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INTEGRATED ECONOMIC-ENVIRONMENTAL-
ENERGY POLICY AND CONFLICT ANALYSIS

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INTEGRATED ECONOMIC-ENVIRONMENTAL-
ENERGY POLICY AND CONFLICT ANALYSIS

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1. Economic Policy Analysis

The conventional theory of economic policy has usually taken for granted the paradigm of rational decision-making on the basis of full information. The majority of models designed for economic policy analysis presupposed rational behaviour of clearly identifiable, individual decision-makers or of one (collective) decision agency. Given a set of axioms for rational actors confronted with a complex choice situation, these models for economic policy analysis were mainly normative in nature (see for instance, Harsanyi, 1979).

In many cases, this traditional view on economic policy analysis (represented inter alia by unidimensional programming or a priori known utility models) was not very realistic, as important institutional and organizational aspects of decision-making were neglected, such as multi-level and multi-group processes, vote-trading, bargaining, power conflicts, impacts of informal pressure and interest groups, and strategic behaviour. These shortcomings have in recent years caused the emergence of multiple objective (or multidimensional) decision analysis (Nijkamp, 1980).

Multiple objective decision models take explicitly into account the existence of goal conflicts, while institutional and procedural aspects of economic planning can be included by means of interactive decision strategies (see Rietveld, 1981, and Spronk, 1981). Furthermore, in multiple objective decision analysis, usually a more modest 'satisficer' principle instead of a strict optimizing behaviour is assumed (cf. Simon, 1958), based on a compromise between different and usually conflicting objectives. In this sense the rationality paradigm receives a more limited interpretation, viz. as a methodological judgement criterion regarding the (ex ante or ex post) justifiability of decisions (see Faludi, 1971). Also Tversky and Kahneman (1981) demonstrate that the usual existence of systematic biases in judgement influencing preference formation violates conventional normative theory on rational behaviour (cf. also Sen and Williams, 1982). And finally Kmietowicz and Pearman (1981) argue that incomplete knowledge (for instance, regarding the impacts of public policy decisions) undermines conventional decision theory. Altogether, a closer look at multiple objective decision-making is worthwhile.

A systematic discussion and presentation of the potential of modern multiple objective analysis (especially multiple attribute utility analysis) can be found in Keeney and Raiffa (1976) and Keeney (1982), among others. For well-structured and simple choice situations, conventional normative utility-based

approaches (such as simple programming models) may still be meaningful, but in complex multi-group, multi-level and multi-attribute decision situations the utility maximizing axiom is often hard to justify in light of conflicting behaviour of actors and groups (cf. Isard and Smith, 1983). In such cases, a communication and learning process between designers of models and decision-makers may be necessary in order to develop and employ flexible decision-support models (e.g., based on interfaces between decision-makers and models) that serve the need to provide relevant information in all phases of multi-stage decision processes. Especially for conflict analysis and management multiple objective models have proven to be extremely helpful (cf. Hafkamp, 1984).

Moreover, complex multi-objective decision processes (in an interactive context, e.g.) can, at each desired moment, be provided with appropriate information regarding trade-offs and efficiency of proposed solutions thanks to the emergence of modern computer-assisted and adaptive information systems (see Nijkamp and Rietveld, 1984). And finally, various qualitative multiple criteria methods are at present available that are capable of treating non-metric ('soft') data in decision analyses (see Nijkamp et al., 1984, and Voogd, 1983).

However it should be added that other types of models may also provide useful insight into complex public choice situations. For instance, simulation models (based on Systems Dynamics, e.g.) may also produce meaningful information on impacts of alternative policy strategies. An alternative and interesting approach can be found in Wakeland (1976) who used a computer-assisted specification of variables and linkages in a complex system in order to derive a system of first-order differential equations that is able to generate simulations of impacts of alternative policy choices. In a different context, Warfield (1976) has developed a so-called 'interpretive structural modeling' methodology in which policy actions in complex systems are analyzed by means of graph-theoretic approaches. All abovementioned approaches are not in contrast with multiple objective decision analysis, but rather complementary. This holds especially true for interactive decision analysis on the one hand and man-computer interaction models on the other hand.

In general, the use of computers appears to have become a prerequisite for structuring and analyzing complex multiple objective choice problems, especially in case of multi-dimensional goal conflicts. Due to cognitive complexity of decision situations (see Janis and Mann, 1977), the need for

heuristic learning principles in multi-person decision-making (see Tversky and Kahneman, 1981), the tendency to adopt 'satisficer' strategies in conflict management (see Eilon, 1979), and the existence of different cognitive styles in judgement processes (see Henderson and Nutt, 1980), modern computer technology constitutes a basic ingredient in individual or organizational decision processes (including government decision-making). In this regard, Decision Support Systems (DSS) have proven to be extremely effective tools in less structured choice situations (see among others Bennett, 1983, and Keen and Scott Morton, 1978). Given the man-machine interfaces in modern (adaptive) decision analysis, many models (including interactive multiple objective decision models) that have recently been developed for policy and decision analysis tend to exhibit both descriptive and normative aspects of multidimensional choice problems.

