, the balance of the capital accounts, but for the moment they are beyond the scope of this research project.

5. Public sector

So far we have not paid any attention to the public sector (central and local authorities). One of the aims of this model, however, is to get an idea about the possibilities for governmental policy with respect to the interdependencies between employment, pollution and energy consumption.

So we will introduce income and expenditures for the public sector, which of course will require adjustments for many preceding equations. In order to avoid a reformulation of all these equations in this section, we only mention here the consequences.

5.1. Public income

a. Taxes on wages:

$$FTAXW(t) = TAXW(t) * \sum_{s, i, \tau} W(s, t) + QLAB(s, i, t, \tau)$$

These amounts have to be subtracted from the right hand side of equation (12).

b. Taxes on profits:

$$FTAXP(t) = TAXP(t) + \sum_i \left[\sum_{\tau} FREV(i, t, \tau) - FSUR(i, t) \right]$$

These taxation effects have to be substituted properly into equations (5), (6), (7), (8) and (9).

c. Taxes on pollution:

$$FTAXS(t) = TAXS(t) * \sum_i QSO2(i,t)$$

These taxes lead to analogous adjustments as FTAXP.

d. Taxes on energy:

$$FTAXE(t) = TAXE(t) + \sum_{i,T} QEN(i,t,T)$$

They also lead to the same corrections as FTAXP.

e. Other taxes:

$$FTAXR(t) = TAXR(t) * \sum_i P(i,t) * QP(i,t)$$

which constitute a burden on the consumption sector, and hence have to be subtracted from the right hand side of equation (12).

5.2. Public expenditures

a. Public employment

The public sector also leads to employment, partly exogenous, partly endogenous:

$$FEMPL(s,t) = W(s,t) * QEMPL(s,t) \geq EMPL(s,t)$$

These amounts are family income (equation (12)).

b. Secondary income

Where the social security sector is lacking in this model, the secondary incomes are assumed to be paid by the government:

$$FSEC(t) = FSECO(t) + \sum_s 0.8 * W(s,t) * \left\{ LAB(s,t) - \sum_{i,T} QLAB(s,i,t,T) \right\}$$

These amounts are also family income (equation (12)).

c. Public expenditures on goods and services

The public sector asks for goods and services, both endogenous and exogenous:

$$FPDEM(i,t) \geq PDEM(i,t)$$

These amounts are final demand (equation (11)).

d. Investment subsidies

The government can try to stimulate the various types of investments:

$$FGRI(i,t) = GI(i,t) * FINV(i,t) \quad i \in \text{industry}$$

$$FGRT(i,t) = GP(i,t) * FPI(i,t) \quad i \in \text{industry} + \text{consumption}$$

$$FGRE(i,t) = GE(i,t) * FEI(i,t) \quad i \in \text{industry} + \text{consumption}$$

These subsidies reduce the effective burden of investment outlays for the recipients in equation (8) and (12).

5.3. Budget

The public sector has to satisfy a budget restriction

$$EXPEND \leq 1.06 * PINC$$

where 1.06 is an exogenous parameter reflecting the maximum shortage on the public budget.

6. The objective function reconsidered

After the extension of the model in sections 3-5, we have a wider range of options for defining the objective functions presented in section 2.6. We can include in the objective functions additional terms reflecting our preference or dispreference for certain relevant factors such as pollution, energy, balance of payments, and public budget.

The extension and the reformulation of the model are the subjects of future studies.

MULTILEVEL MULTIREGIONAL AND MULTIOBJECTIVE
POLICY MODELS FOR ENVIRONMENTAL AND ENERGY
MANAGEMENT

Peter Nijkamp and Piet Rietveld
Department of Economics, Free University
P.O. Box 7161
1007 MC Amsterdam

Summary

In this paper, energy management problems are studied in the framework of multilevel and multiobjective programming methods. After a short introduction into these programming methods, several classes of integrated multiobjective multilevel models are discussed.

