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SYSTEM DYNAMICS PLATFORMS FOR INTEGRATED ENERGY ANALYSIS

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ABSTRACT

The energy field has been dominated in recent years by two different themes: on the one hand, the integrated approach to energy planning, and, on the other hand, the ownership structures for industries' management. This thesis investigates a broad range of problems arising in relation to these themes, including demand-side management, technology diffusion and supply-side management. It also reviews the corresponding approaches to assist the decision making process in connection with these problems.

It is shown here that there is a methodological vacuum with respect to the support tools for energy analysis due to emerging policy challenges in the energy field, and methodological solutions are proposed to this end. The contribution is thus primarily three fold: 1) a methodology to assist both policy analysis and strategic processes, 2) a systems platform to assess policy and strategy, and 3) evaluation of specific policy and strategic issues arising in the new liberalised environments being implemented in both the British and Colombian energy systems. In this case, methodological connections are appropriate as the Colombian Government has incorporated aspects of the British energy system set-up.

This thesis contains seven chapters. Chapter 1, from an extensive literature review, establishes a dilemma in relation to the methodology required to support system analysis and planning. Chapter 2 presents a new methodological proposal to meet the requirements. Chapter 3 concept-tests the proposal and specifies an analysis-support platform as a generic aid to modelling. Chapter 4 develops a case study for the UK energy system, partially testing the proposed approach and the analysis platform especially constructed for this situation. Chapter 5 elaborates upon a case study for the Colombian energy sector, examining in detail both methodology and the analysis platform uniquely designed for this case. Chapter 6, with the support of a platform construct, studies and assesses energy policies for Colombia. Finally, Chapter 7 summarises and concludes the major findings of this thesis.

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1 ENERGY SYSTEMS

The energy field has been dominated in recent years by two different paradigms. On the one hand, the complexity of energy systems has encouraged the integrated analysis and planning paradigm. This leads to "hard" modelling approaches advocated by researchers from engineering and economics disciplines. On the other hand, a recent trend towards a more liberalised environment moves away from central planning to market-based resource allocation, leading to the creation and use of strategic tools, with much "softer" specifications, in the "systems- thinking" tradition.

These ideas have posed dilemmas both at the ideological-political level, in terms of ways of handling complexity through integrated planning versus leaving the resource allocation task to market forces; and at the technical level, where the modelling approaches have produced antagonistic methods (econometric-engineering versus strategic-systems) as a result of the intention to support, assess, and evaluate policies and strategies for government, industries and business organisations. This thesis explores these dilemmas in depth and proposes solutions to this end.

1.1 SCOPE OF ENERGY ISSUES

Under a relatively plausible scenario, the world will reach a population of about 10.6 billion inhabitants by the year 2050, according to Eden (1993). This approximately doubles the population existing in 1990. The same author calculates the total energy demand at about 20.5 Gtoe (Gigatonnes of oil equivalent), by the middle of the next century, compared with 7.9 Gtoe in 1988. He claims that this may be reduced by as much as 40%, to around 12.6 Gtoe, under a special demand scenario which embodies targets for energy efficiency.

Assuming a rather more idealistic view, compatible with Eden's efficiency scenario in terms of total energy demand, Ettinger (1994) argues that this amount of energy could be supplied under 'stringent normative conditions' using natural gas (50%), non-conventional technologies (27%), hydroelectricity (19.5%) and traditional sources (3.5%). Although this is very unlikely from the market perspective, it can not be ruled out as technically infeasible.

Eden (1993), Schramm (1993), Abdalla (1994) and others claim that major efforts will be needed in the energy sector of both developed and developing countries, especially with respect to conservation, the diffusion of new technologies and schemes for financing generation capacity, to support even a satisfactory rate of world economic growth. Indirectly this raises questions of co-ordination, long-term views and systemic thinking. For developing countries, particularly, efficient energy expansion planning is crucial to fulfil economic growth and social well-being objectives. Furthermore, energy policy is still a controversial issue for developed nations, where it is driven more by environmental, regulatory and profitability considerations than by the need to support economic growth.

Planning is interpreted here not in the narrow sense of applying only to centrally administered, public sector energy systems, but, for both public and private market-based systems, as a flexible process to aid rational resource allocation when markets are known to be imperfect. In this case, price regulation seeks to incorporate externalities and subsidies, whilst anti-monopoly regulation seeks to ensure competitive pricing in the consumer interest. Yet there is recognition that regulated markets by themselves are not enough to ensure efficient energy policy in the overall national interest. For example, in the UK, Helm and Pearce (1990) and Helm (1993) argue in favour of co-ordination of regulation in the energy sector and state that markets are not sufficiently reliable to guarantee security of supply, have only a short-term perspective and do not account for externalities. Similarly, the US Energy Policy Act of 1992 establishes that all utilities are required to implement Integrated Resource Planning (IRP), which implies that a broad set of alternatives have to be considered, including rational energy use, rather than just committing a certain amount of resources for building new generation capacity.

Energy systems are complex. There is a multitude of important issues related to demand, supply, technologies, transport (transmission), distribution and the environment. The supply-side involves primarily a large variety of sources (such as oil, coal, gas, water and sun), used in energy production processes (thermoelectricity, hydroelectricity and solar panels), organised in industries with diverse ownership structures (public and private), operating in markets that depend on several mechanisms (bids, pools and trading rules), under a number of regulatory set-ups (environmental, financial and competitive).

The demand-side contains very many diverse forms of energy requirements, from all socio-economic sectors, given their needs for subsistence, development and progress. Energy transport and distribution systems create intricate links between production sites and end-users, and typically consist of electricity grids, gas and oil pipelines, and train and truck operations. One could say that energy depends on technology as much as technology depends on energy. Technology is vital to all stages of the energy process from exploration to development, production, transformation, transport, distribution and end-use. It is reflected in a broad variety of structures such as plant, equipment, tools, instruments, components and materials.

Finally, the environment is becoming a very significant issue in the energy sector, adding another perspective to this already clouded panorama. Its relevance will progressively increase in the years to come, because of its large contribution to pollution and to the global warming effect. Note that different interest groups intervene in these systems: Governments and non-government agencies, private and state-own suppliers, population pressure groups, consumers of all sorts, and international organisations.

Within this ample perspective two particular themes stand out, not only in terms of being significant but also because they pose serious dilemmas. One of these themes is complexity, which leads to integration and planning. The other is related to the recently created market liberalisation movement which is leading towards strategic organisational management. We will examine these issues in much greater depth.

1.1.1 Complexity in energy systems

The energy future in such a dynamic and turbulent environment is by no means clear. Some important and interrelated issues now emerge for both developing and developed countries, including:

- Power generation expansion
- Energy efficiency
- Demand-side management
- Energy substitution
- Efficient end-use energy technologies
- Technology propagation
- Energy transport
- Cultural and political aspects
- Exploitation of energy resources
- The environment.

Thus, almost any subset containing some of these issues becomes very complex because of: a) diverse and varied interrelationships, and b) the difficulties in specifying appropriate decision and policy frameworks. On the one hand, planning, regulation and state intervention options have shown allocative deficiencies in reducing these complexities. On the other hand, it is too early to favour overall market arrangements, as these still have a long way to go before proving their advantages and revealing their limitations. Within the former set-ups, the effectiveness of market performance and the capacity of governments to intervene through planning and/or regulation (to maintain relative equilibrium) is still unclear. Organisational structures, mid-way between fully liberalised and completely government-dominated may be among the alternatives most worth investigating.

1.1.2 Integrated energy planning versus markets

The objective of integrated energy planning is to achieve efficient production, transport and consumption of energy along with social goals, and this obviously includes environmental and financing constraints.

While there are similarities in the general approach among regions and countries, there are also particular features that must be taken into account for each individual nation. The policy emphasis and planning efforts are different for both developed and developing economies. The aims and extent vary substantially depending on the characteristics of each country. The state of development is also a major factor of concern. Furthermore, the degree of government involvement is an open issue in the current debate on public/private ownership. For example, in the UK, although the majority of the privatised industries are performing significantly better than under public management, there is media unrest and a call for more government intervention. Norway, Italy, Hungary, Chile, New Zealand, Indonesia, India, Brazil, Colombia and Australia either have taken steps in this direction or are in the process of moving towards privatisation schemes, but again political pressures are active against these changes and have partially succeeded in reducing government ambitions in some countries, as discussed in Tait (1995) and Flavin and Lenssen (1994).

It is not easy to predict the evolution of these economic liberalisation trends but even in the most industrialised countries it is not expected, in the medium-term, that major changes will occur with respect to technological barriers, externalities and information asymmetries. In this sense it seems necessary to subordinate market forces to the guidance of regulatory entities for proper system operation. Other factors working against liberalisation include strategic rationality (political and industrial competitiveness), the amount of investment in the sector (R&D), the environment, and the rate of depletion of natural resources.

While economic liberalisation is taking place in a number of countries, we are also seeing the virtues of Integrated Resource Planning (IRP) advocated in the US. Although the Energy Policy Act of 1992 requires all utilities to conduct IRP for new capacity, not enough has been accomplished in this area (Stevenson and Ray, 1993). Despite the arguments of Helm and Pearce (1990) and Helm (1993) and others in favour of policy co-ordination in the UK, the energy sector is moving away from planning, towards market forces, for resource allocation purposes. In India, Moulik (1992) established that regional energy analysis, appropriately integrated with national energy planning, would provide the necessary disaggregation for realistic planning and implementation. Nevertheless very little progress has been made in this direction.

In a more general framework, Munasinghe (1992) considers that an integrated approach favours successful policy analysis, planning, and implementation in the energy sector. This is mainly due to five factors: 1) the complexities of modern society; 2) the decision making process that must deal with a multiplicity of actors, criteria, levels, policy tools and impediments; 3) the links between the energy sector and the rest of the economy; 4) the interactions among subsectors, including substitutions between sources; and 5) the need to incorporate the regional/spatial dimension.

Supporting an integrated approach to planning, Meyers et al. (1993) found that past plans have proven somewhat optimistic in a study of nine nations that account for some 55% of the total electricity generation in the developing world. This research also ascertained that financial, institutional and environmental constraints have made it difficult for these countries to achieve the planned goals. In conclusion, the authors favour co-ordination to assure sustainable economic and social development and the best use of limited resources.

The tensions between liberalisation and integrated planning have also been noticeable in Latin American nations. While Argentina was pursuing planning at the national level (Guadagni, 1986), and Brazil was advancing towards regional approaches to planning (FINEP, 1985), Chile was already engaged with the idea of competition and markets (Bernstein, 1988). Also in this part of the world, Colombia moved away from very precarious forms of planning, as exhibited in the National Energy Study (ENE, 1980) and in Basis for Formulating National Policies on Energy (DNP, 1986), to a much more modern approach as indicated in the National Energy Plan (PEN, 1994), which envisages a more competitive environment.

1.1.3 The policy-strategy dilemma

Given the recent, profound, transformations taking place in energy systems around the world, it is too early yet to anticipate the final outcomes of these experiments. No one claims to have a long term perception of the likely structural arrangements, the dominant ownership set-ups and the most widely used instruments for managing energy resources. This is mainly due to the immense external forces and multiple objectives involved, as well as for the large number of open policy options.

In spite of recent trends, the solutions found so far seem to be unstable. Many changes have already occurred, yet even more profound transformations appear likely only a few years ahead. These, along with the environmental issues, have implications difficult to assess due to the vast impact on society at large and their linked political consequences. The emerging ideological and political tensions pose difficulties leading to the following dilemmas:

- Ownership and privatisation
- Market forces formation
- Regulation and planning
- National-regional dimensions.

The traditional tools for analysis appear to be discredited in the present turbulent environments (see for example Lee et al., 1990). Integrated approaches may be part of the solution in this respect, but there is still a long way to go in terms of the development of the appropriate methodologies to support the processes involved. Thus, major questions remain with respect to:

- Analysis and planning methodologies
- Modelling processes
- Evaluation of strategy and regulation
- Assessment of uncertainties
- Model credibility.

1.2 MODELS AND PLANNING

In the energy field there is a long tradition of using a variety of modelling approaches to support policy making, strategy formulation and planning. Nevertheless, there are many contentions in relation to the different dimensions of this activity:

- Detail versus aggregation in relation to size and to integration of components or co-ordination of sub-models.

- Life span of modelling tools relates to the re-usability of models or to the development of analysis frameworks for individual, isolated questions troubling an organisation.
- In-house development or external support address the question of ownership and responsibility.
- Type of end-user. End-users, except for specialists, will need transparency, friendliness and interfaces.
- Decision making or policy support may call for either detail calculations (precision) or broad behaviour patterns (insight).

These issues are reviewed in more detail in the following sections and chapters.

1.2.1 The modelling experience

In general, the industrialised countries make extensive use of models to support planning processes and/or policy making in the energy sector, whilst the least developed countries make much less use of modelling, in spite of the pressures exerted by multinational agencies, such as the World Bank.

Large-scale optimisation and econometric simulation are perhaps the most widely used techniques to support planning and policy making at the subsectoral level (for example in the electricity and oil industries). Optimisation tools such as MARKAL (Goldstein, 1991), have been extensively used throughout the world. Similarly, econometric modelling has been broadly practised for many decades, and special decision support systems such as ENERPLAN (Murota et al., 1985), have been implemented to aid model building in a few developing regions. What is true for both developing and developed countries is that these activities tend to be conducted separately by the great majority of analysts and energy planners.

Linkages between modelling techniques or within model components tend to be weak and sparse. At one extreme of the spectrum, using a non-linear equilibrium approach based on classical economic theory, NEMS (EIA, 1992) and ENPEP (Buehring et al., 1991) are coming to the forefront in the United States and some developing economies. These large systems balance supply and demand by way of energy prices.

At the other extreme, based on feed-back and behavioural economic theory, System Dynamics (SD) has been applied selectively, since the late seventies, to support US energy planning and policy making (Naill, 1992). There have also been isolated applications of SD both at the national as well as the regional level in Europe, Asia, Africa and South America. In these cases, links to other methodologies have been uncommon and modularity has rarely been an issue. Section 1.4 will introduce SD applications in the energy field, but point to the need for it to provide a platform for greater model integration than has been characteristic up until now.

1.2.2 Critique of the current planning technology

At one level of interpretation, the analysis of options for Integrated Energy Planning can be seen as the management of links between separate, conventional energy planning models (e.g. the National Energy Modelling System - NEMS). In this context, large scale optimisation and econometric techniques are perhaps the most widely used functional techniques to support various aspects of planning and policy making at the subsectoral level (for example electricity, oil, transportation). But when one looks at the characteristics of these conventional approaches, a number of methodological limits become apparent. Sterman (1985) makes a critique similar to the one summarised below.

Normative and Directive. In this sense the solutions are prescriptive and the planning methods associated with them tend to be **normative**. The methodology makes no assessment of the social efforts needed nor the way things can be done, nor the participative, organisational or political limitations of achieving solutions via compromise.

Deterministic. The optimum is the main goal and it is usually considered unique, despite the often observed situation of "flat optima" in large scale models. After sensitivity analyses and robustness tests are performed there are generally no further questions on the adequacy of the solution found. There is almost no explicit consideration of the uncertainty of the parameters and the associated risks. Expected values are used, or runs with exogenous sample variants may be performed, but with the present state of the art it is not computationally realistic to include many random variables endogenously.

Linearity. For computational reasons and because of problems of specification, most optimisation and econometric techniques are predominantly linear in their parametric relationships. This limits the possibility of considering higher order interactions between variables, for example.

Absence of Feedback. Most strategic modelling in other business contexts require the use of feedback dynamics to aid policy making, but such capabilities are not common within conventional energy analysis methods. Issues such as delays in decisions, and the corresponding organisational reactions, will thus not be incorporated in a systemic fashion.

Mechanistic and Non-Behavioural. Since strategic and human behaviour are not modelled, there is very little room for social, organisational and political considerations within the classical framework. This may be particularly relevant to modelling consumer behaviour effectively in demand-side modules, for example.

Stationarity in Model Induction. The econometric approaches generally used to project energy demand make strong assumptions about systems stability. So in general, the system structure and the corresponding parameters are assumed to remain invariant for long-term forecasting. However, the history of energy policy has demonstrated major structural changes and technology switches. If nuclear is not an alternative source to oil and gas by the year 2050, the energy market will comprise a large selection of new competitive sources. Historical trends will clearly not work. In general, parameters, such as elasticities, remain fixed during the simulation period, when in some developing countries, for example, it is known that the production systems will become more electricity intensive or that electricity prices will have a much larger weight in the final production costs. Also, change of ownership and the development of competitive markets is having an important effect on energy production systems and price rates. Demand patterns will change and energy efficiency may penetrate more rapidly. Reserve margins and system reliability may vary significantly. With these very important structural differences, medium and long-term forecasts cannot be obtained just by projecting historic behaviour. Indeed, with newly-engineering markets, econometric techniques may completely lose their power in the absence of suitable data sets for model estimation.

Thus, the classical approaches exhibit many drawbacks. They do not assume a systemic method, in terms of information feed-back and systems control. Furthermore, abundant data is not always available during these transitional periods and, when it is accessible, there is concern about its reliability. Complementary methodologies may be capable of supporting energy planning and analysis in search of 'satisfactory' solutions containing the social, political and economical realities of the community.

1.2.3 Alternative approaches

Energy specialists, both academic and practitioners, have been confronting a particularly troublesome environment since the oil embargo in the early seventies. The main conclusion drawn by Lee et al. (1990), Wack (1986) and many others, when analysing these events, is that they produced significant social, economic and technological impacts, creating considerable volatility and making changes unpredictable. Lee et al. (1990) argue that the energy experts have not developed appropriate methodologies to make adequate links between different events, as the ones they possess depended on stable conditions. Furthermore they claim that analysts have been traditionally overconfident of the results produced by optimisation techniques, that the assumptions have not been verified carefully enough, and that the models tend to be excessively large.

Experiments conducted at the International Institute for Applied Systems Analysis (IIASA), using a complex model to assist the decision making processes, came up with the following set of conclusions and recommendations (Lee, 1989):

- Boundary conditions are more important than analytical quality
- Quantitative analysis alone leads to under-utilisation
- End-users should intervene early
- Identify a small set of clue variables
- Modify systems for specific users
- Constantly verify suppositions
- Not everything can be covered by mathematics
- Test findings continuously
- Build simple models.

By and large, this critique was already formulated during the middle of the 1950s with Simon's bounded rationality (Simon; 1955, 1979, and 1990) and with similar behavioural paradigms. The ideas of approximate rationality, intended rationality and bounded rationality had not been incorporated into any major field until the recent advent of Complexity during the eighties (Arthur; 1989 and 1990). There is a great amount of exploratory research being conducted in this field at the present.

The required approach should be able to integrate supply-demand, competition, technology diffusion, 'rational' energy use, efficiency, substitution, losses, cultural aspects, environmental issues and the national-regional dimension, yet still be 'transparent'. It should provide support for policy analysis under profound structural changes in the sector and under uncertainties in relation to the future.

This methodology should allow relaxation of some of the constraints in econometric models, introduce socially satisfactory decision-making rules and provide insights of the socio-economic barriers to technology penetration; and these coupled in a systemic mode by considering feed-back effects from the environment. In this context the new technologies may be capable of handling dynamic environments, under uncertainty. Thus, features such as flexibility and adaptability, which serve the purpose of being easy to update, are strongly desirable for addressing emerging interrelated problems.

1.3 MODELS FOR INTEGRATED ENERGY ANALYSIS AND PLANNING

Integrated analysis for intervention may be a possibility to assist energy management. Models to support it are fundamental. The problem is then far from being trivial. The reason is the complexities of the system.

Figure 1.1 shows some of the most important relationships that take place in energy systems. As illustrated, increases in economic growth lead to increases in energy demand, which on the one hand, makes further use of installed capacity, and leads to a reduction in the cost of energy and a further increase in energy demand. On the other hand, however, increasing use of installed capacity diminishes spare capacity, which generates investment incentives. Now, subject to financial restrictions, there is a resulting increment in energy supply, increasing energy cost (because of the need to pay investments) but decreasing energy demand. Also note that depletion of energy capacity contributes to conservation and that environmental impact stimulates energy alternatives.