2. Integrated Economic-Environmental-Energy Modelling

Economic - environmental - energy planning provides a glaring example of conflict analysis. Integrated economic-environmental-energy modelling has become increasingly complicated over the past decade. Systems theoretic concepts, optimal control models, game-theoretic approaches and multidisciplinary analyses have become necessary tools for economic-environmental-energy analyses. There is a strong tendency towards a more coherent and integrated analysis, in which economic, environmental, energy and regional aspects are brought together in one consistent framework (see Lakshmanan and Nijkamp, 1980). This need for integrated modelling is mainly caused by the fact that the post-war economic growth paradigm intertwined with technological, scientific and educational progress and rising population numbers, has overlooked inter alia the social and ecological dimensions of this process and hence has led to a serious threat for the man-made and natural environment. This development can not only be observed in the developed countries, but also in the Third World countries, especially in those areas where a rapid industrial expansion is not accompanied by sufficient monetary resources for environmental protection and pollution abatement. Integrated planning and policy models provide essentially some necessary means to restore the balance in favour of more emphasis on environmental dimensions (cf. also Guldman and Shefer, 1981).

Models for an integrated economic-environmental-energy analysis should take into account the spatial dimensions of the system at hand, as space is a medium through which the economy interacts with the environment and the re-

source base. Therefore, a closer investigation into the structure of spatial economic - or, more precisely, multiregional economic - models is necessary.

Recently, a world-wide survey of multi-regional economic models has been held by the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, and the Department of Regional Economics, Free University, Amsterdam (see Issaev et al., 1982). The survey, involving approximately 200 multi-regional economic models, showed that 50 models were operational at that time. However, only three out of these 50 models were economic-environmental models (including the analysis of energy problems), viz.

MREED, MEEEI and TLM. A brief discussion of MREED and MEEEI is given below, together with an outline of a more recent, yet incomplete model for the United States, IMM. The design, construction, and results of TLM (Triple Layer Model) will be the main focus of this paper, together with the presentation of multi-objective simulation experiments.

MREED: Multi-Regional Model of the Economy, Environment and Energy Demand.

The purpose of MREED is to determine the economic-environmental-energy consequences of alternative national and regional policies for the United States (see Lakshmanan, 1979). MREED distinguishes 50 regions within the spatial system as a whole, while the production of goods and services in these regions is analyzed and modeled on the basis of 53 sectors. This model has approximately 880 endogenous variables for each region. Some main features can be found in Table 1.

Level	National	Regional
Type of variable		
Economic	Taxes, Depreciation Interest Rates Investments	Sectoral Output Capital Stock Fuel Prices
Employment	Employment	Labor Demand
Environment		Energy Demand Number of Heating Days

Table 1: Some features of MREED

Production functions of the so-called KLEM type are used in MREED, involving functions that have, as arguments, the following factors: capital, labor, energy, and raw materials. The actual production functions used have a translog specification.

MEEEI: Inter-Regional Policy Model for Energy-Economic-Environmental Interactions. The purpose of MEEEI is to study interactions between energy, environment, and the economy in general. (See Lesuis et al., 1983). It is a bi-regional model of The Netherlands modeling the production of goods and services in 11 sectors, containing some 100 variables (see for some details also Table 2).

MEEEI uses an extended I-O model as a production function. Fixed technical coefficients have been assumed for production factors, labor, and energy. The model deals with (exogenous) changes of prices via a regional translog price possibility frontier.

Variable type	National	Regional
Economic		Exports, Production
Employment		Employment
Environment		Pollution, Energy Demand

Table 2: Some features of MEEEI

A new promising approach to multi-regional economic-environmental modeling which is still in an experimental stage, is chosen by Isard et al. in the Integrated Multiregional Model (IMM) for the United States. Its major aim is to combine a series of existing spatial models. Each of these models focusses on specific aspects of the multi-regional system, while there are many overlaps between the various assembled models. The structure and design of this model were first discussed by Isard, Boyce, Lakshmanan, Klein and Caldwell, (1981). The following sub-models are constituents of this "master" model:

- NATLEC: a national econometric model, used to describe changes at the national level in a set of national economic variables, such as prices, final demand, etc.

- MULTIPOL: a model for conflict management encompassing procedures for describing policy decisions that are basic inputs in other models: government expenditure, evolution of energy use, social security, etc.; see also Isard and Smith (1983).
- CICIOP: a model, developed by Isard, uses location theory (notably comparative cost principles) and industrial complex analysis in order to assess optimal production patterns.
- FACTIN: a model developed by Lakshmanan, which determines the (KLEM) factor demand (capital, labor energy, and materials) and regional investments by sector.
- REGLEC: a model developed by Klein, and used for projecting employment variables (labor supply and demand, unemployment) and wage rates.
- DEMO: a model constructed by Caldwell; this is a micro-simulation model of the household sector, describing expenditure behavior.
- TRANS: a model for interregional transportation, constructed by Boyce.

Thus the field of integrated multi-regional economic-environmental-energy modeling is still underdeveloped; only in a few countries do such operational models for policy analysis exist. Apart from data problems, one of the major flaws in designing such models is of a methodological nature: how to combine spatial economic-environmental-energy variables in a coherent and consistent modeling framework?