1. Introduction

Environmental and energy policy analysis is a mode of thinking in a field which is full of conflicts and dilemmas. Examples of such conflicting issues are: the working of the price and market system versus a more centralized or planned system, the aim of a maximum production growth versus environmental interests, the aim of a sufficient energy supply versus risks and ecological disturbances, a central policy co-ordination versus a regional decentralisation, etc.

The present paper aims at providing a framework for analysing such conflicts. Its emphasis is (1) on multiobjective programming as a tool for indentifying compromise solutions in conflicting decision problems and (2) on multilevel programming as a tool for attaining a satisfactory co-ordination between different decision levels (characterized by specific interests) of a policy system. This paper attempts to give an introduction to both modes of thinking, followed by a synthesis. A survey and classification of various kinds of multiobjective and multilevel decision problems will be given as well, while also the relevance of such approaches for environmental and energy policy analysis will be indicated.

2. Conflicts in Environmental and Energy Policy Analysis

As mentioned above, environmental and energy management may lead to various conflictive policies and developments. As almost all regions in developed countries demonstrated a rapid growth in the use of energy resources, they found themselves confronted with greater external dependency. In addition, these regions were faced with mounting levels of waste and pollution arising out of the consumption and production of commodities. Consequently, particularly the technologically

advanced regions have to orient their consumption and production activities to a conservation of energy resources and a preservation of environmental quality.

One may expect that the current problems of high-consumption technological societies will evoke an adjustment process (either through the market system or by public intervention) toward a different consumption and production pattern. Examples of such adjustment processes are: the production (and consumption) of products with a greater durability, the design of a less energy-intensive technology, the construction of more energy-efficient power plants, or the creation of an adjusted location, settlement and transportation system.

It is clear that any change in the composition of the regional production and consumption structure or in the spatial lay-out of a society will have impacts on the regional development pattern. The same holds true for any change in the energy prices and in the supply of energy resources. It is plausible that such impacts will be greater as the changes in technological, economic or political circumstances will be more discontinuous in nature. The risks and uncertainties in the present oil supply are certainly a real danger for an unbalanced regional development pattern. In addition to the price system, alternative policy instruments should not be neglected (for example, rationing, standard setting, etc.); the choice of adequate policy instruments is one of the dimensions of a conflictive policy problem.

There is another conflictive element involved in a policy analysis of energy resources. Several energy activities pose serious threats to human health and to the environment. Any reduction in such threats may induce higher energy costs. The existence of unacceptable threats may even preclude a further development of new energy resources (as is demonstrated by the discussion about nuclear energy plants). Thus, energy policy analysis has to be put in a broader multidimensional framework, in which conservation of energy (including interfuel substitution), preservation of environmental quality and maintenance of a reasonable welfare level are simultaneously taken into account.

The energy situation has also many important spatial

aspects. Due to differences in regional production technologies, the regional sectoral energy coefficients may show much variation. The same holds true for energy use arising from final consumption. However, even the different states of technology among regions do not explain entirely that the regional disparities in energy consumption per capita may be strikingly wide (even within the same country). A major reason for the occurrence of substantial regional disparities in energy consumption is the difference in sectoral composition of the regions. Another reason for the occurrence of disparities in energy use among regions may be - apart from differences in climate and physical conditions - a difference in the spatial location and settlement patterns of these regions.

Such spatial differences in the economic, environmental and energy structure lead obviously to several policy frictions among regions of a spatial system, and decisions of the one region may be neutralized by opposite, uncoordinated decisions in other regions. Therefore, a framework for arriving at compromises between different policy issues and between different actors (regions, e.g.) at different levels may be necessary to increase social efficiency and equity.