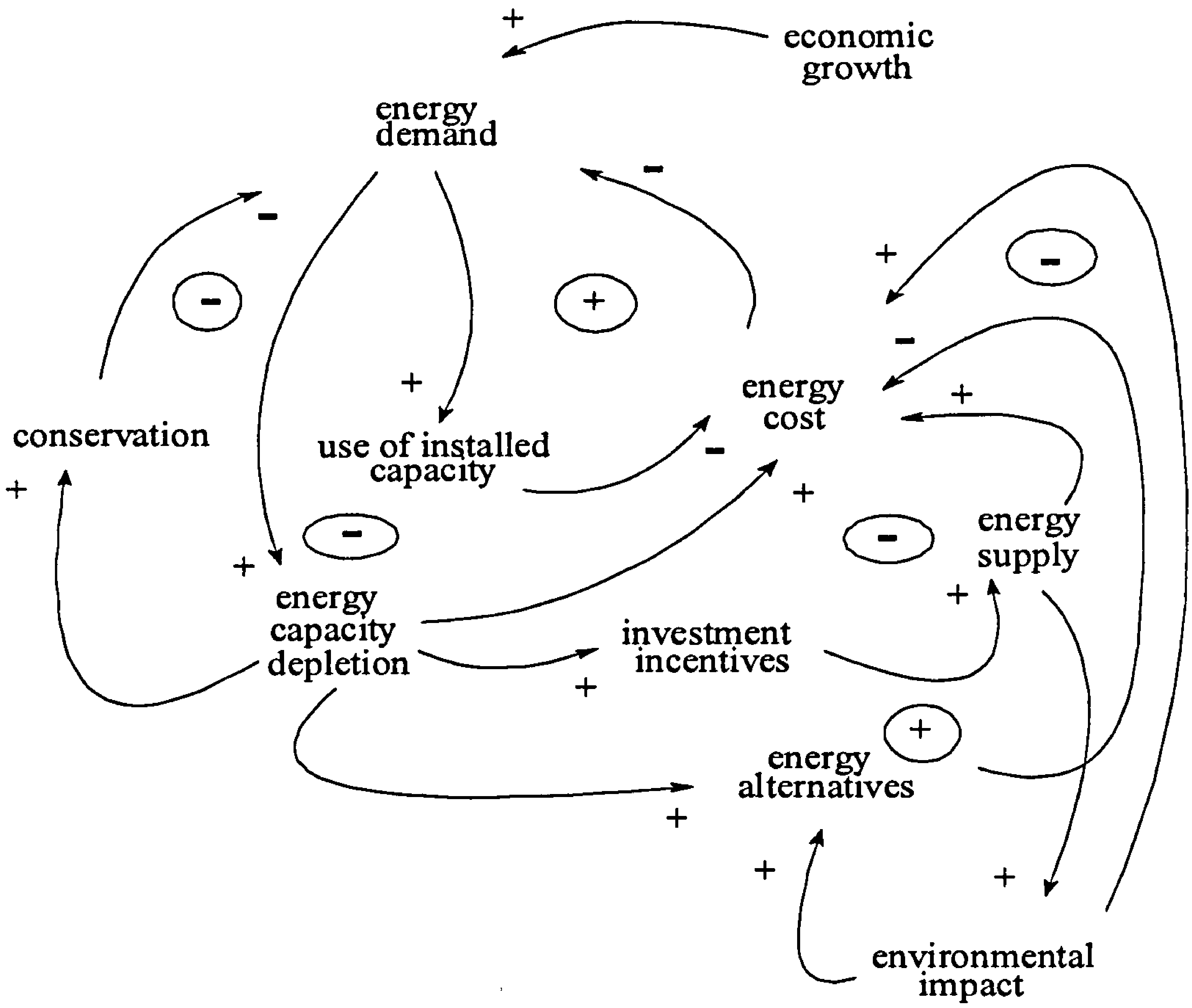

Figure 1.1 Energy dynamics

There are many techniques being used but not all of them are adequate to support integrated energy analysis and/or planning. The required tools are not abundant. The problem will be to develop the appropriate approach. A single universal model does not seem to be a feasible solution. The answer may lie in models that take care of some relevant issues and a process for integrating models to observe some important interrelationships.

Nevertheless, not all methodologies and technologies may be considered. They should be capable of integration in a systems mode, to couple subsectors and hierarchies (Government-regions), to incorporate other sectors, and to include future uncertainties. In what follows, the emerging dilemma of planning-versus-markets will be discussed further, especially in the context of modelling-analysis themes.

1.3.1 Integrated energy planning

In recent years integrated energy planning has emerged as an instrument to reduce the complexities of energy systems, given the drawbacks exhibited in classical planning approaches, as reported earlier. The new paradigm primarily intends to incorporate other dimensions into system capacity expansion and organisational management - this includes alternatives for rational energy use and abatements of environmental impacts.

Rational energy use and efficiency

Rational energy use, demand-side management (DSM), energy efficiency and energy conservation have been mainstream issues since at least the early 80s (Sioshansi, 1995). In general there has not been a clear distinction in the terminology used when addressing these problems. This thesis differentiates the alternative management issues to this end in the following chapters. For example, the problem of subsidies in electricity tariffs is handled together with the introduction of efficient energy sources and concurrently with the analysis of obsolete end-use appliances. These will aid in identifying a number of strategies with the support of specific models.

Success in this area has been partial in spite of the large amount of money invested in DSM programmes and projects. The literature is vast and comprises a wide variety of topics ranging from the socio-psychological perspective to very detailed financial accounting of programmes.

Hassett and Metcalf (1993) prove that under some general hypotheses, for energy conservation investments, end-users tend to assume discount rates that could be as much as four or five times as high as market rates, in the absence of uncertainty. This is basically due to market imperfections. The authors finally argue that energy-efficiency standards or taxes on energy consumption may be the most effective DSM policy option. In a later article, Metcalf (1994) proposes to differentiate window shoppers from crisis shoppers for a better understanding of customers and, consequently, to boost policy effectiveness.

Sathaye and Gadgil (1992) illustrate abundant opportunities for saving electricity mainly in the residential, industrial and agricultural sectors. Although there is a specific reference to the Indian case, a good number of the arguments are valid elsewhere. Barriers to energy-efficient programmes and the corresponding policies to overcome them are presented.

Gellings et al. (1991) take a long-term perspective and evaluate the potential energy savings from efficient technologies. The paper concludes that the maximum penetration goal for the most efficient technologies in the US can lead to savings of up to 43% by the year 2000 (the base year is 1987).

Contrary to what has been found by other researchers, Long (1993) has strong statistical evidence, based on a very large sample, that households in the US increase conservation as soon as they perceive reductions in their energy bill. This makes sense of the public subsidies to DSM programmes.

In the mid-eighties Coltran et al. (1986) investigated the social-psychological foundations of successful energy conservation programmes. The findings lead to the important key variables: vivid information and credibility. The authors emphasise that commitment may be the most important element of successful conservation efforts.

Sioshansi (1991) establishes the difficulties in implementing energy efficiency policies. This paper is mainly concerned with under-investment and organisational issues. It favours third parties for the task of handling energy efficiency programmes, but this view is not necessarily shared by many other authors.

Many researchers have studied the issue of barriers to energy end-use efficiency. Lohani and Azimi (1992), Anderson (1993), Sanstad and Howarth (1994), Sioshansi (1994) and Nilsson (1994) explain the most widely accepted arguments among researchers. Lack of information, organisational deficiencies, financial constraints, low electricity price and price uncertainty are perhaps the most important factors.

On the promotion side, whilst Gadgil and Sastry (1994) report an unsuccessful attempt to draw attention to the use of fluorescent lamps in India, Sathaye et al. (1994) relate a successful conclusion to the very same issue in Mexico. In the same context the failure of the Swedish case (Swisher et al., 1994), is based on the low electricity price and not on political or institutional issues.

Within the planning framework, DSM programmes are being integrated into the expansion plan for power generation in both developed and developing nations across the world. In this sense, DSM projects may be assessed on their individual merits and, also, in opposition to capacity building. Hence, whether at the national, regional, or company level, integrated utilities may naturally choose to satisfy demand, taking actions according to costs, either on the customer side or on the supply side (Parik, 1994; Sioshansi, 1994).

Abatements of environmental impacts

Energy use has a tremendous impact on the environment. The energy chain created to satisfy human requirements for development, which starts during the source exploration stages and moves along via exploitation, to production and transmission phases, finally reaching end-use customers, inflicts considerable damage on the natural habitat of the different species living on earth. Global sustainability is one of the answers to this very complex issue (Goldberg et al., 1993). Nevertheless, an overall acceptance of its precise meaning for energy policy formulation has not been acknowledged yet. The issue of environmental abatement incorporates another angle into integrated energy planning.

Governments usually exercise controls on exploration and exploitation of nature, and these controls tend to be rather harsh when it comes to certain specific energy sources. Nonetheless, for strategic national reasons, some damaging practices might not be referred to the appropriate authorities on some occasions. Note that the transport of resources by pipeline or electric grid follows government regulation schemes, very much along the lines established for the previous stages in the process.

Electricity production and end-use are receiving considerable attention in scientific circles because of the technology and policy implications. They are largely responsible for the build-up of carbon dioxide, the build-up of methane and destruction of the rain forest, which all contribute to the greenhouse effect, causing global warming (Anderson, 1993).

The technologies for electricity production are at the centre of the environmental debate, where the solutions for capacity expansion are proposed in terms of nuclear and, more recently, even in terms of coal sources. Nonetheless, there is no agreement to this end as has been shown by the following small sample from the literature: Kessller et al. (1994), Toke (1990), Cartledge (1993), Chester (1993) and Pearson (1995).

The environmental impact of energy end-use has often been addressed through price mechanisms, especially in the DSM literature. The connections here between rational energy use and environmental abatement generate synergetic benefits to both policy issues. Nevertheless, there are all sorts of problems arising with economic, social and political repercussions. For example, making industry less competitive and, consequently, increasing unemployment.

1.3.2 Ownership and privatisation

During the last 40 years or so there have been major world-wide changes of ownership and state regulation in the energy sector. The US electricity industry, a set of separate vertically integrated systems with a production capacity of over 700 GW, is largely privately owned, and has been so, ever since World War II. This has been comprehensively regulated within a monopolistic framework but it is heading now towards less regulated set-ups (Stevenson and Ray, 1993; Toner and Vera, 1995).

The UK has almost completely privatised the energy sector, but along different lines. The gas industry was made a private monopoly in 1986 and the coal industry was sold to two major companies at the end of 1994. The electricity industry was split into generation, transmission and distribution, before shares started being traded on the stock market in 1991. In the power generation business a deregulated competitive environment is sought while transmission is a tightly regulated private industry. The aim is that the supply business initially moves towards a more competitive environment for the commercial and industrial sectors during the first few years, and for the household sector after 1998 (Bunn et al., 1993).

Norway has also followed the ownership liberalisation trend under a different scheme (Reiten, 1994; Holtan et al., 1994). In this case, where 99% is hydroelectricity, there is competition between public utilities, some owned by the municipalities and some by the state, and few private companies.

India has started its privatisation scheme, on the production side, in search for major foreign investment. This is intending to inject much more dynamism into the electricity industry, to reduce the financial pressure on central government, and to add 30.5 GW to the existing capacity of 70 GW, during the period 1992-1997 (Ranganathan, 1993).

In Latin America, Chile is a peculiar case that has shifted from a mostly privately owned energy industry, during the first half of this century, to a publicly dominated set-up in the middle seventies, and then back to private ownership with state regulation in the late eighties (Bernstein, 1988). Chile, Argentina, Peru and Colombia have closely followed the structure adopted in the UK (Vera, 1995). In particular, Colombia is slowly taking this path as new legislation to support the process has been approved in recent years (The Colombian Parliament; 1994a and 1994b).

When observing the overall dynamics of energy systems, with respect to ownership, there are no major structural or organisational differences in the industries. In this sense, it should not matter if the industry is public or private, so long as the goals, subsidies and incentives are correctly handled. For this reason, the same causal relations, contained in Figure 1.1, which will be examined throughout this thesis, will still hold during the transition from centrally-planned to deregulated schemes. The most important distinction is energy supply. While in a centralised public system the decision making depends only on the government, in a decentralised set-up, with an important private component, the decision making relies on market forces with or without regulatory agents (depending on the characteristics of the system).

However, if energy price replaces energy cost in Figure 1.1, then the situation changes substantially. In this case the manoeuvring effect of dominant strategic players may have undesirable impacts on both competitors and consumers - hence, the need for regulators.

Note that there are three major distinguishable activities in energy systems: Generation (production), transmission, and supply (sales to end users). Each can be differentiated by type of activity according to: Operation, Planning/Regulation and Plan-execution. Table 1.1 indicates the preferences in many countries.

	Operation	**Planning/Regulation**	**Plan-execution**
Generation	Competition	Public	Competition
Transmission	Monopoly	Public	Franchise
Supply	Competition	Public	Competition

Table 1.1 Industry split preferred by a number of countries

Operation

The operation of energy systems in a competitive environment will tend to be more efficient as profit maximisation becomes the main objective. When oligopolistic behaviour is attained energy companies will benefit from high prices, profits will increase and service quality will drop (Green, 1996). In this case there will be everlasting concerns on the cost and security of service.

There is a tendency to run the generation and supply activities under private ownership. This is certainly the case for the electricity and petroleum (production in this case) industries, and can easily be generalised to other sectors.

The transmission activity is generally monopolistic for electricity as well as for petroleum and gas (transport in these two latter cases), when these are transported by electrical power lines or through pipelines, because of the large infrastructure costs and as a consequence there is very little competition on this side of the industries. In the past, these have been mainly publicly owned but there have also been major changes, especially in the developed world.

In electricity supply (sales to end users) it is difficult to decide, for example, who should operate the demand-side management tasks (Sioshansi; 1996 and 1991). On the one hand, it may be correct to assign this function to the utilities because of their close contacts with customers, their knowledge about technology and their credibility on information supply. Some specific DSM projects may also be considered as business diversification with obvious synergy effects.

On the other hand, as utilities depend on sales and profits on sales, energy efficiency and energy conservation are in conflict with the *raison d'être* of utilities. Hence the alternative may be to encourage the creation of demand side management businesses. The oil and gas industries under private ownership, with some government regulation, seem to operate correctly in most nations.

Planning and regulation

Overseeing the overall (integrated) energy system is a major government responsibility. Co-ordination in the sector may be attained via planning and/or regulation (Stevenson and Ray, 1993).

Planning is intended to be applied in a light-handed and indicative fashion. More forceful planning would be unrealistic, because of the drawbacks of the classical approach explained above. To stimulate private participation there should be a portfolio of possible investment alternatives. There have to be incentives and the right price signals (Bunn and Larsen, 1992). Also, it is important to note that correct taxation, pricing and quality control are only feasible if governments have the complete overview. In this context, it is possible to internalise environmental effects through integrated planning and regulation.

In planning expansion of energy generation capacity there is a large set of decisions to be taken. Many actors and subsectors are involved. Through the years technologies evolve and fuel mix varies. The question of optimality arises then. The dynamics of the demand and price variables provide important information to resolve issues such as how much to invest in Combined Cycle Gas Turbines (CCGTs), hydroelectricity, coal plant and, rational use and energy conservation, to seek satisfactory development. An integrative systems approach will then be required.

Demand increase will justify further investment in supply infrastructure. In most situations, large capital-intensive plant will only be utilised at low capacity, immediately after installation. Hence, incremental or short lead time technologies may be more attractive for private investors (Ford, 1985). Economic decisions on the mix will have to be made in terms of what to build and when.

Planning and/or regulating energy generation, transmission and supply is a government responsibility. Some nations have it clearly stated in their constitutions. In the least developed economies and even in industrialised countries there are sectors of the population that require subsidies. Market forces would never work properly in these cases, and governments must have reliable information to provide these subsidies effectively by means of focused policies.

Plan-execution

In the plan-execution (plan-implementation) phase for power generation expansion, the same basic logic holds under both public and private ownership (seeking optimal resource allocation). The archetype (Macro-structure), Figure 1.1, contains this basic logic, which is invariant to ownership structures. The difference lies in the possible strategic manoeuvring of private actors, which may be reduced significantly by regulation. Note, however, that privatisation is being considered by a large number of governments around the world when seeking for new financial resources and system efficiency (Jackson and Price, 1994).

Therefore, independently of the ownership structure, the appropriate expansion of the energy system takes place, in the presence of sufficient customer demand and adequate economic signals. Note that, while private organisations will be expected to attain at least the rates of return on investment established by financial markets, public institutions can afford lower margins.

Organisations assess risk in significantly different terms depending especially on the ownership structure. The private sector will definitely be more risk averse and investments will be expected to be on less capital-intensive technologies. The amount of cash allocated to Research and Development may constitute another major source of differentiation between entities. In general, private companies may discourage government investment on this function (Fri, 1995).

Two major solutions may emerge when trying to make a public monopoly more efficient (in the case that unbundling is possible, and also when competition may be created between companies within the industry). Firstly, the British approach, transferring these independent companies to the private sector and creating regulatory entities; and secondly, rather like the Norwegian approach to the electricity sector, establishing a mixed ownership set-up (partly private and partly public), preferably with the aid of regulatory agencies. In the latter case the major concern will turn to prices, quality and security, whereas in the former case some of these drawbacks may be overcome.

Nevertheless, if privatisation is part of the Government's agenda, perhaps the aim will be to guarantee, through regulation, that the proper market forces operate as they are expected to do. That is, first construct plans and strategies, and then design organisations (including regulatory bodies) to aid making progress in approximately the specified direction. As illustrated in the general causal diagram presented in Figure 1.1, when the generation capacity is depleted more investment is encouraged. For the private sector a clear and timely price signal has to be provided, whereas in a public-based system budgeting and scheduling are the variables to watch. In both cases regulatory bodies will co-ordinate the process.

Plan implementation in the transport and supply of fuels is being conducted by the private sector, on a regulated basis. The most common arrangement, in most countries around the world includes public auctions for the construction phase and also franchises in some instances.

Note that from the modelling perspective, the move towards competition and/or private ownership leads energy utilities to behave more like any other corporate business being concerned, on the one hand, with strategic and competitive analysis and, on the other hand, with systems thinking, under much softer specifications.

1.4 SYSTEM DYNAMICS IN ENERGY PLANNING AND ANALYSIS

In broad terms, two main methodological approaches have been attracting much attention from the academic community in the field of modelling technologies. Firstly, there is the well-established econometric and more normative OR tradition, offering classical tools and techniques. In more recent years, however, a more behavioural approach is being advocated and is still in the process of gaining acceptance among mainstream scholars, where there is still scope for investigation with respect to instruments and tools to support analysis. In this debate System Dynamics appears as one of the candidates to bridge these approaches (Lane and Oliva, 1994).

The history of System Dynamics (SD) models in energy planning can be traced back to the early seventies when research conducted at MIT was primarily concerned with world dynamics, including factors such as economic and population growth, depletion of resources and pollution. Separate studies were conducted to examine the behaviour of energy sources.

This research was the basis for the SD model, called COAL2, created under contract to the US government (Naill, 1977 and 1992; Naill et al. 1992). Improvements to the model have led to the version called FOSSIL2 which has been used as an important tool to support all US energy plans since 1977 and The National Energy Strategy of 1991.

During the last fifteen years Ford has been investigating a number of issues closely related to: investments and uncertainty (Ford, 1982), policy evaluation in the electricity industry (Ford, 1983), and conservation policy analysis (Ford, 1989). Also in the US, Geraghty and Leyneis (1982) studied the effect of external agents on utility performance.

Moxness (1990) presents an interesting model on interfuel substitution in OECD-European electricity production. The paper focuses on the fossil fuels oil, gas and coal. His approach overcomes the inappropriate interfuel substitution representation yield by the constant elasticity demand models. The SD perspective has been incorporated in the large European Commission energy-environment-economy model (Backus, 1994), particularly in relation to the energy component.

In the UK, the capacity expansion process of the electricity supply industry was addressed back in the late seventies (Zepeda, 1978). System Dynamics is now being used to explore a diversity of issues related to the privatisation of the electricity industry (Bunn et al.; 1992 and 1993). Problems related to the reserve margin, market share and plant retirement have been examined. There is still scope for further research in this area. In France, Roche (1989) establishes the importance of the SD approach in the electricity sector and points out the large amount of research needed to be done in the area.

Slesser (1987) reports an interesting SD application to energy planning in Kenya. The model developed intends to give insights into the problem of sustainability and the carrying capacity of a country based on a detailed resource accounting, where energy is the driving force.