As environmental and energy policy analysis usually takes place in a complex field with conflicting goals, various social interests, multiple decision groups and power structures, a methodologically sound policy analysis should take account of the multidimensional nature and energy problems (see Nijkamp, 1981).

In the remaining part of the present paper we will make an attempt at developing an integrated approach to regional-economic-environmental-energy policy analysis by using a so-called Multiple Layer Model (see Hafkamp and Nijkamp, 1982a, 1982b). It will be shown that recently developed interactive (integrated economic-environmental-energy) policy models appear to provide a promising perspective for an integrated multiple objective policy analysis. Two elements are central in such approaches, viz. efficient (or Pareto) solutions for conflicting objectives and interactive strategies among analysts and policy-makers. In this regard, it will also be demonstrated that multi-regional input-output analysis is a necessary ingredient for a meaningful and consistent framework for the above mentioned approach.

3. Interactive Multiple Objective Decision Analysis

In this section, a brief introduction to interactive multiobjective decision analysis will be given, as this approach makes up one of the corner stones for working with the above mentioned class of Multiple Layer Models. Interactive decision analysis is one of the fruitful results of modern computer technology. This approach to decision analysis aims at including, in a step-wise manner, various political (or subjective) considerations in formal optimizing models characterized by multiple policy objectives. A basic feature of this approach is that after the specification of (conflicting) objectives and the identification of a feasible (not necessarily the most desirable) compromise solution, a set of additional policy desires (for instance, minimum achievement levels, reference points, or aspiration levels) may be introduced in order to find new feasible compromise solutions that are more satisfactory and may lead to an acceptable final choice.

Interactive approaches have several advantages: a closer involvement of actors in the choice process, a procedural view of planning, a 'satisficing' instead of an optimizing behaviour, a greater flexibility by means of simulation experiments or scenario analyses, and a greater potential for practical applications (especially because no policy weights have to be specified a priori). The majority of these interactive approaches are based on a reference point (or ideal point) optimization technique, in which an attempt is made at minimizing the discrepancy between a series of points on the efficiency frontier and a (series of) reference point(s). It has to be added that especially procedural interactive policy analyses may be very helpful tools in policy negotiations regarding conflicting issues.

Some essential elements of interactive multiple objective decision analysis will now briefly be described.

Suppose a general (implicitly specified) model containing a vector of decision variables $\underline{z}$ (instruments, e.g.), of policy target variables $\underline{w}$ (with elements $w_i, i=1, \dots, I$), of other endogenous variables $\underline{x}$, and of exogenous data $\underline{v}$:

$$\underline{f}(\underline{z}, \underline{w}, \underline{x}, \underline{v}) = \underline{0} \quad (3.1.)$$

By solving this model for the endogenous variables $\underline{w}$ and $\underline{x}$, the following reduced form for the targetvariables may be assumed:

$$\underline{w} = \underline{g}(\underline{z}, \underline{v}) \quad (3.2.)$$

In addition to (3.2), a set of constraints (technical, social, political, economic, etc.) on the whole system may be defined:

$$\underline{z} \in K \quad (3.3.)$$

where K represents a feasible area for the variables at hand.

Then an efficient (non-dominated or Pareto) solution may be defined as follows: $\underline{z} \in K$ is efficient, if no $\underline{z}^* \in K$ does exist, such that:

$$\begin{aligned} \underline{w}^* &= \underline{g}(\underline{z}^*, \underline{v}) > \underline{w} \\ \text{and for some } i: \\ w_i &= g_i(\underline{z}^*, \underline{v}) > w_i \quad i \in \{1, \dots, n\} \end{aligned} \quad (3.4)$$

consequently, an efficient solution supposes that no other feasible policy exists, which is equally good for all policy criteria and better for at least one criterion (cf. Despontin, 1980; Nijkamp, 1978, 1980). In general, one may impose the condition that any good policy mix is an efficient solution, although it is clear that in practice inferior solutions may occur (for instance, in case of X-efficiency). Nevertheless, a meaningful policy analysis should focus the attention in particular on the efficiency frontier (or Pareto curve) in order to identify a policy that will not be dominated by other policies. This is especially important in the framework of interactive policy models which usually aim at identifying in a stepwise fashion a compromise solution located on the efficiency frontier. The identification of a 'satisficing' (compromise) solution is however, a far from easy task.

Fortunately, in the field of mathematical programming and mathematical economics, much progress has been made in recent years to formulate operational optimization procedures for decision problems with multiple objectives (see among others, Keeney and Raiffa, 1976; Cohon, 1979; Rietveld, 1981, and Nijkamp and Spronk, 1981). At present, there is a whole spectrum of different multiobjective methods available, in both the field of continuous programming analysis (see, e.g. Nijkamp, 1979) and of discrete plan and project evaluation methods (see, e.g. Voogd, 1983).