In general, a multilevel, multiobjective structure of a spatial system with different actors may be represented as follows (arrows denote conflicting interests):

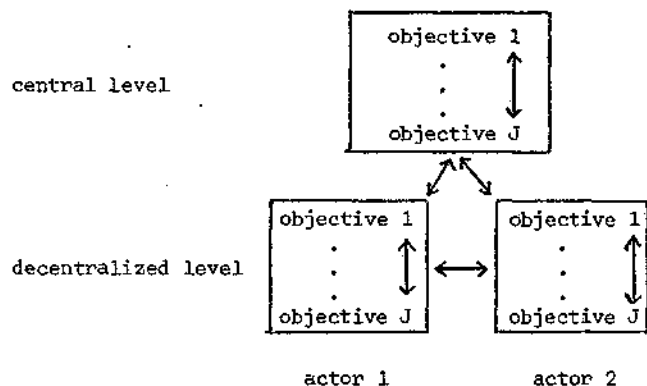


Fig. 1. A multiobjective multilevel policy framework

In order to elaborate on Fig. 1, in the following sections more explicit attention will be paid to multiobjective and multilevel programming problems.

3. Multiobjective Programming

Multiobjective programming methods form a rapidly expanding field of research in operations research and management science. For some recent surveys we refer to Cohon [1978], Hwang and Masud [1979], Nijkamp [1979] and Rietveld [1980]. The aim of these methods is the analysis and solution of decision problems in which a

decision-maker (DM) (or several DMs) faces several conflicting objectives.

The methods are devoted to such activities as:

- the analysis of the conflicts inherent in a decision problem, for example, by determining a series of alternatives in which a best result is strived after for only one objective so as to study the consequences for the other objectives.
- the generation of a representative set of efficient (Pareto-optimal) alternatives.
- the determination of alternatives reflecting a certain compromise between conflicting points of view.
- modelling preference statements of DMs to find alternatives which are in agreement with the DM's priorities.
- detailed analyses of the pros and cons of alternatives in order to rank the alternatives in order of attractiveness - given the DM's priorities.

It is an essential feature of multiobjective programming methods, that an exchange of information takes place between an analyst and a DM. The analyst generates information about the structure of the decision problem by analyzing conflicts and compromises. The DM informs the analyst about his preferences, as far as he is able to express them.

In interactive multiobjective decision methods this information exchange is structured as a process consisting of several runs. The basic idea of interactive methods is that first by means of a standard rule a provisional compromise solution is calculated by the analyst which has to be judged by the DM. Then the DM has to indicate which of the proposed compromise values of the objectives are not satisfactory to him. These preference statements can be incorporated by the analyst as side-conditions in the next run of the analysis. Then the procedure may be repeated again and again, until finally a converging satisfactory compromise solution has been identified.

4. Multilevel Programming

Multilevel programming models provide a framework for the coordination of decisions made in the various components of a system. The aim of multilevel programming is the achievement of an efficient distribution of resources and liabilities (e.g., energy, manpower) among components and an efficient management of spillovers between components (e.g., spatial diffusion of pollution).

It is assumed that the coordination has to be accomplished by a central unit which has the political power to give certain directives to the components. The central policy unit has only fragmentary knowledge

about the structure of the decision problem. Hence, in addition to the communication process described in the preceding section, another communication process has to be introduced, aiming at providing the central unit with sufficient information about the structure of the decision problem.

The information exchange between centre and components takes place by means of essentially two kinds of variables:

- 1) quantities
- 2) (shadow) prices or productivities.

In direct methods, the central unit informs each component about the quantity of the various common resources allocated to this component. Then the components report the productivities of these resources back to the centre. Given this information about productivities, the central unit generates a new distribution of common resources which is again proposed to the components. It can be shown that under certain conditions such an information exchange converges to an efficient allocation of resources (cf. Ten Kate [1972] and Johansen [1978]).

Indirect methods consist of a similar interaction, the difference being that now the centre confronts the components with prices of common resources, and the components report back the quantities demanded of these resources. Dantzig [1963] had provided a proof of convergence for these methods.

5. A Classification of Multiobjective Multilevel Programming Methods

In this section we will present a classification of integrated multiobjective and multilevel programming methods. In Table 1, these methods have been classified according to four dimensions:

(a) The components the centre interacts with:

- regions $r = 1, \dots, R$
- policy sectors $j = 1, \dots, J$. (e.g., economic development, employment, environment, energy)
- regional policy sectors $(j,r) = (1,1), (1,2), \dots, (1,R), (2,1), \dots, (J,R)$.