The oil industry has had some attention from the SD community. For example Mashayekhi (1991) examines the effect of exchange rate policy in a country that faces a decline in oil exports. Using a different approach, Davidsen et al. (1990) developed a petroleum life cycle model for the United States. In India, Chowdhury and Sahu (1992) studied the energy exploration and exploitation industry.

Applications of System Dynamics to the electricity sector in Argentina have been pursued during the beginning of the eighties, Rego (1989), whilst in Colombia SD is being used to study energy efficiency penetration and electricity substitution by gas in the residential and industrial sectors (Dyner et al.; 1993 and 1995).

The System Dynamics methodology has proven to be appropriate in this field and there is potential for further research in different areas of energy analysis and planning, such as:

- residential, commercial and industrial energy efficiency: policies, programs and projects
- propagation of efficiency technologies; incorporating aspects such as cultural (idiosyncrasy), propensity (decision Vs costs) and risks
- rational energy use, DSM and conservation
- load curve management; energy substitution in industry
- losses (technical and thefts)
- environmental impacts
- ownership and privatisation issues; policy and strategy assessment
- uncertainties.

Even though System Dynamics has been widely applied in a number of energy related problems, the methodology is far from being accepted as a major paradigm for energy analysis, policy making or planning. This is largely due to the lack of a systemic method available to address large-scale integrated energy problems as an alternative to those being used by economists and engineering analysts. With the exception of FOSSIL2, most models have been relatively small and focused upon a specific issue.

Since SD cannot be supplied as a closed, black-box, system package, there is a need to develop a methodological framework approachable by a larger number of specialists to elicit problems, to aid the policy making and strategic formulation processes in the energy field, to give insights into possible meaningful solutions found, and moreover to be able to pursue these tasks in gradual stages to observe the benefits of the tool at each stage.

1.5 AREAS OF RESEARCH ON ENERGY MODELLING

In this section, the role of modelling as a support tool for integrated energy analysis, policy making, strategy formulation and planning is assessed. General methods to improve the current technologies are examined for a number of important issues. In many cases areas of research are identified and possible applications are suggested. The different areas of research are classified here according to: a) energy related topics, b) analysis methodologies and techniques, and c) strategy and policy issues.

1.5.1 Energy related topics

Three main energy topics are taking most of the researchers' interest during the 90s. These are DSM, market liberalisation and environmental abatement. Most other areas can be fitted into these three categories.

DSM and rational energy use

The problem of rational energy use, demand-side management, energy efficiency, energy losses (technical and non technical) and energy conservation will be undertaken in depth in this thesis. Concept differentiation will be the starting point to identify a large diversity of specific issues. Further along this line, a number of strategies will be investigated with the support of specific models.

The relationships between rational energy use, demand uncertainty and delay in investments will be studied in this thesis. As stated in Long (1993), long-range electricity projections may be seriously biased unless the effects of energy conservation activities in the residential sector are satisfactorily taken into account.

Privatisation and ownership

The research undertaken here focuses also on competition and privatisation issues and on the transition towards deregulated markets. The major theme will be the search for invariants and differences in the shift from public to private ownership.

A mixture of Hard and Soft system methodologies will be explored in this research. Hard variables include technology availability and population evolution. Soft variables involve those variables on the demand side - for example, when representing consumers' choices or human decisions. The economic theory supporting the latter is founded on the bounded rationality principle with respect to factors such as information, computational ability and price forecasts.

The role of planning and regulation will be examined in the following cases: verifying that markets provide the right price signals, establishing that companies respond promptly to demand forecasts, and assessing whether clean technologies will be adopted for electricity generation.

The environmental dimension

Environmental issues will be addressed, not only when approaching conservation and rational energy use, but also in the case of technologies for electricity generation. Furthermore, strategies for diversification of the energy source for appliances and equipment will be examined as a means for accomplishing a more efficient energy use, for inflicting less damage to the environment and, as a way of reducing the energy bill for lower income customers in developing countries. Nevertheless, the environmental dimension will be very much of secondary importance here, leaving room for further research.

1.5.2 Analysis methodologies and techniques

Analysis methodologies in the energy field vary widely according to the content. Integrated Resource Planning focuses on issues in the monopoly utilities set-up, while economics, system thinking and strategic analysis are used for the competitive environments.

Methodological issues and evaluation

A methodological dilemma thus arises between conflicting approaches. There are several alternatives for resolving the problems posed in this complex environment. One can be under a hierarchical modelling set-up, exploring during several rounds a specific set of separate interrelated issues. Each time such a set of issues are addressed the rest are excluded from the study. In this case relevant feedback structures are not accounted for each time the analysis is conducted. Consequently, a real learning process does not take place, as problems tend to have loose connections and all modelling efforts start from scratch every time a new proposition is being examined. The advantage, however, is that the complexity of interactions is kept at the lowest level possible.

An alternative approach might make use of System Dynamics as a basis for analysis, where organisational problems will be investigated, taking into account interrelated issues. This possibility will be explored in detail throughout this thesis. The task will need to be conducted on an incremental basis, making continuous assessments of the alternative options bearing in mind that not all features have to remain active on all occasions to avoid unnecessary complexity. Re-usability and learning are perhaps the most attractive features of this approach.

The methodology exhibited in the next chapter, does not necessarily consider in depth all the issues involved in the above analysis of the system represented in Figure 1.1. Some components will be considered in depth while others will only be examined marginally. The intention is to demonstrate the viability of the approach and to provide an overview of the system involved. Revisiting all propositions seems advisable, as the system evolves continuously and significant changes emerge.

Modelling technicalities

Models will be evaluated in the light of issues discussed in the previous section on energy-related topics. That is, they will have to demonstrate their capability to deal with complex market-based issues and with incentives for consumers to adopt energy-efficient technologies.

Methodology for including technology diffusion (propagation)

This begins with the introduction of consumer choice mechanisms, followed by a delay function to represent the time lag between economic signals and the selection of the respective equipment or appliance. Then, some causal relations are incorporated to represent different steps in the marketing strategy (evaluating the time for each activity). The length of time for acquisition is represented next and, finally, the time to make the device operational (search, pay, installation, learning, full use) is added to the model.

Accounting the time for implementing a particular strategy should be determined in some detail. In each step there will have to be an established performance criterion, like the percentage of people adopting a specific programme. Different marketing strategies may be evaluated.

Behavioural assumptions as well as estimated parameters will be considered at this point. For example, while in some cases economic evaluation can be based upon well-estimated parameters in others it may just be dependent upon speculative behavioural assumptions. Also, when considering technology penetration, this may take either form according to the precision and depth of estimation procedures. Sensitivity analysis will be useful at this stage to deal with the parameter assumptions.

Uncertainty

This is an important theme in energy analysis. Two major aspects are examined here. Firstly, deterministic non-linear dynamics will be considered in the following chapters. Secondly, investigation is undertaken when there are multivariate interrelationships with unknown outcomes. For analysis and planning purposes it is also important to identify the implications of highly non-linear models and to assess policy robustness.

Also we will examine structural stability and the implications of non-linear relations on the system behaviour. Validation will be conducted by means of consistency evaluation and comparison with alternative models and results.

The problem of reducing uncertainty by way of adding generation capacity with low capital-cost technologies will be addressed here. Alternatively, similar considerations are valid when large capital-cost technologies are possible to modularised. This approach reduces the large costs involved in over- or under-capacity. In particular, micro-hydroelectricity generation plants reduce transmission costs on some occasions. All preceding arguments are closely related to general methodological issues.

In this thesis uncertainties due to stochastic processes have only been examined when analysing a specific strategy in Chapter 4 and when considering an exogenous event in Chapter 6, but neither in the case, for example, where prices follow a Wiener process in the short and medium-term; Nor, in a more complicated case, where in the light of energy depletion pressure builds up for large price increments (according to a stochastic process), followed by fluctuation patterns until stability may be reached, when substitution of the source has extensively taken place or when a new technology has become widely acceptable. These are left open to further research.

1.5.3 Strategy and policy issues

Platforms for strategy and policy analysis based on System Dynamics will need to prove their ability to reduce complexity.

Policy and strategy statements and implementation

Policy may be assessed, both by making interpretations of what is stated in the law and according to the government's goals. We will also investigate the consistency, viability and direction of policy. At the company level, strategies may be incorporated into the modelling approach. The environmental set-up, including the strategic, regulatory, market behavioural and competitive components, may need to be modelled simultaneously to appreciate the major factors involved.

As policy and strategy may be very much affected by the uncertainty issue, sensitivity analysis and robustness tests will be conducted.

The nation-region problem

This is of utmost importance in integrated energy planning and modelling: it is a problem of hierarchies. The plan, even if it is only indicative, cannot be simply the sum of regional preferences but rather an integration of intended actions to fulfil regional necessities. Methodologically, this can be incorporated in the System Dynamics modelling approach by generating general supply necessities as the sum of regional demands. For example, decision making will be based on the merits of regional supply-bidding to the interconnected network. The feed-back mechanisms may help to make adjustments to certain pre-defined decision rules, according to some sort of equity measure of regional distribution (not to have all projects assigned to a specific region). This may also be resolved by means of negotiation. Regional supply not included in the interconnected system will be accounted separately.

Furthermore, for this purpose, all projects have to be ranked and some financial data will be needed. This interesting issue is left to future research.

1.6 THE CONTRIBUTION

A number of important research themes have been identified in previous sections. Not all of these may be realistically undertaken here. Hence, a selection has to be made on the basis of coherence, relevance and opportunity. Let us first briefly summarise the state of the art in the energy modelling field.

In a unique and exceptional way, as explained above, an integrated System Dynamics model has been used extensively in the United States, along with other methodologies, since the first National Energy Plan was released in 1977. This tool, specially made for the necessities of the US, although a good example of a large useful model, provided neither important transportability characteristics, nor a transparent and comprehensive methodology to make it applicable elsewhere. Also, the model has not considered: a) the new liberalisation environment, or b) national-regional tensions. These issues, of significant importance, are now placed at the top of the agenda in different countries and regions around the world. Furthermore, governments and specialists have no clear understanding of how to introduce other countries to a similar processes - thus the need for a methodology.

In the UK there is an extensive and long-standing modelling culture to support planning and policy making including the energy sector. Large-scale simulation and optimisation techniques have been widely used during the recent decades. Although System Dynamics itself has not been broadly used, the approach was recently introduced to evaluate the newly privatised electricity industry (Bunn et al., 1993). Within this framework, there seems to be scope for further research, integrating alternative sources and also considering the strategic manoeuvring of major players.

In Colombia large econometric models were used, for example, in the National Energy Study (MINMINAS, 1981) and in the Antioquia Energy Study (EEA, 1989). Nevertheless, most tools developed in the eighties to support energy planning/policy were limited to individual industries, as in the case of electricity and oil. More recently, there have been modelling experiences to support energy policies from the demand side applying optimisation tools such as MARKAL. Also ENPEP (Buehring, 1991), using a non-linear equilibrium approach, is being implemented to support aspects of energy policy in Colombia. System Dynamics has only been used experimentally at the regional level, for the Antioquia Department of Colombia, to study the substitution of electricity by gas in the residential sector. This latter research integrates supply-demand and also electricity-gas at the household level.

In this thesis, the contribution will be in the areas of methodology, modelling and policy. First, a methodology will be built to support integrated energy analysis, planning and strategy at the national level. Furthermore, the methodology will be shown to be capable of assisting the conceptualisation, analysis and formulation stages for policy and strategy, and is also intended, with minor adjustments, to support the implementation, intervention and follow-up phases. Allusions will be made to British and Colombian cases, where concepts and constructs will be tested, as well as some transportability of experiences across these two different environments will prove to be possible.

Second, there will be contributions to System Dynamics modelling for the integrated energy sector. The methodology, when applied to two countries which are completely different in nature, will show how extensive modelling and learning can take place. Here again, there will be a specific reference to the British and Colombian cases.

Third, the methodology and modelling will provide insights into policy making and strategy formulation, stimulating competitiveness and technology developments in energy. For example, lessons for policy formulation may be drawn i) from the effect of demand-side management on technology penetration, and ii) from strategy assessment on company performance.

Furthermore, the results of this research are expected to have indirect socio-economic influences. At one end of the spectrum, for example, in England just a news report of the regulator's opinion on industry matters can have profound and immediate effects on share prices. At the other end, Schramm (1993) estimates that the least developed countries alone will need direct investments of the order of US $100 billion for the power sector during this decade. Hence, scientific contributions in developing tools to support decision making in the energy sector have a very large and important potential for developed and least developed countries. Specifically, the Colombian energy sector contributes about a third of its external debt. Management of the sector has serious problems, where inefficiencies and losses are significant. The energy sector will need well over seven billion dollars by the end of the century, and these are being allocated in a methodological void at the present.

The following chapter presents a new methodological proposal to support system analysis and planning. Chapter 3 concept-tests the proposal and specifies an analysis-support platform as a generic aid to modelling. Chapter 4 develops a case study for the UK energy system, partially testing the proposed methodology and the analysis platform especially constructed for this situation. Chapters 5 and 6 elaborate upon a case study for the Colombian energy sector, examining in detail both methodology and the analysis platform uniquely designed for this case, as well as assessing energy policies. Finally, Chapter 7 summarises and concludes the major findings of this thesis.

2 A SYSTEMS METHODOLOGY FOR POLICY ANALYSIS, STRATEGY AND PLANNING

In the previous chapter, two important dilemmas emerged: one related to the complexity involved in the management of energy systems and the other associated with the methodologies for analysis and system intervention. This chapter has three aims: 1) to specify the requirements for the methodological process, 2) to determine the corresponding technological support, and 3) to establish its functionality and characteristic features.

Diverse approaches to analysis and planning have been followed in a variety of contexts and under different philosophical and methodological trends over the years. They have used a multiplicity of techniques and have been supported by a variety of modelling methodologies. The more traditional ones, based on prescriptive approaches and sometimes referred to as Hard System Methodologies (HSM), have been applied more or less successfully during the last five decades. The most modern tendencies, mainly known as Soft System Methodologies (SSM), claim to incorporate human behaviour more realistically. These started becoming popular during the late eighties and the first part of the nineties.

When Operational Research and Systems Engineering were being created as disciplines, during the Second World War, or perhaps even a few years earlier, they were very much

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Elements of the methodology proposed in this chapter have been included in a forthcoming paper to be published in the International Transactions of Operational Research (1996).

attached to either the cybernetics paradigm, or to the traditional theory of the firm, or to both, Simon (1979). Basically, the approach consisted of recognising the problematic system situation and then analysts would seek the appropriate tools, with the purpose of optimising organisational output, usually measured in terms of profit maximisation. The system planning paradigm followed closely along the same lines. In this case, managers and specialists would try to identify organisational goals, and then set the global business budget, leaving the tasks of "means definition" and "plan implementation" to the operational staff.

Behavioural ideas and systems learning were not strongly advocated at that time. The diverse actors in the organisation were seldom considered, problem definition was rarely an objective, model simplification was not really a matter of concern, organisational cultural aspects did not bother anyone, and participation was not of interest either. Strong assumptions were made with respect to the ability of specialists in the areas of problem conceptualisation and solution prescription. Therefore, lack of project success was, in many cases, due to the heavy reliance on external agents and the minor involvement of internal actors (Lee et al., 1990).

Often, neither system control nor the necessary information feedback were taken into account for the proposed system interventions. This was largely due to: 1) many of the recommendations and plans never having been implemented (indeed sometimes they were never intended to be), and 2) the execution of the plan not having considered the follow-up and adjustments phases.

In short, these approaches proved to be problematic as issues were rarely addressed correctly, system learning was not considered and system intervention often failed. Thus criticism comes now from many directions, with authors stressing a number of different methodological aspects of problem conceptualisation, systems thinking and the stages of implementation, such as Ackoff (1981 and 1994), Sterman (1994), Forrester (1994), Checkland and Haynes (1994), Jackson (1994), Flood (1994), Eden (1994) and Rosenhead (1989).

2.1 ALTERNATIVE APPROACHES TO SYSTEM INTERVENTION

As yet there is no single widely accepted methodology that claims to have overcome the failures found under the previous HSM paradigm, even though most of the tools and techniques developed in recent years under the umbrella of SSM were intended to eliminate weaknesses of the classical analytical approaches for intervention. In traditional planning, rational comprehensive procedures failed, firstly, because it was undesirable to have a single entity in the organisation in charge of all planning and, secondly, owing to the overwhelming data required and the excessive intellectual demands on policy makers (Rosenhead, 1989).

Thus, in a variety of contexts, the term 'planning' started being redefined, especially since the disintegration of the Soviet Union, not only because of the drawbacks noted above, but also because it has been associated with what is governmental, centralised and dogmatic. Furthermore, it requires a new definition in connection with what is known as privately owned, democratic and participative. This is because recent methodologies, such as strategic and scenario planning, have not had a real opportunity, even within some of the most advanced corporations.

Some researchers advocate the view that markets will resolve the most crucial issues related to planning, not only from the government standpoint but also at the company level. This is questionable, as theoretically-perfect markets never exist, due to information asymmetries, technological barriers and transactional costs, among others.

Hence, planning over-simplification may be catastrophic, not only at the state level but also at the business level. There is obvious room for improving efficiency and effectiveness in the planning processes and protocols; nevertheless precautions have to be taken to avoid making it trivial and unimportant. In this context, it is clear that man will continue to think ahead deeply, seeking foreseeable futures and searching for different means to accomplish them, but the complex interrelationships within systems should make him consider strategies and policies in an integrated manner - if organisational development is a major concern.

Abstractions of reality is the next step to follow. Thus, models and modelling are of utmost importance to the planning process. In recent decades there has been a tendency to use them within Decision Support or Expert System platforms, but the success of these approaches has been limited, mainly because of drawbacks in terms of interactivity and user-friendliness. In many other cases resistance had been manifested by the end user because of the black box effect, which creates distance, lack of trust and little sense of ownership (Kotterman and Davis, 1991).

In the energy sector in the US, for example, the two approaches that have played dominant roles in planning include the econometric-engineering tradition and, on a much lesser scale, the management-policy oriented practice. The former is grounded on very detailed mathematical demand and supply modelling, whereas the latter is based much more on broad, general and strategic modelling, usually representing fewer system elements but, at the same time, attempting to maintain scope and some depth.

One approach claims precision when it comes to representing reality while the other, although from different perspectives, takes into account the human component much more with respect to strategy formation, decision making, consensus formation and even emancipation issues.

Both approaches are supported by different philosophical traditions. Firstly, the traditional approach relies on scientific truth, in terms of model representation, parameter estimation and model validation. This means that tools rely either on data, data-fit, and statistical stability when it comes to the econometric techniques, or on mathematical validity as it is referred to in optimisation techniques. Secondly, the systems camp intends to incorporate into modelling the diverse actors involved in the organisation, their strategies, their interests, their agreements and disagreements; thus, the question, in this case, is more related to model consistency and acceptance than to any other issue.

A new paradigm has not yet emerged, but for some there seems to be light at the end of the tunnel, indicating that a synthesis between SSM and System Dynamics may be part of the solution. This synthesis not only considers that a significant number of the most relevant organisational problems are intrinsically ill-defined and that the implementation of solutions should include negotiation stages, but also that non-linearities, feed-backs and delays should be incorporated as part of the system analysis. The work by Lane (1994), Lane and Oliva (1994) and this thesis, intend to make progress in this direction.

It will be demonstrated that the modelling platforms developed here can be enhanced as part of a systems analysis methodology for strategic management, policy making or light-handed planning, thus filling the technological vacuum regarding system problems of complex structures in dynamic and turbulent environments. It is claimed that this construct contains attributes not exhibited by the classical techniques and that it provides means to pursue the above disciplinary goals. The following section introduces a historical perspective on the systems approach to planning, before moving onto the presentation of the proposed methodology.

2.2 SYSTEMS APPROACH TO ANALYSIS AND PLANNING

Despite the lack of consensus, the systems approach to living organisations is sometimes attributed to Wiener (1948) and Bertalanffy (1956). In this direction, Forrester (1961) developed important instrumental support for this approach to systems policy making. This later method, based on the applications of cybernetics and control theory to socio-economic environments, has as one of its main goals to facilitate policy design for organisational management.

The work of Ackoff (1970 and 1981) is fundamental for elaborating a modern approach to organisational analysis and planning. For many academics his achievements belong to the 'hard' systems approach as will be explained ahead, while for the majority, perhaps, they can be classified as part of the 'soft' system camp. The central idea may be partially encapsulated in the following citation:

> "...planning as an activity within which development takes place, not merely as an activity whose output may contribute to development".