It should be noted however that many multiobjective decision procedures designed in the recent past have not been specifically designed for public-economic decision-making. The usefulness of these diverse methods and procedures for public-economic policy analysis depends very much on the way prio-

rities and conflicts of public actors can be taken into account. With respect to this issue, it may be meaningful to make a distinction between methods and procedures according to the information available on the decision-maker's preferences (see, e.g. Hwang and Masud, 1979). Three cases may then be distinguished:

(1) full information, (2) limited information and (3) no information.

Especially in case of limited or zero information, interactive procedures may be very helpful. In this regard public decision-making also has a learning process. It is worth noting that many problems in an integrated policy analysis do not require an unambiguous solution that represents once and for all the optimal state of the system concerned: compromise strategies appear to prevail. In light of the process character of many decision problems, an interactive policy analysis may therefore, be a reasonable and operational approach. This approach is usually composed of a series of steps based on a systematic exchange of information (based on computer experiments) between decision-makers and analysts. Such interactive approaches are normally characterized by the following pair of steps:

- the analysts propose meaningful and feasible (trial) solutions on the basis of a well-defined compromise procedure.
- the decision-makers respond to each (trial) solution by indicating in which respect (i.e., in regard to which effects) the proposed compromise is still unsatisfactory (given their views on minimum achievement levels, aspiration levels, etc.).

These pairs of steps are then successively repeated, until after a series of computer experiments, a convergence is assured and a final satisfactory compromise solution has been identified. As mentioned before, a large number of interactive models has recently been developed (see among others, Rietveld, 1981 and Spronk, 1981). Interactive policy analyses based on multiobjective programming methods have already demonstrated their significance in various policy problems, also in a public-economic context. No doubt, they may be regarded as having many significant advantages compared to traditional optimization methods (see Nijkamp and Spronk, 1981).

In the present paper, only one specific type of interactive policy method will be dealt with, viz. the method of displaced ideals (see Zeleny, 1976 and Nijkamp, 1980). Figure 1 provides a concise presentation of the steps in this interactive optimization procedure. More details regarding this method can be found in Hafkamp and Nijkamp (1982b) and Hafkamp (1984).

The abovementioned procedure can also be aligned to scenario analyses for economic policy-making. A scenario is a consistent set of prospective values of plans, goals, instruments and exogenous circumstances. Both single and compound scenarios may be dealt with. Choices among different scenarios may also be generated by means of the above mentioned interactive multiobjective methods.

Fig. 1. Steps of an interactive optimization procedure

After this concise discussion of the basic elements of interactive decision analysis, the next section will be devoted to the design of some foundation stones for the operational Multiple Layer Model used in the sequel of this paper.

4. Principles of Multiple Layer Projection

Multiple layer projection is an aid for modelling a system in which spatial economic, environmental and socio-political aspects are to be integrated. The spatial element implies that the system is analyzed at the level of regions interacting with the national level. Consequently, a Multiple Layer Model (MLM) is a national-regional economic environmental model. A MLM is the

result of projecting a complex real-world system on (three) mutually interacting parallel layers or dimensions:

- an economic layer
- an employment layer
- an environmental layer.

Clearly, the number of layers may be higher than three.

Several aspects of a complex and multidimensional system can thus be depicted in various submodels, according to their respective different aspects and consequences.

In addition to a set of layers representing a relevant cross-section or submodel of a complex system, one also needs a methodologically sound design method for an integrated model.

The design strategy of MLM implies a three stage procedure, where first a simple model is constructed, so as to depict the multiple layer structure and to delineate the scope and detail of the model, for instance, by means of simple graphs, (see also Hafkamp, 1984). The second step of the design procedure is the construction of a conceptual multiple layer model. The conceptual model presents the most important actors and their behavioural mechanisms in a non-operational and unspecified form. This second step is described in the present section. The third step, assembling the operational multiple layer model, is dealt with in the next section. This three-stage design procedure is akin to Hempel's 'bridge' principle.

The conceptual model presented here is a multi-regional model of an economy where economic, socio-political and environmental aspects of a society are of main importance. Public decision-making and planning in such a spatial system will be analyzed in a way analogous to allocation mechanisms in formalized economies with public goods and external effects (see also Ruys, 1975). We shall explicitly deal with groups of individuals belonging to a certain region of the spatial system and to a certain interest group (e.g., environmentalists, labour unions).

Conceptually, the model has the following structure. The spatial system consists of a set of regions:

$$\bar{R} = \{1, \dots, R\} \quad (4.1)$$

The elements which are important for regional decision-making are income, employment and environmental quality. We shall adopt the following formal notation for conceivable states of the system:

$$\begin{aligned} \underline{x}_r &= (y_r, l_r, z_r), r \in R & \} \\ \underline{x} &= (\underline{x}_1, \underline{x}_2, \dots, \underline{x}_R) & \} \\ \underline{x} \in X & \subset R^{3 \times R} & \} \end{aligned} \quad (4.2)$$

$\underline{x}$ is an R -tuple of vectors describing the state of the entire spatial system. $\underline{x}_r$ is a vector describing the state of the system for region r , where y_r denotes regional income, l_r denotes regional employment and z_r denotes regional environmental quality