For the ease of presentation, l will be used as a general indicator of a component ($l = 1, \dots, L$). Consequently, $l = r,j, (j,r)$ for the three cases mentioned above.

(b) The structure of the objective functions of the centre (U_c) and the components (U_l) and the relationships between them. The following combinations can be distinguished:

- U_l is one-dimensional and U_c is the unweighed sum of the U_l (e.g., national energy consumption is the sum of regional energy consumptions).

- U_l is one-dimensional and U_c is the weighed sum of the U_l (e.g., the national objective function is the sum of the outcomes for a number of policy sectors, each supplied with an appropriate weight).
- U_l and U_c are multidimensional. The weights attached to the various objectives by the centre and the components are not necessarily identical.

(c) The type of information flowing upward and downward (see Section 4 for the distinction between direct and indirect methods).

(d) The availability of information about the weights to be attached to the various objectives. In Section 3 it has been indicated that in the case of "no information available" interactive multiobjective programming may be helpful to determine satisfactory solutions.

	$r = 1, \dots, R$	$j = 1, \dots, J$	$(j,r) = (1,1), (1,2), \dots, (J,R)$
components interacting with centre	w_r $\sum_r w_r$	w_j $\sum_j w_j$	w_{jr} $\sum_{jr} w_{jr}$
objective of component	$\sum_r \lambda_r w_r$	$\sum_j \mu_j w_j$	$\sum_{jr} \nu_{jr} w_{jr}$
objective of centre	$\sum_r w_r$ $\sum_r \lambda_r w_r$	$\sum_j w_j$ $\sum_j \mu_j w_j$	$\sum_{jr} w_{jr}$ $\sum_{jr} \nu_{jr} w_{jr}$
direct method	known weights not known weights	7 8 9 10	11 12 13
indirect method	14 15 16 17 18	19 20 21 22 23	24 25 26

Table 1. Classes of multiobjective multilevel programming methods

We will use the following notations to sketch the various classes of multiobjective multilevel programming methods. Let $\underline{x}_1$ denote the vector of decision and state variables of component 1. In multilevel programming, there are essentially two types of constraints:

- constraints holding for each component separately, e.g.,

$$B_1 \underline{x}_1 \leq \underline{b}_1, \quad \underline{x}_1 \geq \underline{0}, \quad (1)$$

where B_1 and $\underline{b}_1$ denote a matrix and vectors of appropriate size.

- constraints holding for several components simultaneously, implying interdependence of components, e.g.,

$$\sum_1 A_1 \underline{x}_1 = \underline{a}, \quad (2)$$

The vector $\underline{a}$ denotes the available amounts of the common resources.

Given this information, the central decision problem reads:

$$\left\{ \begin{array}{ll} \max! & U_c(\underline{x}_1, \dots, \underline{x}_L) \\ \text{s.t.} & \sum_1 A_1 \underline{x}_1 \leq \underline{a} \\ & B_1 \underline{x}_1 \leq \underline{b}_1 \quad 1 = 1, \dots, L \\ & \underline{x}_1 \geq \underline{0} \quad 1 = 1, \dots, L \end{array} \right. \quad (3)$$

Since we assume that the centre has incomplete information on the B_1 and $\underline{b}_1$, decentralization of decisions is necessary. In direct methods of decentralization, the decision problem of component 1 reads:

$$\left\{ \begin{array}{ll} \max! & U_1(\underline{x}_1) \\ \text{s.t.} & A_1 \underline{x}_1 \leq \underline{a}_1 \\ & B_1 \underline{x}_1 \leq \underline{b}_1 \\ & \underline{x}_1 \geq \underline{0} \end{array} \right. \quad (4)$$

where $\underline{a}_1$ is the amount of the common resources assigned to component 1 ($\sum \underline{a}_1 = \underline{a}$). The indices reported back to the centre are the marginal productivities in the use of $\underline{a}_1$ with respect to U_1 . These indices can be determined as the shadow prices of the constraints $A_1 \underline{x}_1 \leq \underline{a}_1$.