In a similar form, Hicks (1959) indirectly suggests the inclusion of systems thinking into mainstream economics. He explains that virtuous and vicious cycles are based on causal relationships; and, also, that the effect of economic 'signals' in economic planning and decision-making processes may produce complex dynamics.

Under an evolutionist framework, that leads to a new scheme for organisational analysis, Checkland (1981) presents the interrelationships developed through time between systems engineering and systems analysis. The first one is associated with large man-made infrastructure works and the information flows associated with them (e.g. the pyramids, telecommunication systems and car production organisations). The second one is primarily identifiable with long-term strategic and technical planning, such as has been achieved at RAND corporation and at IIASA (e.g. cost evaluation and the analysis of alternatives to reach some proposed goals).

Against this background, 'Hard systems thinking' is then defined as a synthesis between the two previous approaches to problem solving. It seeks to eliminate the difference between what is desired and what is real through the selection of the best among a set of alternative possibilities.

From a different perspective, 'soft systems thinking' or 'soft systems methodology' (SSM) is based on a method of recurrent analysis to problem solving. Initially, a search is pursued to identify system characteristics and problem situations. This is followed by a system analysis phase seeking to improve, modify, or redesign the organisation. Finally actions are implemented. The main difference with 'hard systems thinking' is that it is not goal-oriented, basically because it is believed that problems in these areas are always ill-structured.

The methodology developed by Checkland (1981) consists of seven stages, starting from the description of an unstructured problem, going through the model conceptualisation phase, up to the implementation of actions to improve the problem situation. For the conceptualisation phase a variety of methodologies are considered, but no specific method is proposed for any of the stages. In particular, modelling is a distinct task within one of the activities, but is not conducted continuously through the whole process.

There has been some progress within SSM in recent years. Instruments and tools have been created such as SODA (Eden, 1979), the strategic choice approach (Friend, 1979), and Robustness analysis (Rosenhead, 1979). However, Rosenhead says "methods with the characteristics which I have been discussing are quite under-developed".

What are known as critical management sciences may be considered a further development of soft systems thinking (Mingers, 1992; Jackson, 1994). This approach, based on the Habermas theory of constitutive knowledge, establishes the need to enlighten (clarify) problems, which are viewed as the product of the present power and authority schemes. This approach has important implications for participation and negotiation processes. The final goal is a proper rational society in which citizens are free to choose their destiny.

In applications to planning, the attention in Ulrich (1987) is switched from "how to do it" to "what to do with it", by asking critical questions in two forms: What is it really? What should it be? Nevertheless, the methodology is still at a rudimentary stage with limited progress, as there is neither the mechanism for the questioning nor the means to promote changes (Mingers, 1992).

In a different area, Porter (1991) intends to develop further the theory of strategy. The idea is to use frameworks instead of models, arguing that the former are more structured and precise than the latter and that they make it easy to understand the competitive business environment and its market portion. This is largely due to the fact that models are based on economic theory, in which case variables are considerably fewer. Nevertheless, he acknowledges that this is not really applicable to the simulation-type methodologies, such as System Dynamics or similar techniques. It is interesting to note that the approach is complemented by incorporating causal chains in a manner similar to that in System Dynamics.

When taking a broad view of the systems approach, it has been shown that this has evolved considerably to incorporate a more realistically human and less machine-like response to policy. However, the soft system method itself does not resolve all the issues posed as a consequence of the complexity involved; for example, in the energy systems case when integrating demand-side management into electricity expansion or when making structural transformations which lead to market liberalisation. The systems analysis methodology requires technology support to address the following modelling problems:

- Scale and modularity
- Seamlessness and transparency
- Adaptability
- Transportability and transferability
- Behavioural and negotiating characteristics
- Continuous system adjustments and uncertainty
- Simulation.

Hence, the proposed analysis/planning methodology not only needs to be capable of incorporating the functional specifications established by the new systems thinking trend, but also requires technology support capable of fulfilling the requisites described above. This is a necessity under the conditions of system complexity described in Stacey (1994) and Lane and Maxfield (1995).

2.3 THE PROPOSED METHODOLOGY

From the preceding discussion, the proposed methodology should thus be based on a systems approach and possess the property of being holistic although incremental and strongly modular. This primarily modelling oriented methodology needs to incorporate functional capabilities for strategy and policy (planning) support. It also needs to be enhanced with an analysis/planning platform containing the specific technological features described above, including seamlessness, adaptability, transportability, transferability and behavioural characteristics. Furthermore, its modelling features should be adequate to undertake continuous system adjustments and simulations to address, among others, uncertainty and negotiation issues.

2.3.1 The methodological process

The starting point is system conceptualisation, where information feedback, organisational learning and delays play a dominant role, taking into account that policies and strategies are at the centre of the organisational dynamics (they are the *prima motif*). The reason for this is that systems operate on a very active environment, and policies or strategies ought to be continuously assessed, according to the chosen goals. These actions need swift adjustments in a learning situation. These adjustments should be based, however, on information feedback, and ought to consider that decisions have time-lag effects. As planning is light-handed and participative here, there is a delicate evaluation (negotiation) process before the actual implementation takes place. These interrelationships can be broadly represented in Figure 2.1. Note that the two small lines crossing an arrow mean a delay or a retarded action.

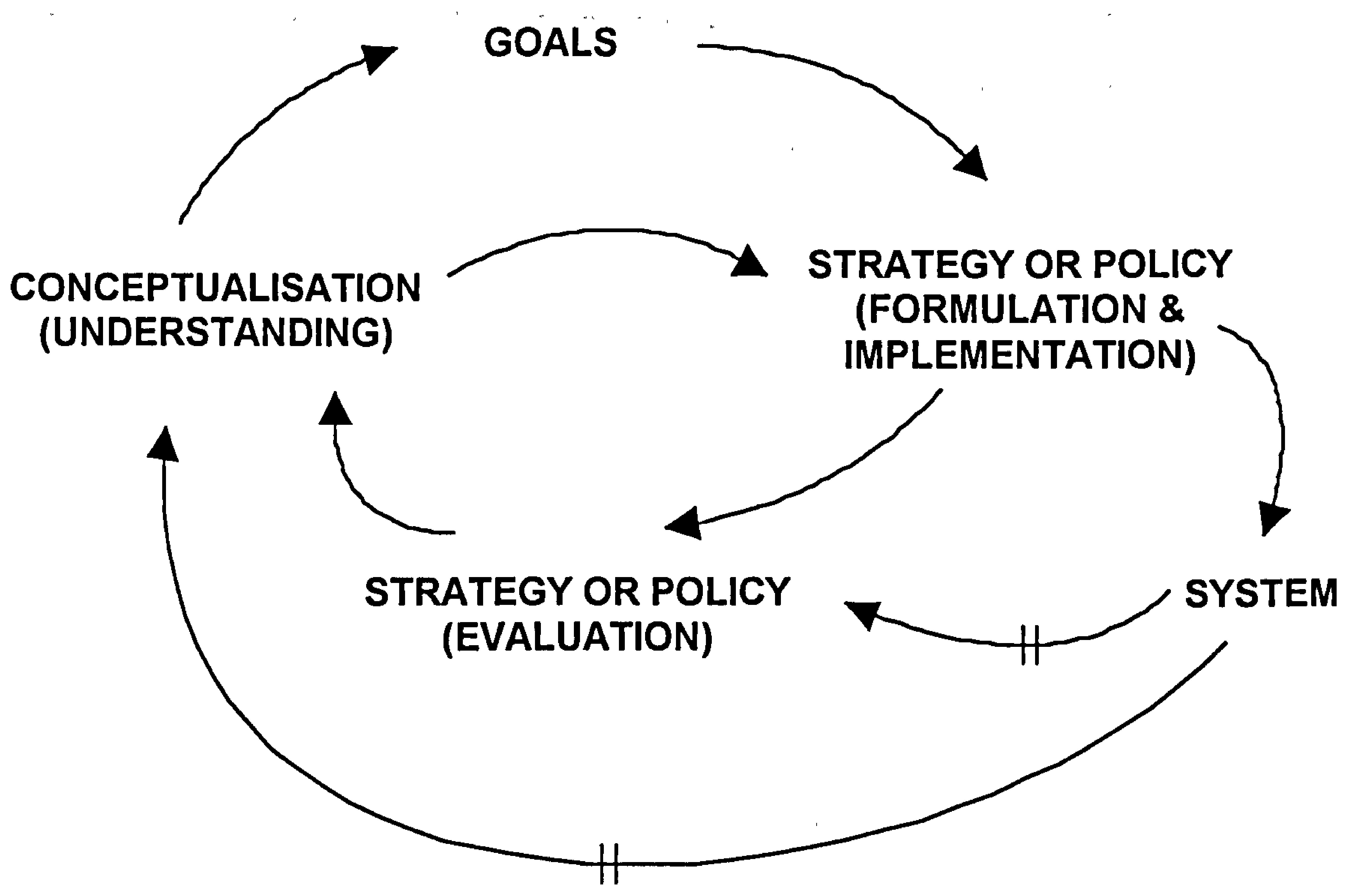

Figure 2.1 General system analysis environment

The "double causal loop" for learning (Sterman, 1994) may easily be seen in this case. It is also shown further ahead in this chapter and, again, when developing specific analysis frameworks in the following chapters.

Looking closely into the decision making process, the proposed methodology acknowledges feedback effects as can be observed in Figure 2.2. Even when the purpose is system analysis for its own sake or when it is only intended to aid policy evaluation or strategy formulation, the methodology takes into account the conditions imposed on a very dynamic environment - as it should do. The distinction in this case is that system intervention is not considered at all, as it would be in the case when planning is the final aim of the exercise.

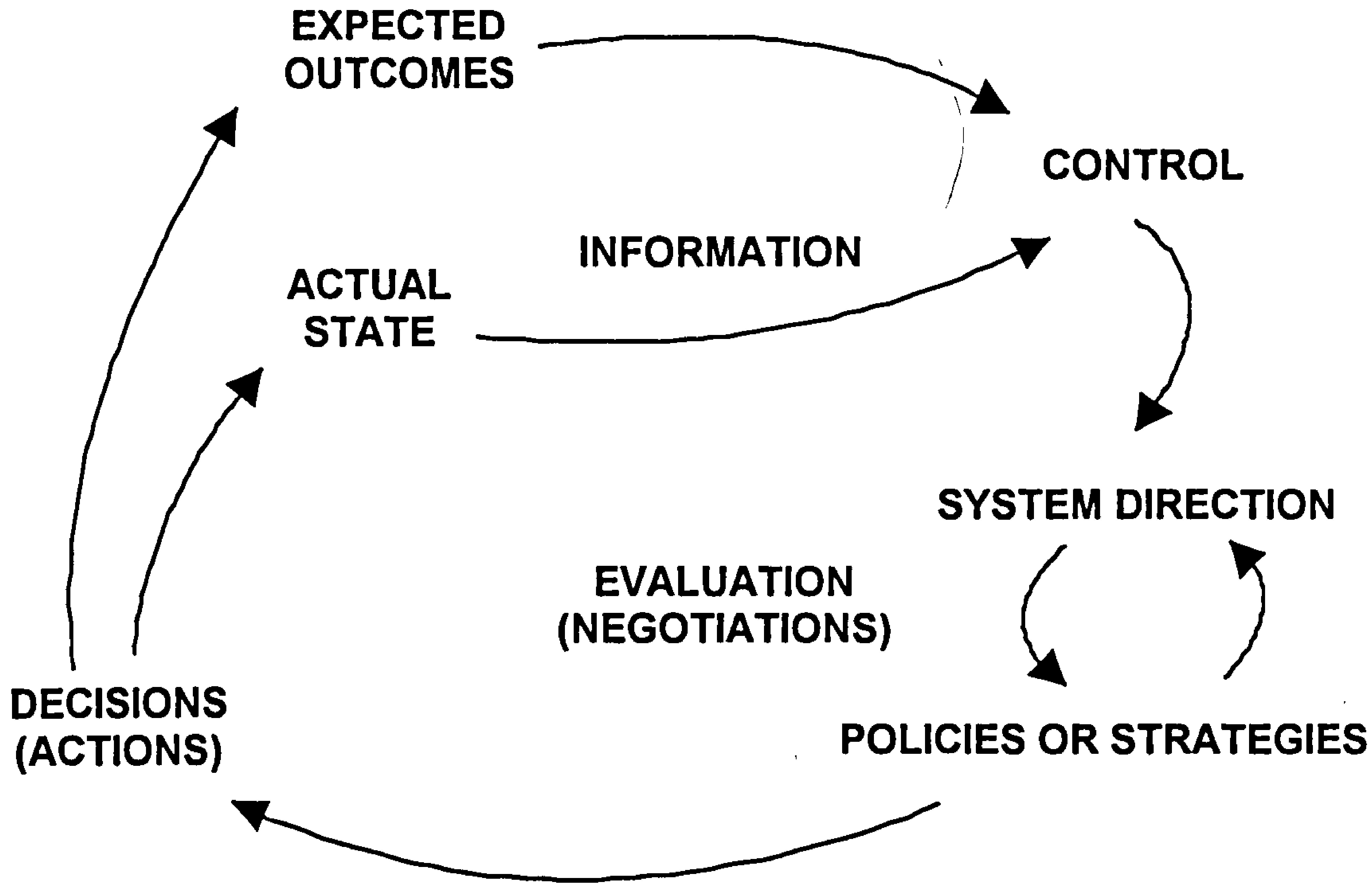

Figure 2.2 A detailed cross-section of the system analysis environment

The schemes shown in Ackoff (1981), Ackoff (1994a) and Eden (1994) may be appropriate for enhancing analysis/planning capabilities into the relevant organisational structures. In what follows, the proposed methodology is described in general terms with respect to its characteristics and attributes. Its operationalisation will become clearer in the case studies shown in chapters four, five and six.

Overall modelling

Here modelling is an intrinsic part of the planning/analysis process. It starts from the conceptualisation stage and continues all the way to the implementation of actions. It has specific functions. It should contribute to the identification of the essence of a problem, to its conceptualisation, and it should also support strategy or policy analysis by way of assessing likely consequences for the organisation as a whole. Models are not only instruments for problem representation but, more importantly, they can also be thought of as tools to aid the understanding and clarification of complex situations.

Causality chains

In the overall modelling framework problems are identified with the aid of broad causal diagrams, in the context of the organisation. Issues are then isolated in relation to anomalies or system deficiencies, but in an integrated fashion, taking components of the system as parts of a whole. This means examining large numbers of causality chains.

In practical terms, the process of building a detailed causal model has no limit as it is always possible to discover new relationships between variables. Hence, model depth is primarily determined by the defensibility of decisions being considered. This occurs when decisions are proved to be 'robust' under a given model specification. Models must be capable of explaining the present behaviour of the organisation (i.e., a reference scenario). However, in more advanced versions, they have to incorporate the proposed system transformations and the likely consequences.

The so-called Cognitive Mappings developed in Eden (1989) are a more elaborate alternative to the causal diagram structures used in System Dynamics. These constructs, which may include thousands of variables in the initial stages, are of some help for problem structuring and negotiations in a troublesome environment. The transition towards a System Dynamics model is briefly explained in Eden (1994). The idea is to reduce drastically the number of interrelationships to obtain an operational model. Therefore, Eden's methodology differs substantially from the one proposed here. Arguably, Eden's method is much more cumbersome as it is not intended to be progressive and incremental unlike the one proposed in this thesis.

Learning via models

The use of models for learning assists in a process of 'hardening' through representing a problem situation. The softer the issue being addressed, the more modelling is required in the earlier stages. At the same time, this implies a deeper enquiry, more learning and, perhaps, more detailed representation - inducing chains of causalities. But learning does not stop there and actions have to be taken (within the policy or strategy framework). In this sense, learning is not passive. On the contrary, it takes an active part in the process leading to decision making. Hence, in the early learning stages models tend to be vague, soft and fuzzy; but they will be transformed into much harder configurations as there is better understanding of the system improvements and as the models become suitable for policy formulation or strategy design. Note that they will have greater depth by the decision making stage. This feedback process can be represented by Figure 2.3.

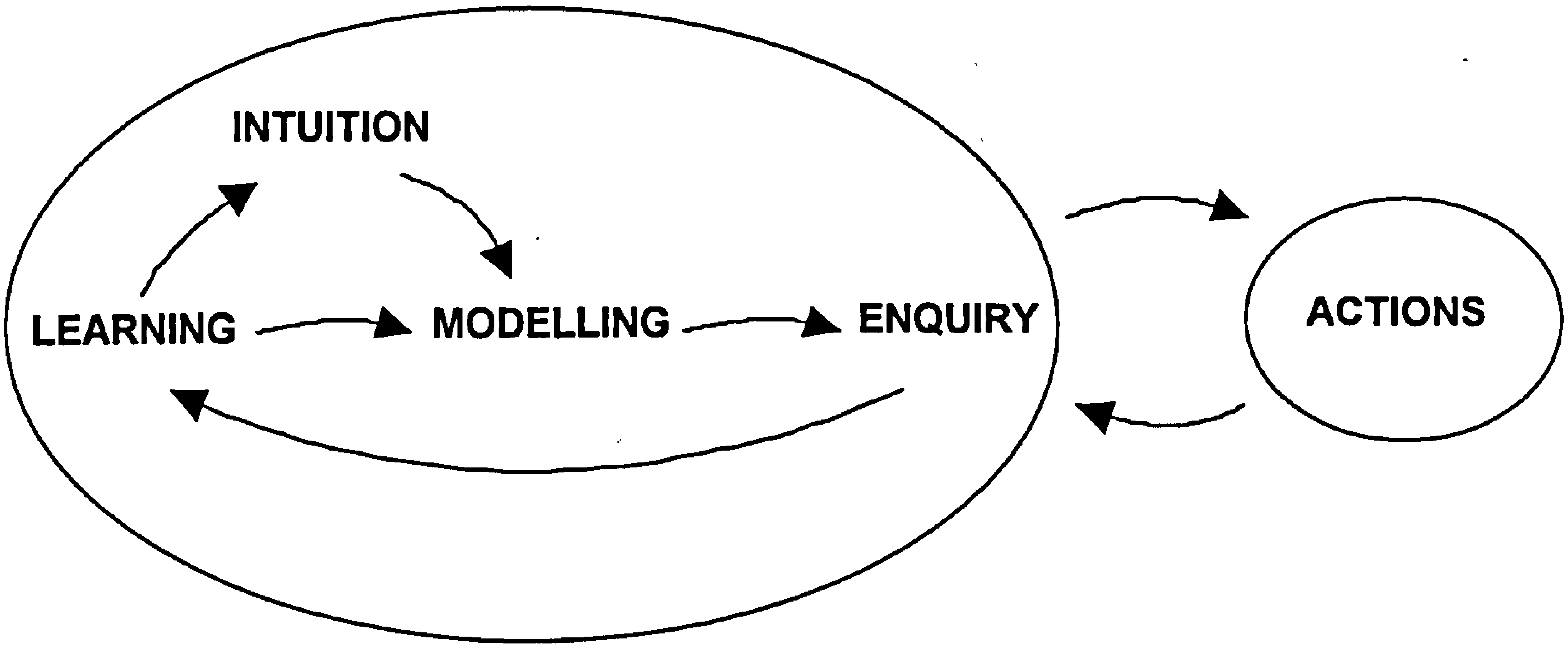

Figure 2.3 Modelling as learning

Here, the double feedback learning process takes place when the results of actions have emerged. At this stage it is worth noting that policy or strategy decisions have a meaning in a blurred sense, not in the context of the classical theory of decision making. This will be dealt with in greater depth further ahead.

2.3.2 Methodology functional capabilities

The methodology needs to support the following functional capabilities:

Goal construction

Here the instrument is blended with the method in an organic symbiosis. The process of modelling and planning/analysis are concurrent. Modelling helps in identifying barriers and also in thinking about desirable futures. The planning objectives and goals are adjusted according to the differences between what is expected and what is observed in reality (or by way of simulations). A more realistic alternative method should consider the direction as well as the final objectives. This can be understood as a complement, in terms of aiming for an interval rather than for a single goal point, as conducted in statistical theory with the interval estimation techniques. In this sense there are no ultimate individual goals, but preferably a band, or an interval, containing final aims.