We assume that a region's welfare position is determined by regional income, employment and environmental quality, without being affected by the welfare position of other regions (no jealousy effect). In this framework we abstain from the intraregional choice process per se. Therefore, instead of defining a regional welfare function, we do assume that a region(al authority)'s choice for one or more of the region's objectives can be made, according to a well-established choice rule:

$$C = \{ \underline{c} = (c_1, c_2, c_3) \in R_+^3 \mid c_1 + c_2 + c_3 \leq 1 \} \quad (4.3)$$

If a region r is presented with a specific state $\underline{x}$, with a regional characteristics vector $\underline{x}_r$, it may for instance, indicate that regional environmental quality is to be improved most urgently by choosing $\underline{c}_r = (0, 0, 1)$. If the region cannot decide between an improvement of regional income and regional environmental quality, it will choose $\underline{c}_r = (\frac{1}{2}, 0, \frac{1}{2})$. Thus $\underline{c}_r$ may be considered as region r 's 'choice budget'. In the context of this paper we will not discuss the regional preference orderings. Further details on the aggregation of individual preferences to regional preference orderings are found in Hafkamp (1984). Here, we define regional preference orderings broadly as:

$$P_r: X \rightarrow X \quad P_r(\underline{x}) = \{ \underline{x} \in X \mid \underline{x} \succ_r \underline{x} \} \quad (4.4)$$

where $\succ_r$ is used to denote that state $\underline{x}$ is preferred by regio r over $\underline{x}$; $P_r(\underline{x})$ is the set of states preferred over $\underline{x}$.

Regions, of course, would like to see their objectives (income, employment and environmental quality) at a maximum level, simultaneously. In reality this is impossible; not all desired states are equally and simultaneously attainable. We adopt the following notation for attainable states of the spatial system:

$$\left. \begin{aligned} \underline{s}_r &= (y_r, l_r, z_r) \quad r \in R \\ \underline{s} &= (\underline{s}_1, \underline{s}_2, \dots, \underline{s}_R) \\ \underline{s} &\in S \subset X; \underline{s} \text{ is compact and convex} \end{aligned} \right\} \quad (4.5)$$

Various policy mixes (combinations of regional economic policy, environmental policy, and labor market policy) are assumed to enable a central authority to "control" the spatial system so as to reach, in principle, any situation which is reflected by an element of S . The spatial system, composed of regions, can now be concisely characterized by:

$$EE = \{\bar{R}, (X, C, P_r), S\}$$

A state of the system is called Pareto-optimal, if an improvement of any region's welfare position is only possible (i.e., within S) through affecting at least one other region's welfare position. It should be noted that here an efficiency criterion is defined rather than an equilibrium criterion. The set of Pareto-optimal solutions is also known as the set of efficient or non-dominated solutions. The presence of different interest groups that want to maximize respectively regional income, employment or environmental quality makes it impossible to identify one single overall best solution. Consequently, formally a multi-decision-maker, multi-objective problem has to be solved in order to achieve a state of the system that is a compromise for the conflicting interests among groups and regions. This can be done by using the interactive method based on displaced ideals and described in Section 3.

The steps of the interactive compromise procedure are already contained in fig. 1. A more detailed description of the way a MLM is coupled with an interactive multi-objective procedure is contained in Hafkamp (1984).

5. An Operational MLM-model for an Integrated Economic-Environmental System: TLM.

The operational MLM-model is called Triple Layer Model (TLM), since it is composed of three sub-models - one for each layer: an economic, an employment

and an environmental sub-model. A detailed discussion of all equations, variables and data of these sub-models can be found in Hafkamp (1984). In this section we only discuss the main lines of the various sub-models.

The economic sub-model comprises a national-regional economic model of the Dutch economy. It is the result of coupling the so-called Secmon-model (see Driehuis, 1978) with a multi-regional input-output model of five Dutch regions. The following goal variables are included in this sub-model: inflation, current and capital accounts, and economic growth. Policy instruments are: taxes and public expenditure, monetary instruments, exchange rate, wage and price control. Economic factors are: households, firms, government and other agents.

The relationships between the components of the economic sub-model are described by means of 8 modules: production (based on input-output tables); final demand (consumption, investment, public expenditure and exports); imports (final products, raw materials and manufacturing inputs); production capacity; wages and prices; income; government expenditure and social insurances; monetary system. An extensive description of the economic sub-model can be found in Hafkamp (1982, 1984). Here only a summary of the model will be given.

The employment sub-model analyzes primarily the demand for labor at both a regional and sectoral level. For the time being, the supply-side of the labor market is considered exogenously determined by demographic and social developments. It would be worthwhile however, to include more detailed information on demographic developments, education and training endogenously in the model.

The environmental sub-model describes 3 aspects of environmental quality:

1. Emission of air pollutants caused by:
 - a. combustion of fossil fuels
 - b. process emissions, etc.
2. Concentration of air pollutants (via diffusion)
3. Reduction of emission by:
 - a. energy saving, selective growth, etc.
 - b. alternative choices of energy sources
 - c. anti-pollution technology.

The way in which the components of these 3 modules are linked is represented in fig. 2.