In indirect methods, the decision problems of the components read:

$$\left\{ \begin{array}{ll} \max! & U_1(\underline{x}_1) - c(A_1 \underline{x}_1) \\ \text{s.t.} & B_1 \underline{x}_1 \leq \underline{b}_1 \\ & \underline{x}_1 \geq \underline{0} \end{array} \right. \quad (5)$$

where $c(A_1 \underline{x}_1)$ denotes the costs, charged by the

centre because of the use of common resources. In this case, the indices reported back to the centre are the quantities $A_1 \underline{x}_1$ of the common resources demanded by the component concerned.

In this contribution we will not treat in detail how the centre generates the indices for the components. Suffice it to say that by an appropriate reformulation of (3), the centre can digest past responses of components to generate new indices leading ultimately to convergence (cf. Dantzig [1963], Ten Kate [1972], and Nijkamp and Rietveld [1980]).

We will now give a more detailed description of the indices exchanged in some of the classes of methods distinguished in Table 1.

Class 1. The indices produced by the centre are quantities $\underline{a}_r$ for each region r . The indices reported back are the marginal productivities of the resources $\underline{a}_r$ with respect to U_r . Class 6 and 11 are similar to 1. From the view point of the indices exchanged, also the classes 2, 7 and 12 are similar to 1, the only difference being that the centre weights the productivities reported by means of certain factors γ .

Class 14. The centre submits prices π to charge the regions for their use of scarce resources. These prices hold for all regions. The regions report back the quantities demanded of the common resources. The classes 15, 19, 20 and 24 are similar to class 14.

Class 4. The effect of the multidimensional character of the objectives is that the productivities reported to the centre also have to be multidimensional. Thus, for each common resource k , the region r reports the marginal productivity with respect to all individual objectives w_{jr} . Consequently, when K is the number of common resources, each region generates $J \cdot K$ indices in virtue of the centre. An important consequence of divergent weights is, that the components may use the resources in a way, different from the intentions of the centre. Thus, from the centre's view point sub-optimal solutions may be reached. Class 9 is similar to class 4.

Class 17. The multidimensionality of objectives has for this class consequences, which are comparable to class 4. For each common resource k , the centre generates a vector of prices $(\pi_{1kr}, \dots, \pi_{Jkr})$ to be charged to the regions for their use of common resources. Consequently, the total number of indices produced by the centre equals $J \cdot K \cdot R$. Similar classes can be found in cells 22 and 25 of Table 1.

Class 5. The introduction of uncertainty about weights means for the interactive multilevel methods that a second process of interactions has to be built in,

namely between DMs and analysts, at the level of the centre as well as of the components. The resulting process can be sketched as follows:

- (a) Interaction at the central level between the central DM and his analysts to determine a satisfactory provisional distribution of common resources.
 - (b) This provisional distribution is proposed to the regions.
 - (c) Interaction at the level of the regions between each regional DM and his analysts to determine a satisfactory allocation of the resources.
 - (d) Each region reports back J.K shadow prices corresponding to this allocation (cf. class 4).
 - (e) Go back to (a) until convergence has been reached.
- The classes 3, 8, 10 and 13 have the same structure as class 5. The classes 16, 18, 21, 23 and 26 can be found as a straightforward adaptation of the above-mentioned structure to the characteristics of indirect methods as shown in classes 14 and 17.

6. Conclusion

The above-mentioned multiregional, multilevel methods have a general scope, but also a particular relevance for environmental and energy policies, in so far as these policies are being performed at different levels and with conflicting priorities among actors (such as regions). Given the operational nature of these methods and the wide variety of such methods, they may be regarded as flexible tools for a large set of environmental and energy management problems.