In this respect, there is room for improvement in the area of software frameworks. The prototype presented in Ninios, Vlahos and Bunn (1995) is a step forward in this direction, although further developments can be made, such as the incorporation of optimisation rules.

Policy design

Once models have been built, through the learning process shown above, policies or strategies can be evaluated. Model development here follows very much the traditional model building stages, except perhaps for data sampling which should not be necessarily drawn during the earlier stages of the process. This modelling exercise not only includes the definition of the functional relations among system variables, it also incorporates parameter estimation, evaluation, and validation of the model, as is explained in the vast literature on simulation, e.g. Pidd (1992). Thus simulations are conducted to run experiments for the purposes of strategy or policy design, very much along the lines of Sterman (1985) and Morecroft (1988).

Strategy formulation

Even though the aim may be to simplify the planning process or to follow mainstream strategic management, according to Porter (1991) or similar approaches, the analysis framework proposed in this thesis, based on System Dynamics, incorporates chains of causalities.

In this case, each strategic option is thoroughly checked through many chains of causalities, and through interactions between the different events involved. Strategic management needs not only the tracking of contemporary trends, as in Hamel and Prahalad (1994), Drucker (1992), Dyson (1991) and Naylor (1986), but also specific forms of action such as the one provided in Mannheim (Popper, 1957):

> "The political problem, therefore, is to organise human impulses in such a way that they will direct their energy to the right strategic points, and steer the total process of development in the desired direction".

Although strategic planning may speed this process, by no means may this be thought of as a justification for not carrying out planning as thoroughly as it should be. A comprehensive and flexible plan may be required.

Organisational structures should be prepared to respond effectively, without threatening the right of individuals or groups, while also encouraging individual's capacities for being inventive and imaginative. Perhaps, they should seek a balance between rigid and lenient organisations.

Decision making

The transition from policy design to policy making, using the same analysis framework, has been explained reasonably comprehensively. Nevertheless, there is still the need for a smooth transition to decision making, as it is understood in classical decision theory.

One way would involve running simulations through the conditions of each decision branch in the same way as conducting scenario planning. The second way would be to incorporate decision trees (endogenously) within the simulation model itself. The construct in this thesis does not address this specific case, but it is possible to carry it out as explained above. To this end, however, Ku (1995) suggests model synthesis between diverse methodologies.

Contingency planning

The approach to planning proposed here is very much at the global level. This leaves room for each unit to perform its function according to its role within the organisation. However, this does not imply that the system performance is not assessed, but rather that there are broad indicators to establish the state of the organisation as a whole and that individual units will be accountable on the basis of a more detailed operational plan.

Perhaps the word “monitoring” contains much of what is intended via the planning process being designed in this thesis. Nevertheless, when uncertainty analysis is conducted, some responses for ‘relevant’ unlikely events ought to be considered, because of their potentially catastrophic socio-economic and political consequences on the system, such as earthquakes or even sudden nation-wide disruptions in electricity supply.

A contingency plan may then be required. This can be constructed very much along the lines of the investigation of reverse causality when searching for undesirable uncertainties. The process to follow for contingency planning will be similar to the one developed for any system on the verge of collapse. The system design may consider convenient to create incentives for units which are prepared for contingencies and to establish penalties for those not reaching minimum agreements.

2.3.3 Technology features

Support platforms for the proposed methodology should possess features capable of dealing with the following features:

Seamless transitions

One of the major problems arising in the analysis process leading to system intervention is the cognitive dislocation imbedded in the modelling process. With existing platforms (analysis frameworks to support policy/strategy) the path through the various process stages tends to be tedious and often very complicated in terms of the required tools, languages, computer packages and the statistical techniques required. This means that a number of translations of specialised knowledge take place: from concepts to logical-mathematical expressions, statistical estimations, via computer languages to the interpretation of simulation results. The expertise needed, then, includes sociology, economics, mathematics, statistics, operational research and engineering, among others. It has always been a challenge to get these disciplines to co-operate, and to obtain beneficial results to the client organisation. The barriers are still plentiful, and there is a need to overcome the communication difficulties resulting from the varied specialist terminologies and idiosyncrasies of different disciplines. In general terms, the transition calls for an approach as follows:

Models dislocation ⟶ seamless transition in the modelling process

The proposed methodology needs to offer a unique common language. To prevent model dislocation, the platform design should facilitate the seamless (transparent) transition through the different stages of the modelling process. In a System Dynamics-based platform, the initial causal maps (elaborated in the conceptualisation-learning stages) are used to construct stock and flow diagrams, which may be written in computer-based programs (such as i'think, POWERSIM and VENSIM), facilitating the tasks of equation formulation and system simulation.

In this environment, the approach seems to provide a seamless transition via modelling, but it still needs to prove viable in practice. This requires a unique technique, an integrated expertise, a single computer-based program, and the same use of vocabulary, terminology and language. Thereby, modelling will be more approachable by strategists and policy analysts, and will become more familiar to the different specialists involved. Their task will then be accomplished more efficiently and effectively.

System analysis for intervention and planning needs to be endowed with a dynamic modelling framework for problem conceptualisation, learning, goal setting, policy and strategy formulation, programme and project implementation, and system control. Models need to evolve through the different planning stages, but language and vocabulary should remain the same. In this process the various model versions containing more detail and refinement should not need for translations through the different phases.

It is a requirement that the proposed platform resolves the technical/terminological problems, leaving greater freedom for analysts to focus on conceptualisation, learning, understanding, policy feedback appraisal and evaluation of alternative options. More attention may then be given to social, political and strategic issues.

Fragmentary modelling and adaptability

Complementary to previous holistic arguments, planning is required as advocated in Popper (1957). This is intended in the sense of addressing difficulties in a fragmentary mode, making continuous adjustments and re-adjustments to policies and strategies, and evaluating the overall effects of any actions implemented in the organisation.

The 'totality' of the system is always observed but actions are taken gradually. Therefore, the system is transformed step by step based on global strategies previously designed. In this manner, continuous adjustments are possible, not losing control over the organisation, and aiming to avoid its possible collapse.

Causal models may help identify system components, when the methodology proposed here has been closely followed. Model fragments or features can be adapted from similar environments, with appropriate adjustments. These components resemble the idea archetypes proposed in Senge (1990). Hierarchisation, prioritisation and ordering schemes may be drawn, after examining possible global consequences. Hence, detailed modelling of the selected sequential actions may be investigated.

Transportability and transferability

Although very much related to modularity and adaptability, the issues of transportability and transferability also refer to model ownership, as well as to construct- and concept-testing. These features have implications for the model development environment, as well as for the number of individuals participating simultaneously in this task.

The reference here is not made exclusively with respect to the capability of adapting archetypes (modules), as previously mentioned but also of transferring the complete modelling environment to a new owner for further development and for a continuous assessment of related and complementary policy and strategy issues. Also, in the developing stages, model components can be brought from similar environments or transported across to a new platform for the appropriate coupling.

In this context, the intention is more towards construct- and concept-testing rather than towards software integration. Constructs and concepts here are examined for relevance and appropriateness.

Continuous adjustments.

The ongoing nature, or continuity, of the planning/analysis process is not only a theoretical concept. It has practical and cultural implications for learning and experimentation (trial and error) because of the inherent and permanent revisions resulting from the process. On the one hand, learning is a continuous activity. On the other hand, planning requires a permanent revision of direction. In this sense, the goal is not to reach the objectives once set in the past but rather to orient the organisational forces towards the chosen target. Therefore, adjustments are made according to recursive approximations of ideals that continuously move out of reach. This could not possibly contradict the long term view for strategies with the short term view for tactics.

Both are complementary as each one has a meaning with respect to the other, as is conveyed by De Geus (1988 and 1992).

Behavioural and bounded rationality

No assumption is made here with respect to the classical economics theory of perfect rationality, or in relation to the search for a single organisational goal. In this sense, the methodology ought to include behavioural components according to ideas expressed in Simon (1955, 1964, 1979 and 1990) and Arthur (1987, 1990, 1991 and 1994). Thus, rather than econometric or optimisation tools, the use of simulation methods for untested behavioural rationality may be indicated, as in the case of strategic manoeuvring of markets, as shown below.

The idea is along the lines that "the intention is not 'to model the treatment and the personal relationships in a more realistic form' but rather to represent the reactions of groups to policies and the existing operating obstacles" (Popper, 1957). In some circumstances, this is conducted as expressed in Bowen (1994), seeking aid from the cognitive theories of decision making to understand better, individually and collectively, the structure of mental decision models of, and the reactions to, system influences. This explains technology diffusion issues in some particular instances as in Arthur (1987).

The main objective, however, is the representation of human behaviour. As it does not presuppose absolute human rationality, the methodology facilitates model building in a flexible mode, integrating observed community manifestations (cultural aspects) which tends to approach rationality in the long term. Popper (1957) states this as follows:

> "Human beings hardly ever act quite rationally, but they act, none the less, more or less rationally; and this makes it possible to construct comparatively simple models of their actions and inter-actions, and use these models as approximations".

Much of what is stated towards the end seems to be naive at the light of the present debate among hard and soft system thinkers. For the former, modelling 'more or less rational criteria' produces an endless number of non-trivial conjectures whereas, for the latter, the basis for applying the classical statistical techniques disappears because of the underlying assumption of parameter instability or the lack of reliable information not yet available due to organisational dynamics. Nevertheless, for both, the fuzzy logic addition to System Dynamics thinking intends to overcome these drawbacks (Milling, 1988).

These ideas emerge ubiquitously, since in analysis and planning the aim of models is to represent the human decision making processes. Many of these ideas carry through to corporate strategic planning where the objective may not always be profit maximisation. For example, a dominant company may risk some important assets at the expense of maintaining an important share of the market. These problems present challenges to both policy makers and modellers.

Participative planning

Planning in which those subject to the plans also participate in the process is comprehensive and contains a variety of features. It signifies decentralised management, 'circular-like organisation' designs as indicated in Ackoff (1994), agreement on actions to be implemented and, in general, group decision making. With respect to planning (plans, designs and recommendations), Rosenhead (1989) calls for effective participation in the process of formulation, debate and refocusing. Also, Checkland (1981), Checkland and Haynes (1994), Eden (1994), Flood (1994) and Jackson (1994), argue along the same lines, with some differences in relation to the final purpose of the exercise. The proposed platform needs to support the conceptualisation, participation and negotiation processes as well as thorough investigation of the likely consequences.

Uncertainty

The overall organisational learning process itself will help lessen uncertainties. The different modelling stages and the continuity of the process will help to identify the main sources of undesirable effects. Nevertheless, the problem has many other angles, and this can not be the ultimate solution.

There are uncertainties related to the environment, the markets and the development of technology, and their treatment depends on a number of circumstances for each specific case. On some occasions, though, it is possible to attenuate uncertainties through the investigation of reverse causalities, in the case of foreseeable system failures. This obviously has its limits as a result of the system's operational conditions, and its efficiency and effectiveness, as established in Jackson and Carter (1992). For example, in the case of an energy system with a high hydroelectricity component, energy shortages may arise during the dry season, because of insufficient water availability. A better balance between thermo- and hydro-electricity installations may then be called for. However, alternative sources should also be considered, such as solar and wind. In this particular case, reliability of the distribution networks should be examined next. Simultaneously, energy management schemes should be promoted, seeking end-use diversification in terms of appliances or equipment source fuel, leading to a more robust system.

In other cases, when uncertainties are exogenous to the system, the inclusion of random variables should not create obstacles in the proposed methodology, taking into account the fact that successes and failures trigger different causality chains.

The methodology should try to reduce uncertainty given that controls are established with respect to the system direction rather than on a specific (unique) objective. This is the case as aims are expressed in terms of intervals and adjustments are conducted continuously - from time to time reverse causality arguments may be explored to address large discrepancies. Hence, we will attain a more robust system, in the sense defined in Rosenhead (1989). The confidence limits for the trajectory can, in this way, be made narrower.

Computer simulation

The seamless transition in the model building process, from system conceptualisation to writing equations, is evident when it comes to the creation of computer simulation models. As stated before, causal loop diagrams lead to Forrester diagrams (stock and flow diagrams) which are then easily translated into equations in one of the specialised System Dynamics languages mentioned above. Although model relations in the different stages do not always convert one-to-one, they often convert almost so; and more importantly, the most robust ones tend to remain when the transition is smooth.

Computer simulation models are thus obtained, and are then ready to serve as experimentation laboratories for policies, strategies and planning. Theories and the probable system direction are then tested and analysed, and issues of consistency and validity can be discussed.

The software technology should be user friendly and simulation runs help to give insights into the problem situation being analysed, as possible trajectories of the system's evolution may be displayed in a variety of forms. Ninios et al. (1995) make some progress in this direction. Nevertheless, there is still room for improvement in this respect, for example, for the multivariate case, which requires higher dimensional spatial representations.

In this thesis, at one level of understanding, platforms are conceived as integrated by model components, which fulfil some of the requirements above. They have been known as such for many years in the energy field for optimisation and simulation purposes. However, as energy industries started evolving towards more liberalised and competitive set-ups, and company strategy emerged as an important driving force, these tools are requiring now major re-engineering to incorporate feed-backs and delays, as well as evolutionary, seamlessness and transferability characteristics.

Yet, at another level of understanding, these modelling structures ought to be capable of supporting construct- and concept-testing features for the investigation of ideas being transferred from one country to others with different ambitions and goals. Summarising:

In this thesis, platforms are model-based environments for evolutionary policy and strategy analysis, and also for testing constructs and concepts, especially under very dynamic circumstances.

2.4 SYSTEM ANALYSIS FOR POLICY AND STRATEGY ASSESSMENT

When issues are concerned with system analysis for policy evaluation and strategy design, rather than with planning, the modelling platform should still support problem conceptualisation and organisational analysis (no implementation stages are intended or considered here).

These new analytical frameworks arise when systems are left to perform according to market rules with little state intervention via light regulating entities. These may be especially true in relation to prices and fair competition, as long term policy effects often need to be examined. This is especially relevant in the case of the utilities industry.

In recent years, countries such as England, Norway and Chile have privatised some of their public utilities and many more are creating legislation to move in that direction. In these situations, even though planning has been ruled out for the most part, the regulator needs to analyse market performance and consumers benefits as some of the created industries are natural monopolies (e.g. electricity transmission).

Hence, when there is major concern for policy evaluation, strategy design or light-handed planning, with system goals in terms of coverage, reliability, quality and environmental impact, the methodology proposed here (endowed with a system analysis platform) can then be viewed as a simplification of the traditional planning approach, as illustrated in Figure 2.4. This fulfils the different methodological requirements illustrated in more dynamic environments, as listed in the first chapter. Although important, it is beyond the scope of this thesis to address explicitly implementation issues related to policy and strategy.

In the case of the privatised utilities, an integrated analysis is preferred as markets, on many occasions, operate under a wide range of limitations, including organisational structure deficiencies (competition), information asymmetries, imperfections in capital markets and environmental impacts. Nevertheless, an integrated analysis is not mandatory, and its use will depend on the particular issues being studied.

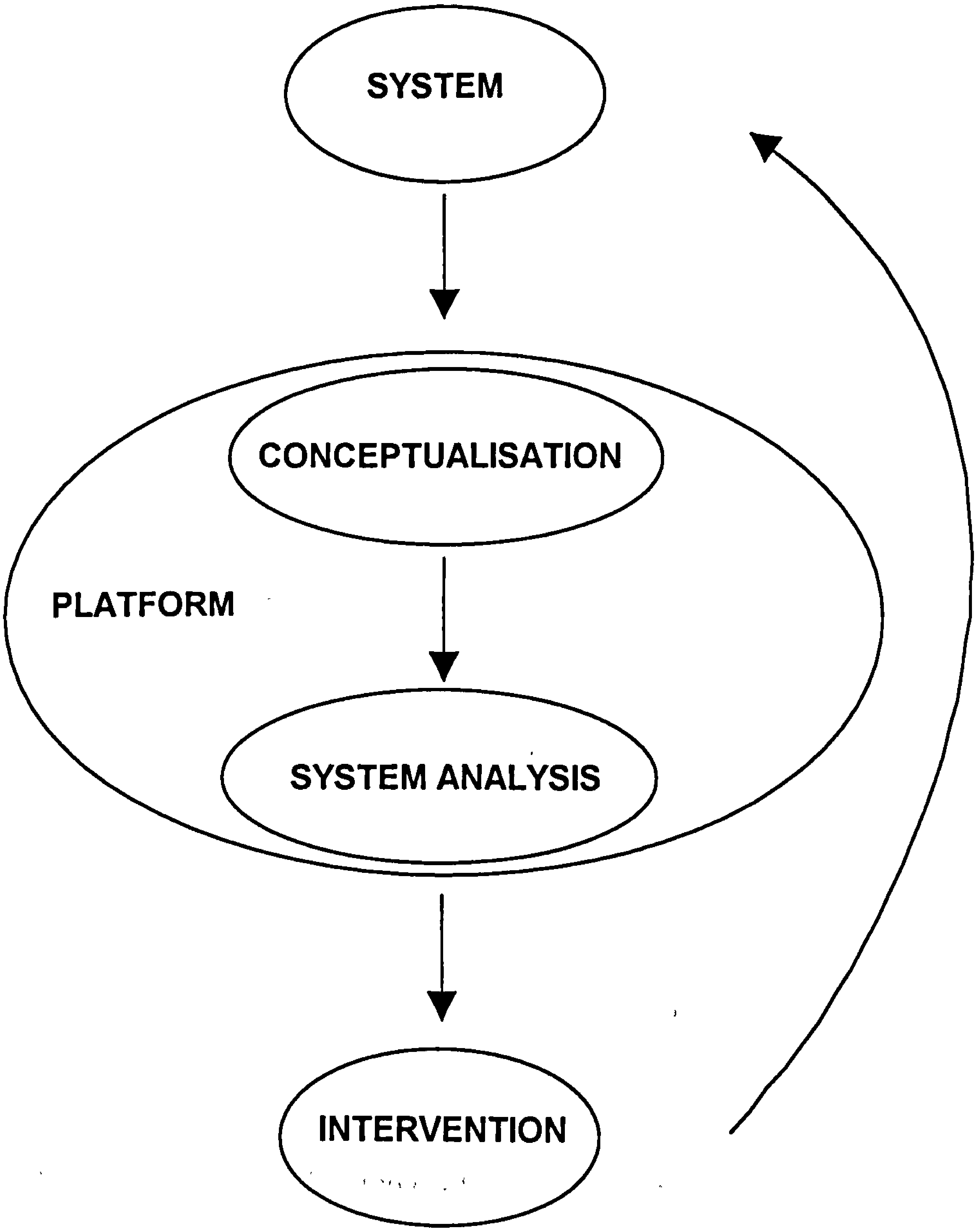

Figure 2.4 A platform for system analysis

The platform needs to facilitate discussions on conceptualisation and analysis and it should encapsulate important information required for policy making and strategy design. Some ideas borrowed from planning are taken across to observe likely consequences for the system evolution, in order to avoid undesirable outcomes. In this sense, the platform does not support a search for a system optimum, but rather a search for policies either to stimulate some specific behaviours or to discourage others. In this environment competition and markets rather than optimality in planning are supposed to improve efficiency. Yet maximisation should be the aim when monopolies operate. Nevertheless the regulator still has a job to do in both situations.

2.5 SUMMARY

In Chapter 1 some methodological and instrumental dilemmas emerged as a consequence of the complexity involved in energy systems and the corresponding ideological/political systems management alternatives. In this chapter the requirements for a suitable planning/analysis methodology have been outlined and the constituent features of the support technology have been described, along with its prescribed functionality.

The simplified Systems Thinking/System Dynamics symbiosis proposed here appears to offer the scope to fulfil the methodological requirements previously discussed, namely:

- Seamlessness (transparency)
- Behavioural and participative
- Continuous adjustments to handle uncertainty
- Simulation capabilities.

Furthermore, a System Dynamics-based platform has the potential to provide support for such a methodology, although it needs to have a multifaceted perspective on its use. In particular, the application of SD should go beyond the classical approach, specifically with respect to the following problems:

- Scale and modularity
- Adaptability
- Transferability and transportability.

These features cannot be acknowledged as part of the classical approach, when considered simultaneously, as they would require a closer theoretical scrutiny. It is still an open question as to whether and how well an SD-based platform can fulfil these modelling and policy-support ambitions. For this purpose, in the next chapter, the possibility of an extension of the SD approach will be examined. Chapters 4, 5 and 6 develop applications to assess this in practice.