Fig. 2: The Triple Layer Model, sub-models and major policy impacts.

Pollution of water and soil is not taken into account here, nor is any attention being paid to the phenomenon of synergetic effects. The following pollution categories are taken into account: sulphur dioxide, nitrogen oxides and dust particles.

The choice of energy source also has an important influence on the emission of air pollutants. For example: SO₂ emissions in the Netherlands decreased drastically after a large-scale introduction of natural gas, but since a switch back to coal or oil took place, a drastic increase occurred. Especially the shift of electricity plants 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.

6. Interactive Multi-objective Programming with the Triple Layer Model

In this section, we will apply the interactive compromise procedure introduced in Section 3, to the operational version of TLM.

In the model five major Dutch regions are distinguished, with three objectives each -- income, employment, and environmental quality. This means that the compromise procedure produces compromises between regional interests as well as between objectives at the regional level. Therefore, a multitude of versions of the procedure could be designed so as to reflect a variety of institutional arrangements under which socio-economic decision-making takes place. These institutional arrangements may imply that a single authority, viz. central government, is a centralized decision-maker. They may also imply that decision-making is entirely left to regional planners, whose decisions, votes, wishes, and actions are added up only at the central level. Various intermediate arrangements are possible as well, and can be described as multi-level decision-making procedures (see in particular, Rietveld, 1981).

The basic version of the interactive procedure involves a separate optimization of all 5 x 3 objectives at every iteration, while a choice can be made in the procedure between fast convergence ($\phi=1$; this parameter will later be discussed) and slow convergence ($\phi<1$). Simplified versions of the procedure, for instance, optimizing separate objectives only at the national level in each iteration and adjusting the constraint set for objectives at the national or regional level, are possible as well (see Hafkamp, 1984).

Since the Triple Layer Model has approximately 500 endogenous variables, it would be very inconvenient to present the results of each simulation run for all these variables. Therefore, throughout this Chapter, we shall express the values of the objectives as index numbers. As a base for these index numbers, a feasible solution for the model is used which is found by setting all instrument variables at a fixed, zero value.

In order to demonstrate the interactive compromise procedure we will now discuss it step by step -- using figure 1 as a guideline -- for several successive iterations.

1) Start

The structure of the decision problem is specified for multi-objective optimization using a computer optimization package (the APEX optimization package by CDC). The selection of unsatisfactory values of objectives is to be done by the decisionmakers themselves. For example, they may follow a negotiation procedure if they are regional planners. If they are the inhabitants of the regional system, they may use a voting procedure, or any intermediate procedure between negotiating and voting. In our application of the compromise procedure to the operational version of TLM, we have adopted a simulation approach rather than actually having regional planners or voters indicate their choices, so that we have only assumed a potential outcome of a negotiating or voting procedure. The interactive compromise procedure thus carried out only provides a tentative scenario for a simulation experiment in a multi-objective decision-making context. We have carried out the procedure with a convergence speed parameter $\phi = 0.50$. The significance of this parameter will be discussed at step 6, where the constraints set is adjusted.

Iteration 1

2) Calculate Pay-Off Matrix

The pay-off matrix is found by optimizing consecutively all 15 objectives. Every single optimization of these objectives leads to one column of the well-known payoff matrix, which is shown in Table 3.

Table 3: Pay-off matrix of iteration 1. Separate optimization of objectives: income, employment, and environmental quality at a regional level.

Regi.	max y1 max z1 max z1	max y2 max z2 max z2	max y3 max z3 max z3	max y4 max z4 max z4	max y5 max z5 max z5
1	y1 127 116 95	y1 118 116 118	y1 112 118 120	y1 116 116 121	y1 104 116 119
	z1 115 116 114	z1 116 116 112	z1 114 116 110	z1 110 116 110	z1 110 116 110
	z1 84 81 117	z1 96 81 98	z1 83 81 96	z1 96 81 98	z1 82 81 98
2	y2 128 131 132	y2 133 131 99	y2 127 132 131	y2 126 131 130	y2 111 132 133
	z2 115 115 114	z2 115 116 112	z2 114 115 111	z2 115 115 110	z2 109 115 110
	z2 86 74 83	z2 80 74 113	z2 73 74 83	z2 90 74 83	z2 81 74 83
3	y3 117 120 117	y3 117 120 118	y3 122 119 91	y3 116 120 115	y3 103 120 118
	z3 116 116 115	z3 116 116 113	z3 115 117 112	z3 116 116 111	z3 110 116 110
	z3 88 78 88	z3 88 78 88	z3 72 78 116	z3 88 78 89	z3 89 78 89
4	y4 120 122 122	y4 120 122 123	y4 119 122 123	y4 127 122 94	y4 111 122 120
	z4 115 115 113	z4 115 115 112	z4 114 115 110	z4 115 115 109	z4 109 115 109
	z4 88 77 85	z4 90 77 84	z4 77 77 85	z4 82 77 114	z4 89 77 91
	y4 119 118 119	y4 120 118 119	y4 116 118 120	y4 120 118 120	y4 127 118 94
	z4 116 117 115	z4 116 117 113	z4 115 117 112	z4 116 117 111	z4 110 117 110
	z4 111 89 109	z4 109 89 110	z4 86 89 107	z4 109 89 109	z4 71 89 120