References

- Dantzig, G., Linear Programming and Extensions, Princeton University Press, Princeton, 1963.
- Johansen, L., Lectures on Macroeconomic Planning, North Holland Publ. Co., Amsterdam, 1978.
- Kate, A. ten, Decomposition of Linear Programs by Direct Distribution, Econometrica, vol. 40, 1972, pp. 883-898.
- Nijkamp, P., Multidimensional Spatial Data and Decision Analysis, Wiley, New York, 1979.
- Nijkamp, P. and P. Rietveld, Multiobjective Multilevel Policy Models, European Economic Review, 1980, forthcoming.
- P. Rietveld, Multiobjective Decision Methods and Regional Planning, North Holland Publ. Co., Amsterdam, 1980.
- Cohon, J.L., Multiobjective Programming and Planning, Academic Press, New York, 1978.
- Hwang, C.L. and A.S.M. Masud, Multiple Objective Decision Making-Methods and Applications, Springer, Berlin, 1979.

30) Serie Research Memoranda:

- | | | |
|---------|---|---|
| 1977-1 | L. Hordijk, P. Nijkamp, | Estimation of Spatiotemporal Models
New directions via distributed lags
and Markow schemes. |
| 1977-2 | P. Nijkamp, | Gravity and entropy models: The state of the art. |
| 1978-1 | J. Klaassen, | Valuta problemen in de Jaarrekening. |
| 1978-2 | P. Nijkamp, M.W. van
Veenendaal, | Psychometric scaling and preference
methods in spatial analysis. |
| 1978-3 | P. Nijkamp, J. Spronk, | Interactive Multiple Goal Programming. |
| 1978-4 | P. Nijkamp, P. Rietveld, | New Multi Objective Techniques in
Physical Planning. |
| 1978-5 | P. Nijkamp, | Decision Models for Planning against Stagnation. |
| 1978-6 | P. Nijkamp, | A Theory of Displaced Ideals.
An Analysis of Interdependent Decision via
Non-Linear Multi-Objective Optimization. |
| 1978-7 | P. Nijkamp, | Conflict Patterns and Compromise Solutions
in Fuzzy Choice Theory.
An Analysis and application. |
| 1978-8 | J.D.P. Kasper, | De Bijdrage van Detailhandelsmarketing aan
Maatschappelijke Welvaart en Welzijn. |
| 1978-9 | H.J. Blommestein, P.
Nijkamp, P. Rietveld, | A Multivariate Analysis of Spatial Inequalities. |
| 1978-10 | F. Palm and A. Zellner, | Large Sample Estimation and Testing Procedures for Dynamic Equation Systems. |
| 1978-11 | J.H.T.H. Andriessen,
P.A. Cornelis, H. van der
Flier, | Participatie, Invloed, Satisfactie en
Groepseffectiviteit.
Een onderzoek bij deelnemers aan een
bedrijfsspel. |
| 1978-12 | W. van Lierop and
P. Nijkamp, | A utility framework for interaction models
for spatial processes. |
| 1978-13 | R.J. Joseph, | Beschermingsconstructies in het huidige en
komende vennootschapsrecht. |
| 1978-14 | P. Nijkamp en
W. van Veenendaal, | A multi-attribute analysis of spatial
choice Behaviour. |
| 1979-1 | A.A. Schreuder-Sunderman,
Frans Blommaert en Hein Schreuder, | Werknemers en Soc. Jaarverslag. |
| 1979-2 | H. Schreuder, | De maatschappelijke verantwoordelijkheid van
Ondernemingen. |
| 1979-3 | P. Nijkamp en P. Rietveld, | Multilevel Multi-objective Models in a
Multiregional System. |
| 1979-4 | J. Arntzen, G. Bornmalm-
Jardelöw and P. Nijkamp, | Duality, Segmentation and Dynamics on a
Regional Labour Market. |
| 1979-5 | P. Nijkamp, A. Soffer | Soft Multicriteria Decision Models for
Urban Renewal Plans. |
| 1979-6 | drs. A.J. Mathot | A Model of choosing a car with or without
a credit. |
| 1979-7 | H. Blommestein, P. Nijkamp
en W. van Veenendaal, | Shopping Perceptions and preferences: A multi-
dimensional Attractiveness Analysis of
Consumer and Entrepreneurial Attitudes. |
| 1979-8 | H.J. Blommestein and
F.C. Palm | The Aggregate Demand for Money in the Netherlands
a new look at a study of the Bank of the
Netherlands. |