3 ARCHITECTURE OF SYSTEM DYNAMICS PLATFORMS TO SUPPORT POLICY AND STRATEGY

Following the modelling philosophy and platform requirements identified in Chapter 2, the platform architecture exhibited in this chapter is based upon the need to implement generic, modular, adaptable and transportable structures, capable of supporting the process of systems analysis for intervention in each particular energy system.

As has been discussed in previous chapters, to reduce the complexity involved in managing energy systems, structural changes have been produced in two directions: integrated planning and market liberalisation.

It has also been established earlier in this thesis that the US has led the way in incorporating DSM into Integrated Resource Planning (IRP) which implies that a broad set of alternatives have to be considered, including rational energy use, rather than just committing a certain amount of resources for building new generation capacity.

To support IRP two major platforms were developed in the US (namely NEMS and ENPEP). NEMS is a serious attempt to co-ordinate inputs and outputs of separate functional components that deal for example with international markets, oil and gas, electricity, residential demand, transportation demand, out of a total of 12 modules. Although ENPEP is similar to NEMS, it is slightly more modest, containing 9 modules and a limited modelling capacity able to represent only up to 30 different energy end-uses. Both use similar non-linear general equilibrium economic approaches which intend to provide 'a picture of long-term trends in energy development'. Being myopic, as equilibrium calculations are made on a term by term basis (yearly for ENPEP), they do not address short term effects or transitional policy issues.

In previous chapters, it was also established that the UK took the lead in a different approach. In this context, it is not so much the liberalisation of its energy sector, which prompted change of ownership, as the overnight deconstruction of a vertically integrated electricity utility into groups of separate companies competing for generation and distribution. The ability of the newly engineered spot market to deliver fair prices and efficient investment signals, together with a regulatory regime seeking to stimulate competition and control prices, had posed many open questions.

The difficulty in seeking to answer these questions comes from the novelty of the markets being created. Without direct experience or close analogies elsewhere, empirical modelling and economic theory are relatively limited in their practical implications. Because of this, and the imperfect nature of the competition resulting from too few competitors and high barriers to entry, strategic business simulation modelling had been found useful in providing some broad insights into the dynamics of investment, pricing and regulation (Bunn et al.; 1992, 1993). The focus in such an approach is to model some aspect of the system as it is designed to operate over time (e.g. the price setting mechanism), the various important companies in terms of their possible objectives and strategic options, various regulatory responses, and through extensive sensitivity analysis gain some insight into the intrinsic volatility and controllability of the focal variables. Such models are selective in their scope, rather than being comprehensive in detailing the whole sector, yet in terms of focusing upon the behaviour of the strategic players in the system, they can provide an effective way of understanding imperfect competition and regulation in an evolving market.

Some countries such as Colombia, are now pursuing a path that synthesises both approaches. In this case it is thought possible for liberalisation and planning to work hand-in-hand. This is seeking a) to promote a gradual evolution of free markets in all activities, when possible, under a regulated framework to protect end-users from market "failures", and b) to incorporate in planning: major environmental issues, appropriate economic signals to guarantee the expansion of generation capacity to satisfy demand, and sufficient resources to meet subsidies for the lower income socio-economic groups.

However, analytical tools are not yet available to examine policy options, specially during the transitional stages. Hence the need to develop a modelling framework, as mentioned in previous chapters which is in particular:

- Modular
- Transferable and transportable
- Behavioural.

The purpose of this chapter is to develop the general platform architecture and some preliminary structural components. These facilitate the construction of specific platforms as will be shown in chapters 4, 5 and 6.

3.1 GENERAL PLATFORM ARCHITECTURE

Figure 3.1 summarises the structural transformations taking place in energy organisations and the place occupied by systems analysis methodologies, as has been discussed above. Figure 3.1 illustrates how integrated planning and market liberalisation, as well as a synthesis of these two, have been used to reduce complexity, which have led to system analysis approaches.

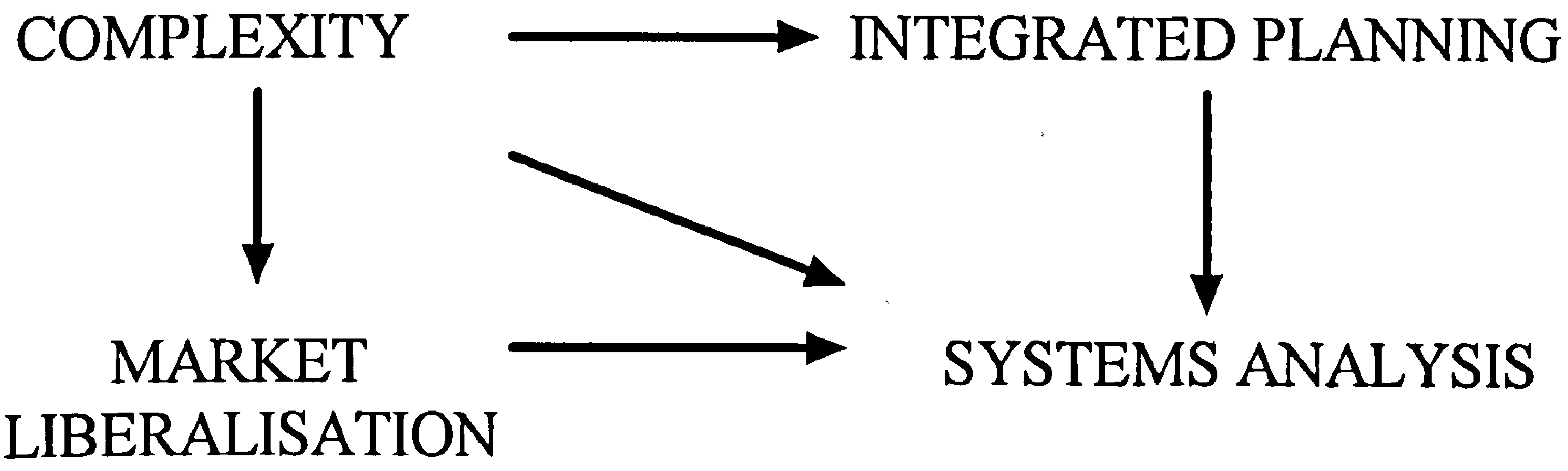

Figure 3.1 Response to energy management complexities

Hence, the required platform for systems analysis has to meet, above all, a modular architecture. This necessarily has to consist of a core component, integrated with particular submodels or components focusing on specific functions or issues.

Taking this into account, as we examine energy systems the first idea to emerge is the separation between demand and supply sectors. Demand is the system's driving force, but this only becomes effective when overall economic performance becomes satisfactory. Hence, one of the components needs to represent the summarised macroeconomic dynamics and, possibly, some relevant socio-economic variables leading to demand.

Representing the demand side can be as simple or as detailed as necessary. When, for example, system growth is very stable, during the period being investigated, it may even be sufficient to express this by a constant. On the other hand, when system evolution is very dynamic, and different community and economic activities are affected by energy management policies, modelling specifications will be more demanding. In this case, some components are required to represent each particular socio-economic group (households, industry, transportation and commerce), along with the corresponding driving forces. On some occasions, it may be unavoidable to detail final energy use according to appliance (e.g. electric, electric efficient and gas appliances). In consequence, at this point, disaggregation extends to three levels: socio-economic group, fuel and appliance.

Other platform components are essential to represent the supply side and the technologies for transforming fuels into energy. Depending on the policy or strategy focus it may be necessary to model the energy source cycle in some detail (ultimate availability, development, production and transport). Energy transformation, such as electricity generation (hydroelectric, gas combined cycle and nuclear stations) may also be crucial in the research enquiry. Hence, depending on issues involved, there is a need for bridges between power generation structures and the production and imports of oil, coal and gas.

Thus, when conducting system simulations, interrelationships between different platform components and the core component, may lead to growth, stagnation and/or decay. Figure 3.2 illustrates a variety of possible links between modelled items. Apart from co-ordinating actions, the platform core-component contains some endogenous variables and may also be used to produce simulation results and balances between supply and demand. Furthermore, the control panel for scenario and simulation run specifications should also reside in this component. The variable 'cost' that appears in Figure 3.3 may be part of the core-component. In this case component 1 represents, for example, the electricity distribution industry, component 2 the power generation industry, component 3 the corresponding regulator and, component K the gas industry.

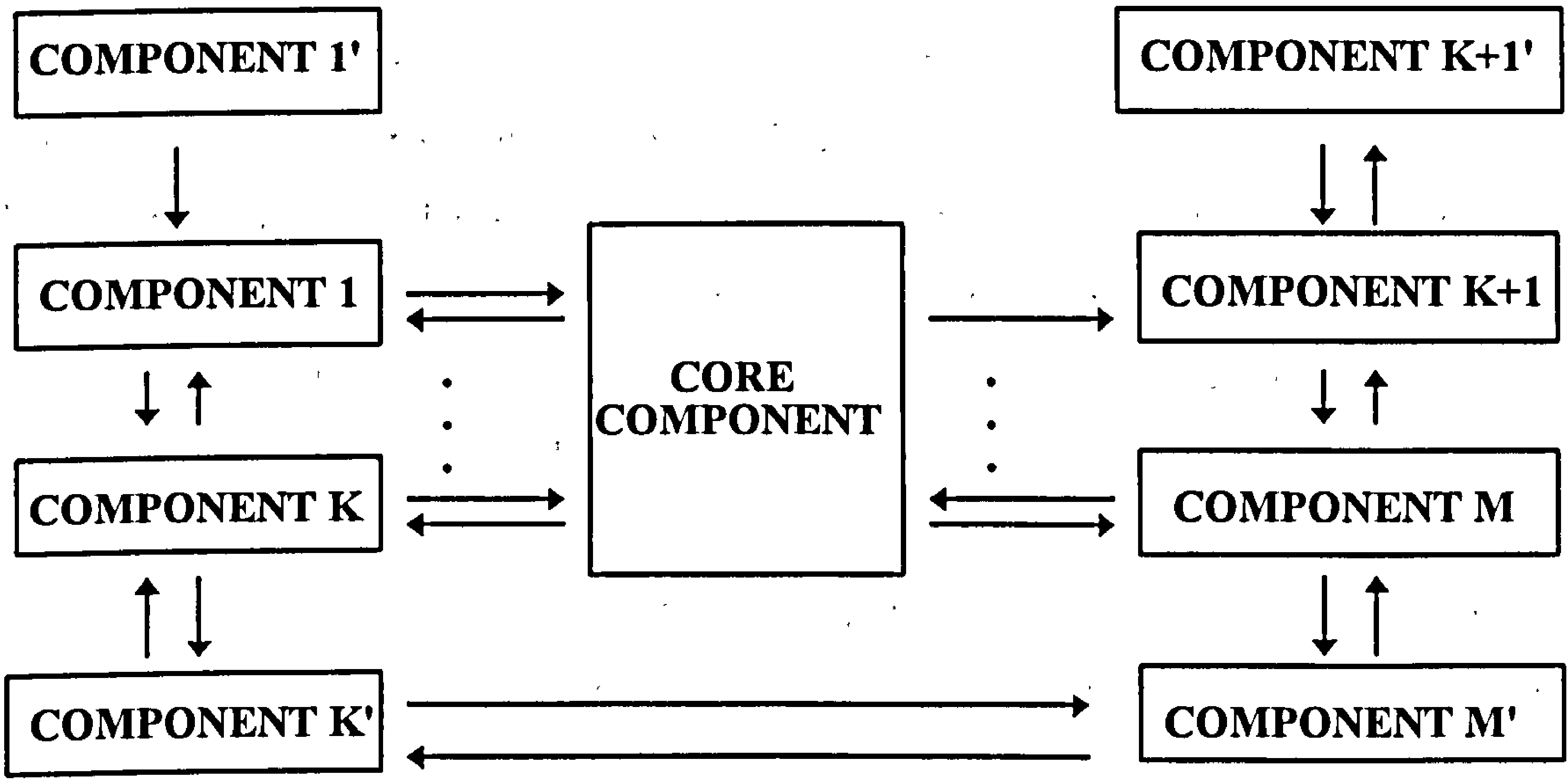

Figure 3.2 Platform structure

This architecture is capable of supporting components representing, for example, the competition between gas and electricity-efficient appliances as alternatives for end-users, and also ownership structures or environmental matters. These can be useful for examining policies on tariffs, losses, subsidies, rational energy use and resource allocation, and additionally to follow enquiries about correct economic signals to guarantee satisfactory reserve margins or fair competition. With this tool, it may be also possible to evaluate strategies for additions to the generation capacity, when actors are exposed to evidence on plant retirement dynamics, fuel price evolution, environmental legislation, or even regulatory uncertainties. Furthermore, as individual players may search for arbitrage possibilities leading to larger returns on investments, it may be possible to incorporate new components into the platform to address the specific issues of interest.

A model component can be integrated into the platform when Demand-Side Management is called to attention. For example, making available efficient light bulbs, or introducing financial incentives to reduce costs of efficient technologies or by way of offering payment instalments. With minimal effort, model disaggregation from the national to the regional level may be achieved, to deal with some specific issues related to privatisation, conservation or energy efficiency policies. Some of these representations are attached to a component, but with no link to other components or to the core model, as illustrated by component 1' in Figure 3.2. In this case, component 1' deals with issues, for example, related to the substitution of electricity appliances by gas fuelled ones, and component M' accounts for the amount of CO_2 produced by the chemical industry. Thus the link between K' and M' updates, for example, the total pollution yield in the substitution of the source (i.e. gas for coal) in this particular industry.

There is much overlap in this structure, since some components may contain detailed versions of other components. This is one of the reasons why some components do not have an arrow back to the core model, deactivating, in this way, the information supply to the main model, as what is illustrated with component (K+1) in Figure 3.2.

Thus, for a particular simulation run, some detailed and some aggregated modules may be activated, avoiding extremely large structures which may produce confounding effects, which are difficult to analyse. With this approach the model size remains "acceptable" and at the same time integrity is preserved. This special feature of the incremental building process can also be useful for verifying model consistency.

The causal diagram in Figure 3.3 yields an overall view of the system. This is a further development of Figure 1.1 presented in Chapter 1. Here, some of the most interesting matters of concern are boxed with dotted lines. The model is envisaged as developing on an incremental basis, first addressing some policy issues that may be of great relevance depending on circumstances and needs (goals). In this sense, learning takes place as features are implemented. In the following sections, the various platform components will be described in some detail.

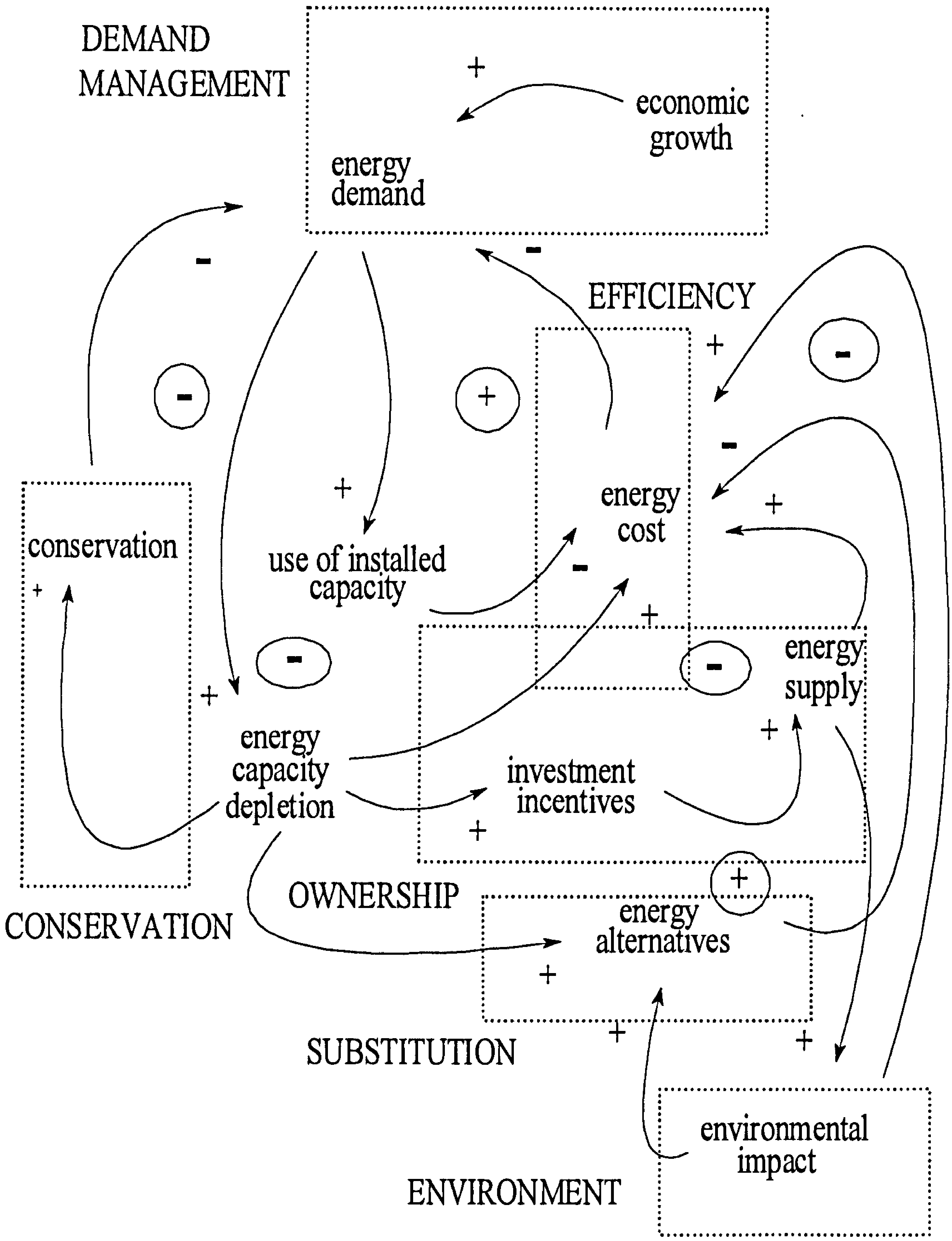

Figure 3.3 General causal loop diagram

3.2 INVESTMENT INCENTIVES AND OWNERSHIP

As can be observed in Figure 3.3 above, when significant depletion of energy capacity occurs, investment incentives clearly emerge (whenever prices reflect costs) with no misleading signals, because of the intrinsic inertia in the dynamics of the system, irrespective of idiosyncrasies and socio-political structures. These characteristics are very much imbedded in the survival and development mechanisms of social organisations.

When planning the entire energy sector a schedule of new projects will be contemplated. Each project is considered on its own merits, taking into account the overall system needs and restrictions through time. Nonetheless, in this respect there are major dissimilarities between the different industries in the sector - for example between the oil and the power generation industries. In what follows, specific reference will be made to the electricity generation business, where three basic energy management approaches are considered.

3.2.1 "Optimal" expansion plan.

Two alternative appraisal approaches may be followed. Firstly, taking the expansion plan as fixed, and then evaluating its performance under different scenarios for the likely dynamics of the system. And secondly, making tentative plans, leaving space for options with short-lead times (such as CCGTs) to complement the plan and to avoid supply shortages and over-investment.

Figure 3.4 illustrates in broad terms the causal diagram that integrates the addition of capacity to the system. As may be observed, the effect of an increment in energy demand produces higher generation-capacity utilisation (when this is possible), creating investment incentives in the industry. For a particular technology, this implies that new projects will be selected from a set containing more expensive plants than the ones already operating (as least-cost mechanisms aim to develop the cheapest projects first). In this case, energy price increases, discouraging energy demand.

An interesting dilemma emerges here. On the one hand, what has just been argued indicates that electricity cost-rises occur continuously at the verge of capacity depletion. On the other hand, it is known that average prices have exhibited a declining trend during the last hundred years except, perhaps, for a period during the seventies (Flavin and Lenssen, 1994). The dilemma can be partially explained, if one understands the difference between short term and long term effects. The former part of the dilemma is more related to spot market behaviour, whereas the latter part reflects the corresponding lead-time effects due to technology developments. Hydroelectricity technologies follow very much along the lines of the first argument since the cheapest dams are built first, while thermoelectricity follows the second argument because of the permanent improvements exhibited in plant efficiencies. Arthur (1990) explains the cost interactions between the dynamics of these two technologies.