3) Generate Tentative Compromise Solution

In order to generate the tentative compromise solution, it is necessary to identify in the pay-off matrix the maximum and minimum value for each objective. This leads to the first and second column of Table 4. The compromise solution is now found by minimizing a standardized distance function which measures the distance between feasible solutions and the ideal, but infeasible maximum solution which is given in table 3.

$$\begin{aligned} \min d = & \left| \frac{127 - y_1}{127 - 95} \right| + \left| \frac{116 - l_1}{116 - 110} \right| + \left| \frac{117 - z_1}{117 - 81} \right| + \\ & \cdot \\ & \cdot \\ & \cdot \\ & \cdot \\ & \left| \frac{127 - y_5}{127 - 94} \right| + \left| \frac{117 - l_5}{117 - 110} \right| + \left| \frac{120 - z_5}{120 - 71} \right| \end{aligned} \quad (6.1)$$

Minimization of (6.1) leads to the compromise solution which is the third column of 'Iteration no. 1' in Table 4.

4) Compromise Solution Satisfactory?

As discussed in Step 1 of this procedure, we did not have actual decisions by regions or regional authorities on compromise solutions reached, so that a hypothetical scenario approach had to be used. At this point we assumed NO, implying that the compromise solutions of the first iteration were not satisfactory.

5) Identify Unsatisfactory Values of Objectives

We assumed that the following regional objectives had to be most urgently improved:

Iteration 1		
Region	Objective to be Improved	
1	income	y ₁
2	environmental quality	z ₂
3	income	y ₃
4	income	y ₄

6) Adjust Constraints Set

At this point in the first iteration, the constraints set is adjusted in such a way that in the next iteration the compromise values for the objectives selected under the previous step (5) will be higher than the actual compromise values given in Table 2.

The general formulation of raising lower bounds of objectives can be written

$$x^{L,i+1} = x^{L,i} + \phi(x^{C,i} - x^{L,i}); \phi \in (0,1). \quad (6.2):$$

where:

$x^{L,i}$: Lower bound on objective x in iteration i

$x^{C,i}$: Compromise value of objective x in iteration i

ϕ : Parameter denoting convergence speed.

The convergence speed parameter is to be set at the start of the interactive procedure. A high convergence speed ($\phi=1$) implies that from one iteration to the next one large improvements are found for objectives selected at step 5, while a final compromise may be reached in relatively few iterations, as relatively strong constraints are added in each iteration. For the present application of the procedure the convergence parameter was set at .50. Consequently the following lower bounds for objectives were added to the constraints set:

$$y_1^{L,2} = 95 + 0.50 (117-95) = 106 \quad 1)$$

$$z_2^{L,2} = 73 + 0.50 (88-73) = 80.5$$

$$y_3^{L,2} = 91 + 0.50 (115-91) = 103$$

$$y_4^{L,2} = 99 + 0.50 (118-99) = 106$$

$$z_5^{L,2} = 71 + 0.50 (94-71) = 82.5$$

¹⁾ This calculation of lower bounds is illustrative only; rounded off figures were used. According to Figure 1 we now proceed to the next iteration.

	Iteration no. 1				Iteration no. 2				Iteration no. 3				Iteration no. 4			
Region	Solutions Maximum Minimum Compromise				Solutions Maximum Minimum Compromise				Solutions Maximum Minimum Compromise				Solutions Maximum Minimum Compromise			
1	y1	127	95	117	y1	127.4	105.7	126.9	y1	127.4	105.7	121.2	y1	126.8	105.7	121.2
	11	116	110	115	11	115.8	107.7	115.6	11	115.8	108.4	115.2	11	115.8	109.1	115.2
	z1	117	81	108	z1	116.0	68.8	87.9	z1	116.0	78.4	102.4	z1	116.0	90.4	102.7
2	y2	133	99	131	y2	133.4	99.2	123.2	y2	131.3	99.2	117.6	y2	131.3	108.4	123.0
	12	116	109	115	12	115.3	107.7	115.1	12	115.3	108.0	114.8	12	115.3	108.6	114.7
	z2	113	73	88	z2	112.5	80.0	104.3	z2	112.5	92.2	107.1	z2	111.9	92.2	106.5
3	y3	122	91	115	y3	122.1	103.1	121.4	y3	122.1	103.1	115.6	y3	121.7	103.1	115.6
	13	117	110	116	13	116.4	108.0	116.2	13	116.4	108.3	115.8	13	116.3	108.4	115.8
	z3	116	72	95	z3	115.0	72.4	85.2	z3	115.0	78.8	96.9	z3	115.0	87.9	97.0
4	y4	127	94	118	y4	126.9	106.1	125.9	y4	126.9	196.1	120.1	y4	126.6	106.1	116.6
	14	115	109	115	14	115.0	107.5	114.7	14	115.0	107.9	114.4	14	115.0	108.4	114.3
	z4	114	77	96	z4	112.8	69.5	82.9	z4	112.8	77.2	93.5	z4	112.8	85.5	94.3
5	y4	127	94	122	y4	127.0	94.4	113.2	y4	127.0	120.1	125.6	y4	126.9	120.1	125.6
	15	117	110	116	15	116.6	108.0	116.3	15	116.5	108.4	115.9	15	116.5	108.4	115.9
	z5	120	71	94	z5	119.7	80.9	108.4	z5	114.2	80.9	92.7	z5	114.2	86.6	92.8

Iteration 2

2) Calculate Pay-off Matrix

The pay-off matrix is, again, found by optimizing consecutively all 15 objectives. The difference between this pay-off matrix and the previous one are entirely due to the fact that the lower bounds derived in step 6 of the previous iteration were added to the constraints set.

3) Generate Tentative Compromise Solution

The second compromise solution is found by minimizing the standardized distance between the unfeasible maximum solution (see Table 3) and the adjusted constraints set. The actual outcomes are contained in Table 4 as the second compromise solution.

The compromise values for regional objectives in iterations 1 and 2 give a rough approximation of the existing trade-offs in the operational version of TLM, the most noticeable being those between regional income and environmental quality: An improvement of 1 percent in environmental quality of regions 1, 2, and 5, roughly leads to a 0.5 percent loss of regional income. Regional employment appears to be quite invariant under the choices made, because employment policy can be carried out independently from policies that aim for either economic growth or environmental quality (both of which have favorable impacts on employment). The compromise solution of the first iteration caused the choice of priority in region 1 to move to regional income. As a result, the compromise solution of the second iteration shows that regional income was increased by 8.5 percent. Along with this increase of income came a sharp decrease of the environmental quality indicator by more than 18 percent. This sharp switch may result in a general tendency to support the environmental interest in the second iteration.

In region 2 a reverse trade-off was chosen. The first iteration indicated that there was strong support for environmental quality. The actual outcome, an 18 percent improvement of the environmental quality indicator against a decrease in income of more than 6 percent, may be very satisfactory to the core of environmentalists but, to many, this may be an "over-exchange". In this region the tendency may be to support the objective of regional income in the second iteration.

In regions 3 and 4, the choice for regional income resulted in a 6 percent improvement of income which is paid off by a decrease of environmental quality of over 10 percent. This choice situation is equiva-

lent to that of region 1. In region 5 a situation has arisen which is comparable to that in region 2. A choice for a better environment results in a strong improvement of the environmental quality indicator by 15 percent which is accompanied by a 7 percent decrease in regional income.

4) Compromise Solution Satisfactory ?

We assume the second compromise solution is not satisfactory.

5) Identify Unsatisfactory Values of Objection

The discussion of the compromise solution at step 3 allows us to assume the following objectives as 'most unsatisfactory' at the regional level:

Iteration 2	
Region	Objective to be improved
1	environmental quality z_1
2	environmental quality z_2
3	environmental quality z_3
4	environmental quality z_4
5	income y_5

6) Adjust Constraints Set

The constraints set is now adjusted in the same manner as in the previous iteration. New lower bounds are added to the constraints set.

Iteration 3

2) Calculate Pay-off Matrix

The pay-off matrix is derived in an analogous way to that of the previous iterations, taking into account the lower bounds on objectives which were raised in step 6 of the previous iteration.

3) Generate Tentative Compromise Solution

Generation of the third compromise solution is identical to that of the previous iteration. Actual outcomes are contained in Table 4.

4) Compromise Solution Satisfactory?

In order to demonstrate the procedure to its full extent we, again, assume that, the third compromise, is not satisfactory.

5) Identify Unsatisfactory Values of Objectives

We assume that environmental quality is to be raised in regions 1,3,4 and 5. In region 2 an improvement of income is assumed to be necessary.

6) Adjust Constraints Set

For the objectives selected in the previous step of this iteration lower bounds are adjusted according to the procedure described in step 6 of the first iteration.

Iteration 4

2) Calculate Pay-off Matrix

The fourth pay-off matrix is calculated in a way analogous to the previous ones.

3) Generate Tentative Compromise Solution

The fourth compromise solution is also contained in Table 4. Clearly, from the third to the fourth iteration the adjustment of the constraints set by imposing new lower bounds on selected objectives has induced only marginal changes.

5) Compromise Solution Satisfactory?

Now we assumed yes; of course, the procedure could easily be continued.

7) Tentative Compromise is Final Compromise

The abovementioned empirical simulation of the multiregional model with conflicting intertests is particularly interesting, this procedure involves a double trade-off, viz. conflicts between regions operating in the same national system and conflicts between policy objectives operating at both a regional and a national level. Clearly, from iteration to iteration, the interactive decision-making procedure does not only give information to the decisionmakers on the actual trade-offs

between objectives (as inherent to the model); but also allows the analysts to deduce, from the choices of (groups of) individuals, the actual preferences. However, in order to arrive at an accurate assessment of these preferences, it would be necessary to carry out the procedure over a large number of iterations. This interactive method may thus be an important learning mechanism in an integrated policy analysis.

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