When only a lightly regulated oligopoly intervenes in the system, capacity depletion does create incentives to increase energy supply, stimulating electricity prices rises to hedge against risks associated with construction costs. However these costs might never be brought down again (or might only reduce very slowly), even when more energy is available. In this case, once a specific project is undertaken there is very little incentive for an efficient operation.

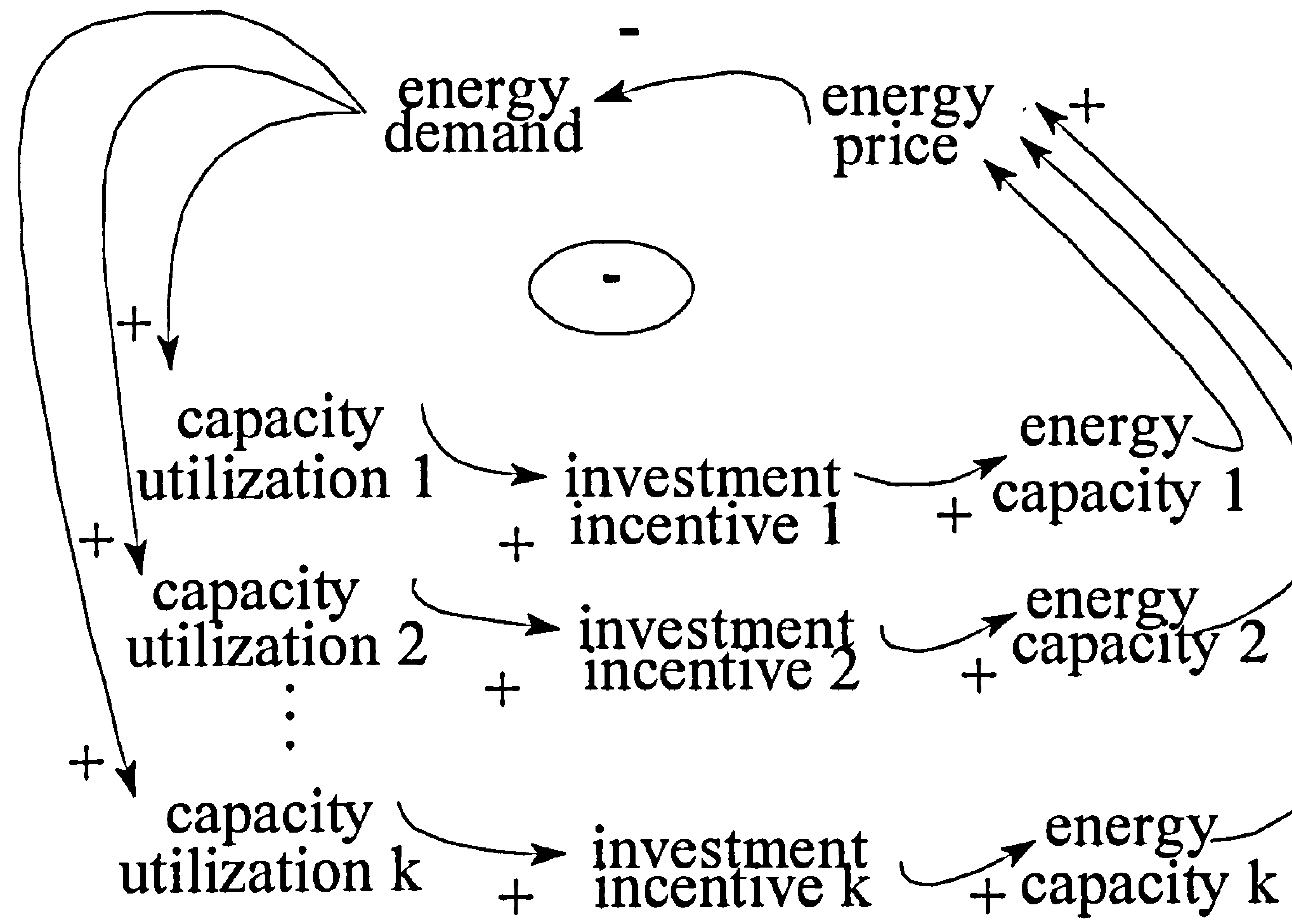

Figure 3.4 Capacity addition dynamics

3.2.2 Indicative or light-handed planning

This approach is considered a 'soft' optimal-expansion plan; it assumes competition and private participation in electricity generation and in the supply of coal and/or gas. In this case publicly owned utilities often hold a large market share.

Many countries fall within this category or plan to move towards similar approaches. There must be a clear definition in terms of the State's role with respect to regulation. Questions such as price, incentives, subsidy schemes, reserve margins, market split and the role of the regulator can be addressed with the aid of the platform.

Potential private investors need clear government policies and signals. Issues such as trust become important as Independent Power Producers (IPPs) will be competing with publicly owned companies. IPPs will assess their returns on investment considering the major risks involved in this activity. Short lead-time options, such as CCGTs, although they may be slightly more expensive than, for example, hydroelectricity, are actually less capital intensive and also turn out to be a natural hedge against price and demand uncertainties. The continuous adjustments to 'soft optimal' plans require taking into account the dynamics of the system. Furthermore, there is a call for carefully designed contingency plans to address under-installment capacity issues during periods of crisis or, incentive problems in general, when these do not operate properly.

Bunn et al. (1993) developed a model to represent a system with similar characteristics to the one being described in this section. Although specifically implemented to represent the UK electricity industry, its general structure remains valid for most of what has been argued here. In this case, few strategic management issues had been investigated. In the next chapter the model is redesigned, following the platform structure described in Figure 3.3, with the purpose of addressing a broader set of complementary strategic issues.

Figure 3.5 shows a very synthetic causal diagram which describes a competitive environment. As may be observed, each company seeks efficiency in order to reduce unit production costs - obviously intending to maximise sales and profits.

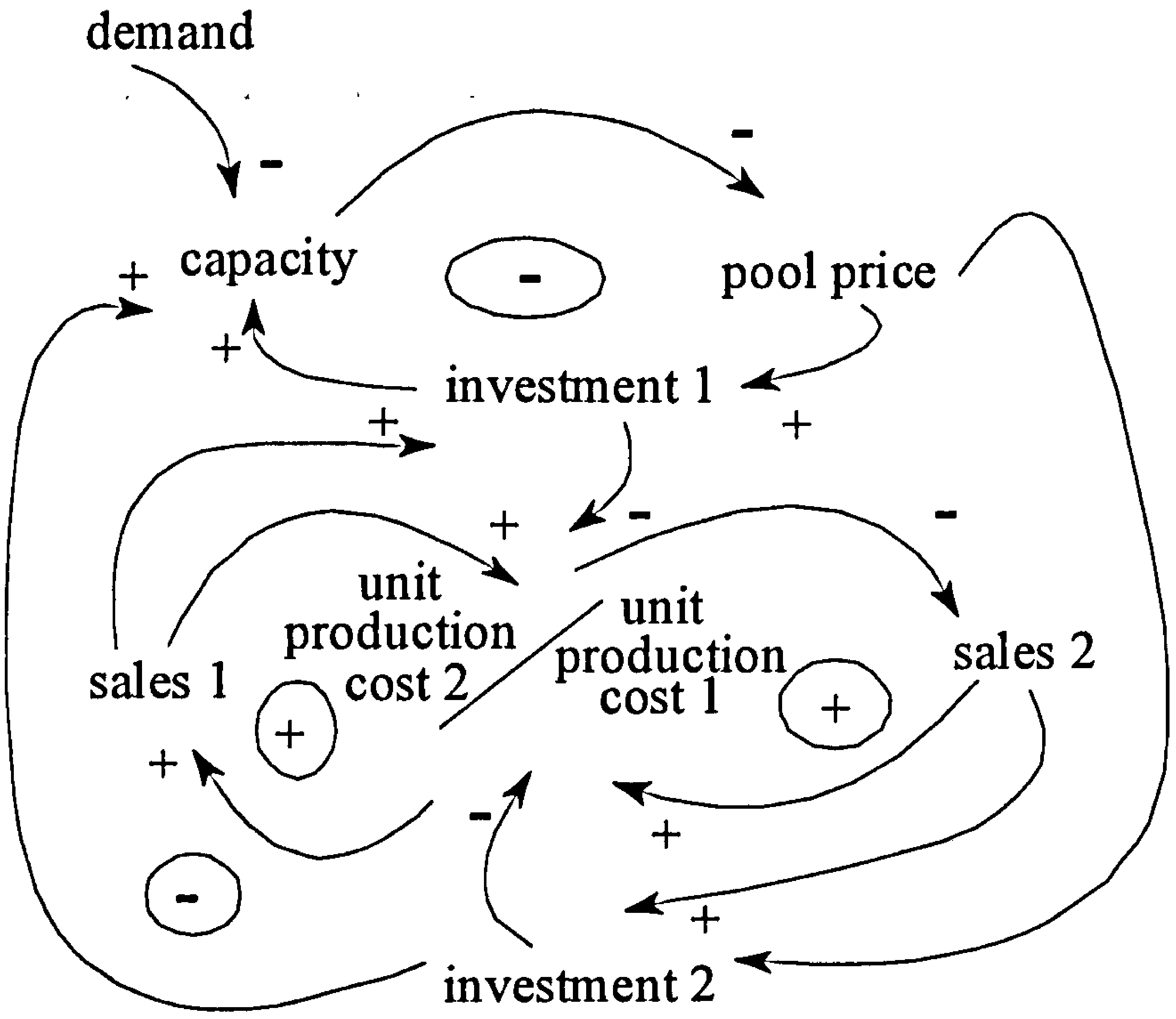

Figure 3.5 Capacity addition under competition

3.2.3 Towards a market system

The transition paths from light-handed planning with regulation, towards completely liberalised power-generation market arrangements can not be assessed by way of economic theory only. To consider eliminating government regulations, at least the following fundamental principles must be guaranteed: a reasonable number of generators, good antitrust legislation, good information systems, security of supply, well-established standards for supply and clear environmental constraints. In practice, these premises do not seem easy to fulfil, because of the intrinsic dynamics of the system and its uncertainties, and furthermore, because it requires accountability to effective enforcement agencies. Nonetheless, a drive towards these schemes may always be part of the agenda. In this case, for example, social subsidies can be dealt with directly through the end-users.

Under market conditions, each generator needs to optimise its operation, to advance down the learning curve, and to acquire more efficient technologies, in order to have cost advantages over its competitors. As shown in Figure 3.5, markets create conditions for price reductions. Bunn et al. (1993) studied a number of company strategies aiming to deter new entrants. However they did not consider a regionalised framework as discussed further ahead in this chapter.

The major advantage of this new market environment is that companies will tend to be smaller, less influential, and the market more 'democratic'. Also, under this new scheme, investigation of energy efficiency may give some insight into the behaviour of generators.

In this section there has been an explicit reference to the general causal loop presented in Chapter 1, Figure 1.1. As details are worked through (for the most general case) unexpected discoveries arise. That is, the transition from a centrally planned industry towards a market set-up may be depicted as the path from a growth mode to a balanced mode in System Dynamics.

3.3 DEMAND-SIDE MANAGEMENT

Demand-side management embraces at least three different sets of issues:

- Energy losses. These, in turn, may be of two types: technical and non-technical (pilfering). Policies that ought to be considered include internal network maintenance and renewal, meter fault audits, rewards for "good behaviour" and legal action against thefts.

- Conservation. Actions considered will include time-dependent tariffs, energy conservation programmes (installation of water heating timers or insulation) and energy supply interruptions (extreme case).

- Rational energy use. Demand-side management (e.g. tariffs based on market prices and financial incentives for acquiring efficient technologies) may encourage rational energy use to complement market efforts through information diffusion or exhibitions. This will be in the areas of source substitution (type of energy), efficient operation of outfits and the renewal of equipment and appliances.

Figure 3.6 shows the formal general causal diagram. Here, in response to increased supply depletion, there is a call for more initiatives by way of demand-side management, leading to more activity on policy design and thus on programme formulations related to DSM concerns. In a planning perspective, these will lead to specific projects on three fronts: energy losses, conservation and rational energy use. These aim to make more effective the diffusion of demand-side management programmes and to reduce energy demand. Policies discussed here are connected with technology diffusion processes, represented below in this chapter.

Delay variables are of utmost importance in systems modelling and they are particularly sensitive in the technology diffusion domain. A careful analysis of how they operate is called for, so the process representation captures more fully the system behaviour.

Here, the effect of demand-side management and market forces upon energy demand ought to be carefully considered. The interactions of such forces will ensure a better customer response, as synergy effects will emerge. Note that the two small lines crossing an arrow mean a delay or a retarded action.

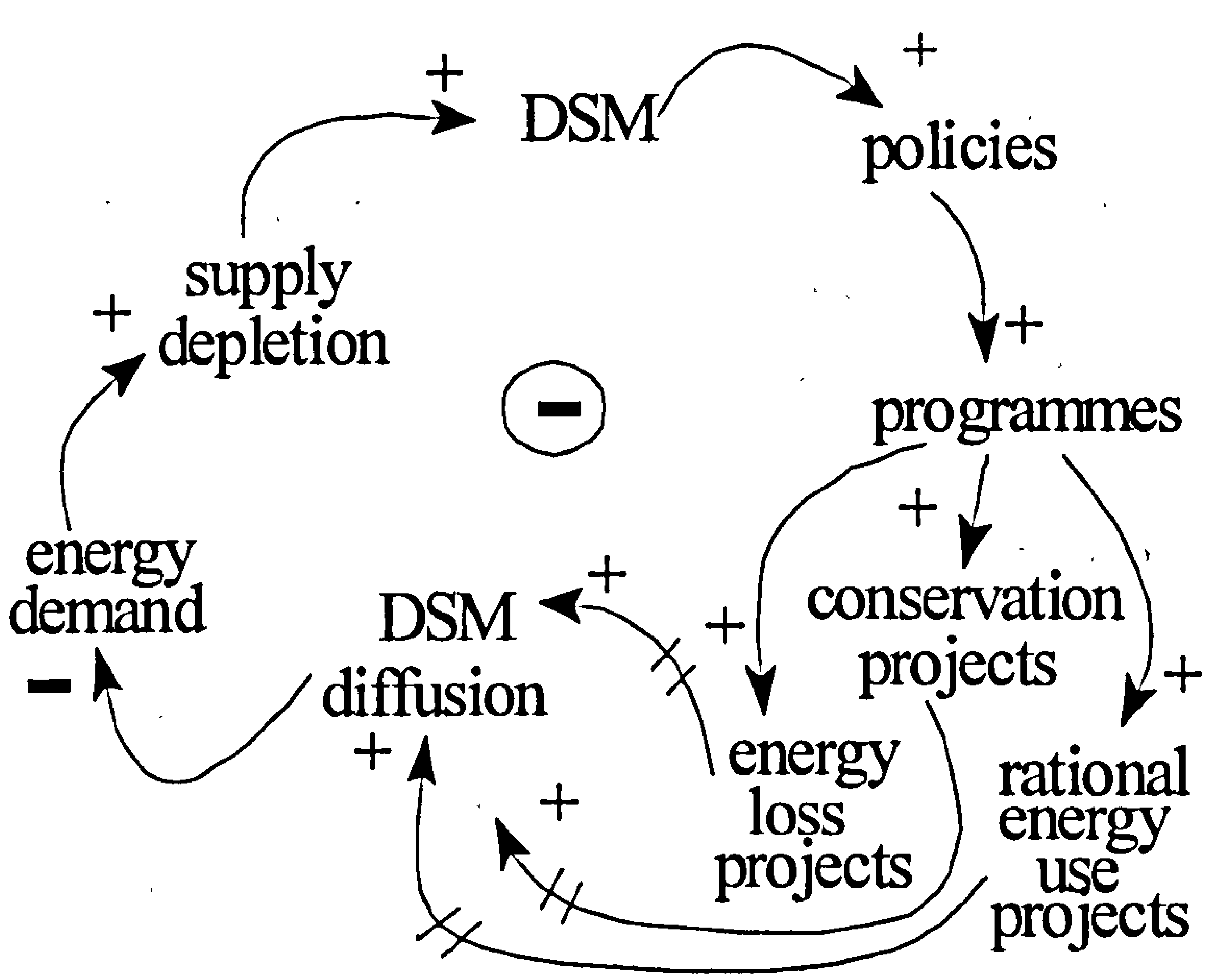

Figure 3.6 Demand-side-management issues

3.4 THE ENVIRONMENT

Environmental problems receive some attention when considering DSM issues in this thesis. Although they are important in their own right, when examined simultaneously synergies arise and benefits become more apparent. On the supply side, environmental effects are largely manifested in electricity generation and transmission.

To reduce these negative impacts, under a liberalised set-up, a possible solution may consider the delivery of DSM services by independent companies. In this case, it will require clear legislation on standards to guarantee sustainable levels of contamination and to prevent the diffusion of, for example, certain poor-quality technologies. At the same time, regulation or planning should address these issues, determining acceptable levels of environmental effects and reducing transportation losses (especially in developing economies). The incorporation of superconductive technologies may be a future challenge.

Figure 3.7 shows close relationships between DSM and environmental impacts. In this causal loop diagram energy development and delivery are not considered independently. As can be observed, DSM effectiveness reduces the necessary capacity for energy supply and at the same time reduces environmental effects. They both affect the price positively, reducing energy demand, except when this creates competition for energy alternatives. This encourages cheaper and cleaner forms of electricity generation but it produces a counter effect as price decreases, consequently stimulating demand.

Here, once more, demand-side management, market operations and environmental policies produce combined effects upon energy demand. These should be considered concurrently to assure a better customer response, as synergy effects will emerge. However, in spite of its importance, separate research efforts on pollution abatement matters will not be made in this thesis.

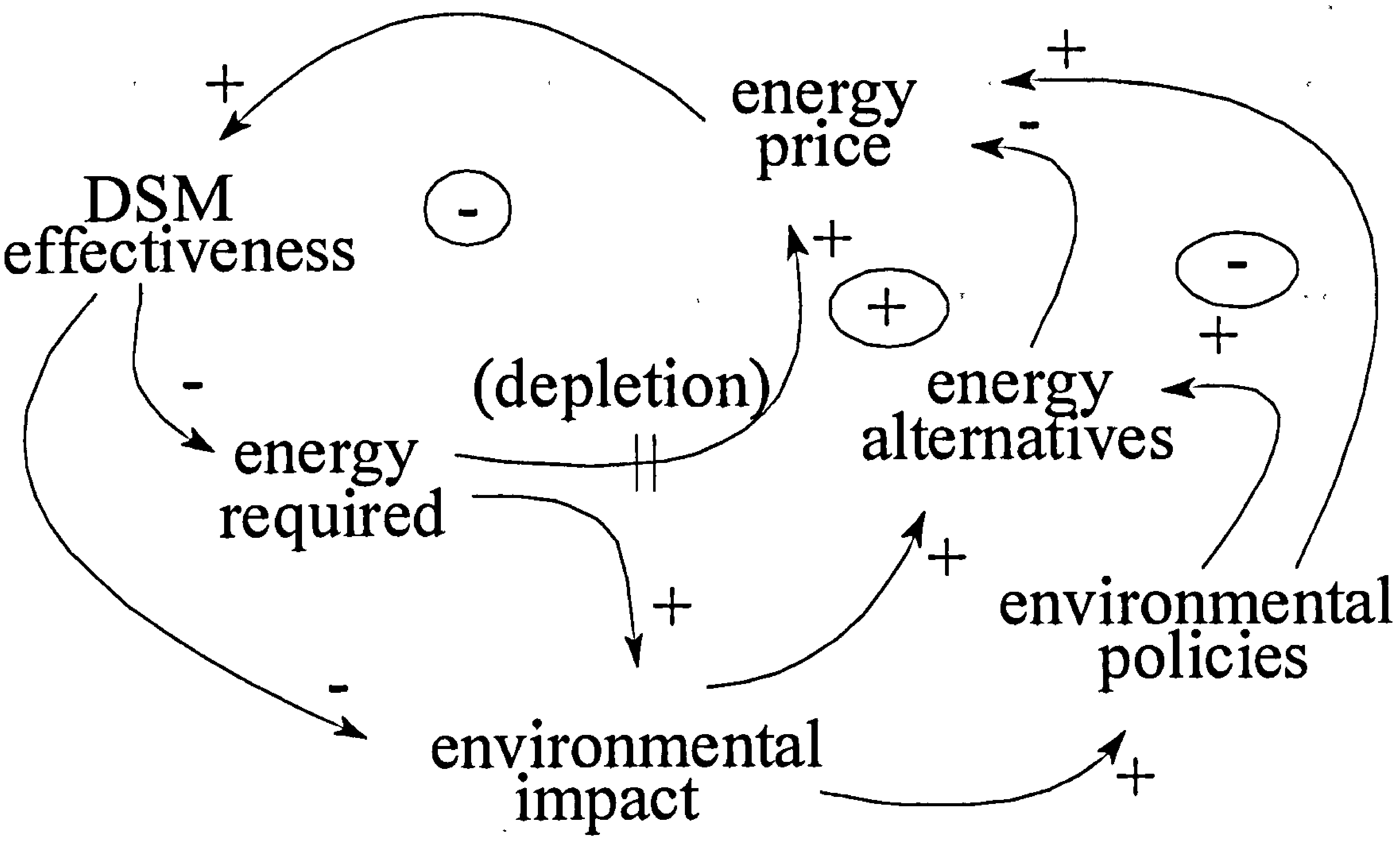

Figure 3.7 Dynamics of environment effects

3.5 ENERGY ALTERNATIVES AND SUBSTITUTION

Modelling a variety of decision making processes that take place in the energy field turns out to be an interesting, and sometimes challenging, problem on its own. Substitution processes fit this category. Thus, for example, choosing energy alternatives is rather different depending on whether end-users are new entrants or existing users are considering substituting a source already being used. For new end-users, the selection procedure includes the evaluation of price, security, supply reliability and the social response. This last variable involves a number of issues relating to technology diffusion such as customer acceptance and customer perception.

For old users, circumstances are somehow more complicated, as the selection of energy alternative includes the substitution of equipment and/or appliances themselves. For them, the equipment price and life-expectancy may be perceived as being as significant as the source price uncertainty. In this case, customers will be taking economic decisions based on the annual equivalent cost, AEC, or on similar financial grounds. For the present discussion, the energy alternatives considered are only gas or electricity, and the equipment type depends on the source it operates (e.g. traditional electricity, efficient electricity or gas fuelled).

Here the AEC is evaluated annually, for each individual appliance with the corresponding source, as follows:

$$AEC = (EC * P) + I + M,$$

where

EC means average energy consumption,
P means average energy price,
I means investment, in the case of substitution, and
M means average maintenance costs.

Averages are estimated over the equipment life expectancy. The average price calculations may be a difficult exercise in the light of forecasting uncertainties. Nonetheless, under this criterion, a rational decision is reached when customers opt for the source S_i*, such that it has the least AEC_i, $i = 1,2,...,n$. That is,

$$S_i* = \{ i / MIN \{ AEC_i, i = 1...n \} \}.$$

In the case being considered here, as substitution may require replacing the internal distribution network, customers will have to make eight calculations (as electric appliances use the same transmission network) to find three different AECs, as can be appreciated:

APPLIANCE	TRANSMISSION	FUEL
GAS	GAS	GAS
TRADITIONAL ELECTRICITY	ELECTRICITY	ELECTRICITY
EFFICIENT ELECTRICITY	ELECTRICITY	ELECTRICITY

A more widely used consumer choice model has the form of the Logit function, formulated as:

$$S_i = \frac{AEC_i^{-\gamma}}{\sum_j AEC_j^{-\gamma}} \qquad i = 1, 2, 3$$

where, instead of the AEC, sometimes it is sufficient to use the average price P, for each alternative being examined, or a proxy of this variable. The parameter γ need not be estimated, and it is often used for calibration purposes to fit the model as appropriate.

This model is more realistic as the parameter γ incorporates other non-financial elements into the selection processes. Furthermore, most consumer choice models adopted in Section 5.4.2 consider some specific bounded rationality criteria, as they include other factors, such as financial constraints, technology diffusion processes and response time-lags.

Figure 3.8 shows a causal diagram that takes into account the substitution dynamics. As can be observed, as more energy is required, more energy alternatives become available (for simplicity only, electricity and gas are examined in this case). Further, as more gas is being supplied, more gas fuelled appliances are selected, bringing down the ratio of electricity supply to gas supply. In turn, when this ratio grows, gas becomes expensive (because of a reduction in economies of scale) and, after a time lag, there will be less demand for this type of energy source, and consequently, less demand. Similar arguments follow when electricity fuelled appliances are selected instead of the gas fuelled ones. Attention to demand-side management and market force effects upon energy demand ought to be considered simultaneously and with care - given the synergies they will render.

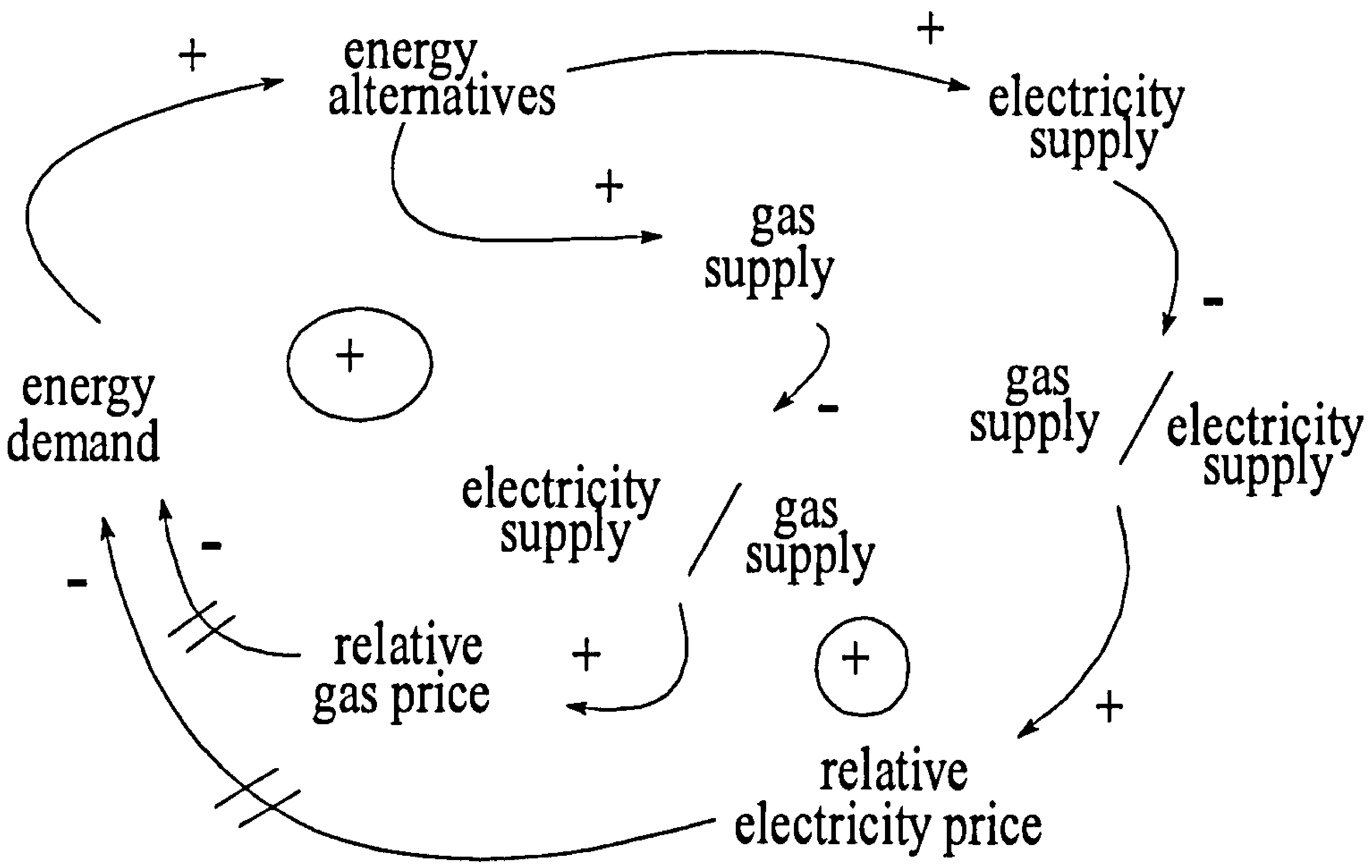

Figure 3.8 Substitution dynamics

3.6 A DIFFUSION COMPONENT

The introduction of new household appliances, for example, addresses the problem of technology diffusion. Diffusion models have been a matter of concern in the general economic literature (Arthur, 1989; Krugman, 1991), and even more in the management field (Leyneis, 1993). In the energy context they render a very special meaning in a rather more dynamic environment, where privatisation and competition are coming right to the forefront, in terms of its importance to managerial activities.

In competitive markets, consumer choice depends on a number of product characteristics such as price, quality, fashion, availability, opportunity and information, as well as on consumer features such as taste, income and wealth.

From figure 3.9 it is possible to appreciate a number of factors favouring the consumer choice for technology 1, when its market share is largest. More money can be spent on technology improvement, reducing production costs, and the competing technology will tend to lose market share as it (product 2) becomes more expensive. It is possible to reverse this situation with environmental regulations or because of the depletion of the source.

Finally, the diffusion processes depend very much on the ownership structure, the market conditions, and the environmental and demand-side management policies. These should be considered simultaneously to ensure a better model structure.

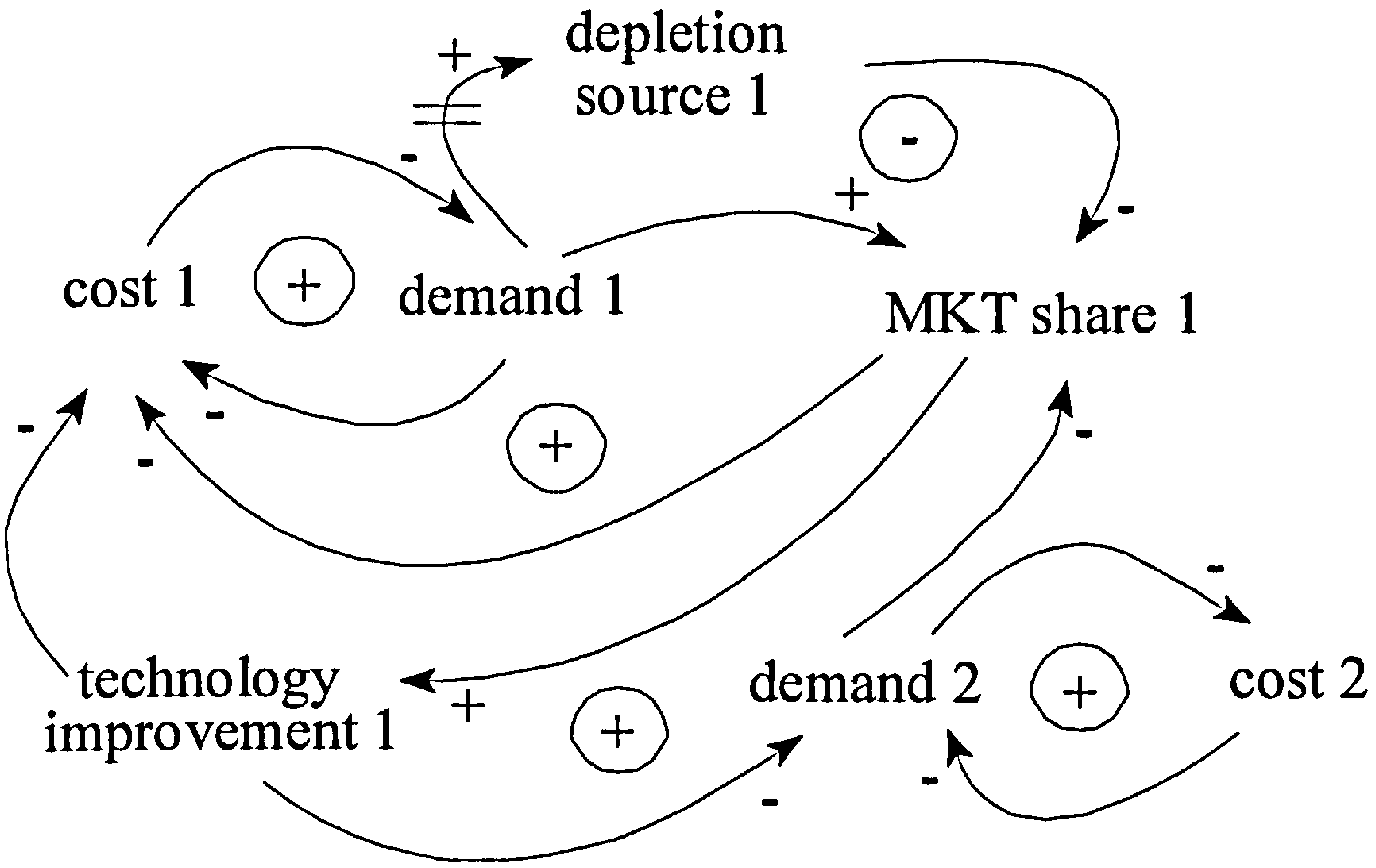

Figure 3.9 A diffusion prototype

3.7 NATIONAL-REGIONAL INTEGRATION

The integration of national-regional markets as well as of government planning and policy schemes are delicate and crucial matters in any country, requiring careful design, which should include consultation and participation processes.

Planning and policy making may take a number of different approaches and the corresponding models to support the processes will have to represent regional and national dynamics, as much as they represent interactions. Effectiveness, therefore, is only proved when these are articulated and implemented.

A region is a subsystem within a nation, trading with other regions and often with other nations. Therefore, the regionalised national model consists of interconnected regional models, where interchanges take place according to market interest and government policies and regulations.

The energy balance of a particular region usually includes reserve margins, exports and/or imports. In the case of surplus, it may be possible to trade-out excess production to other regions or nations. In the case of deficit, the region must try to fill the gap with what is available in interconnected systems, otherwise it may be forced to exercise energy rationing.

In developing economies, market formation is often problematic as the nation controls the vast majority of resources and the regions expect support from the central government. When a global deficit arises, rationing may need to be enforced in all regions, according to policies which may take account of population size, industrial throughput and commercial volume. For modelling purposes, this is not especially more complicated, but it does require the proper assessment of the issues for adequate representation.

Ideally, each region aims for a satisfactory, if not 'optimal', outcome according to the feedback structure represented in Figure 3.2. That is, when sources are depleted, the region will simultaneously reinforce conservation programmes, promote energy alternatives and make adjustments to its expansion plan. Nevertheless, in practice, regions tend to rely on the central government to obtain support for new investments. In this manner, subsystems behave inefficiently.

Strong government intervention could promote this ideal regional behaviour, and complement its actions with a national resource-allocation expansion plan, based on an optimum criterion, or by way of attracting private investment into the system. This will counteract some of the drawbacks that became apparent when discussing the first two energy management approaches presented in the previous section on ownership issues. A scheme with these characteristics 1) will create a more competitive environment between regions, 2) will be much more decentralised, and less bureaucratic (although there may be some duplication of functions) and 3) will yield a more profound sense of participation.

A systems modelling platform can thus be useful for construct- and concept-testing. Particularly, as has been examined in this chapter, it can help to assess, for example, energy capacity additions, DSM programmes, environmental issues, the diffusion of energy technologies, and the regional effects of national policies.

3.8 SUMMARY AND CONCLUSIONS

The platform architecture exhibited in this chapter is based upon the need to implement generic structures capable of supporting the process of systems analysis for intervention. This provides a context-rich basis for investigating a number of different strategies or policy issues. Although a similar framework has been applied in the US continuously since 1976 (Naill, 1992), the open literature gives limited information with respect to the modelling protocol that needs to be followed if such a platform is to provide a sustained level of strategic or policy support through changing circumstances.

As has been shown in this chapter a System Dynamics-based platform has the potential to provide modular, behavioural, adaptable, transportable and evolutionary strategy and policy support under complex environments, although it then needs to have a multifaceted perspective on its use. In particular, the application of SD in these circumstances goes beyond the single focus of providing insight into a pre-selected policy issue. Yet, if the traditional approaches of optimisation and econometrics are losing some of their relevance in the new era of market liberalisation, and SD is well placed to fill the new modelling requirements, it seems that it must offer governmental energy advisors some of the same features of longevity, modularity, adaptability and detail that the other approaches have provided. These features constitute the requirements for a clearer modelling protocol to be developed on systems simulation platforms.

Creating platforms is then a task as much of providing an environment to address a number of interrelated policy or strategic questions as of providing the appropriate functionality for construct- or concept-testing. In this context, they can help evaluating structures or mechanisms being considered for operation in a specific energy system (e.g. pool price mechanism and an expansion plan), and also government policies or company strategies (e.g. rational energy use policies or diversification strategies). For these purposes, the template in Figure 3.2 establishes the platform specifications under which model components or constructs may be examined, whereas Figure 3.3 indicates the broad dynamics followed by the embedded energy system. Figures 3.4 to 3.8 in this chapter are only indicative of the most important platform components.

This chapter has initially concept-tested the platform specified in Chapter 2. In the following chapters these characteristics will be assessed in practice by way of case studies, especially in relation to the modular, incremental, transportable and seamlessness features for systems analysis and policy formulation. There are a number of practical questions which the case studies will illuminate, specifically with respect to:

- The possibility to incorporate feed-back structures under modularised frameworks.
- The platform credibility when large numbers of behavioural assumptions are considered.
- The software capability to incorporate detail.
- The methodology transparency when the platform becomes large.
- The flexibility of energy advisers to think strategically.

4 A SYSTEM DYNAMICS PLATFORM FOR THE BRITISH GAS AND ELECTRICITY CASE

This chapter explores important dilemmas emerging in the energy field as a result of the liberalisation that has been taking place in Britain since the mid 80s. Here it is shown that the methodology proposed in Chapter 2 helped to identify some critical issues of the British energy systems, and at least one of them has been explored in depth, thus testing both the analytical process as well as the architecture of the support platform, which was described in Chapter Three.

This chapter also exhibits some of the features of the System Dynamics platform desirable for the analysis of circumstances such as the arbitrage opportunities emerging in the electricity and gas markets, and shows the specific implementation for exploring the extent of such eventualities. In this case the construct proposed here will prove to be capable of dealing with platform's required features relating to size, modularity and transportability.

In the next section the new structure of the British energy system is explained. This is followed by a close examination of the role of the System Dynamics platform proposed in this thesis as a support tool for regulation analysis or strategy design. Subsequently, the modelling itself is the focus of attention and platform components are presented in

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Results of this chapter have been included in a paper presented at the 1995 international conference of the International Association of Energy Economics (IAEE) held in Washington DC, USA.

some detail. Finally, as experimentation is undertaken, simulation results will be shown to provide insights into strategy formulation.

4.1 THE PRIVATISATION TIME-TABLE

The British energy system has been going through significant transformation processes since the mid eighties. A large proportion of its component industries have been privatised or are in the course of leaving the public sector, strong competition is already taking place in the industrial sector, gradual liberalisation is emerging in the household sector, and yet a further wave of structural industry changes is just getting under way.

Consequently, management has changed considerably. The major concern now is not with cost minimisation, but rather with profit maximisation. There is also a shift of focus, with regard to efficiency prospects, from Research and Development (R&D) to labour down-sizing and expenditure cuts. And, under present conditions, investments take into account a different perspective towards risk, technologies and discount rate - all of them obviously interrelated. Furthermore, competition and market handling become, in this new environment, most important issues.

The near future seems likely to bring still more dynamics into the sector. Companies are expected to play vigorous strategic games, and regulators will have no alternative but to take an active part in this match.

It has been argued that the recent time-table for the British privatisation scheme, set during the early 1980s, was not strategically designed in terms of the consequences to the different energy industries involved (Newbery, 1994), but rather in terms of the complexities of the privatisation scheme itself and its ideological and political impact (Helm, 1993).

4.1.1 The gas industry

The gas industry was the first part of the energy sector to go private when shares of the British Gas PLC (BG) were offered for sale in November of 1986. In those days the industry took the form of an integrated regulated monopoly. Accounts of the major landmarks in the history of the gas industry, including the most recent events, can be consulted in BG (1991) and Quast (1994).

Even though BG was not split up in the early days of privatisation, the Government's initial idea was to introduce competition in gas supply to large consumers - users exceeding 25000 therms per year (this threshold decreased to 2500 in 1992). Consideration was also given to regulating the business in terms of price, security, reliability and quality, aiming primarily to defend small consumers. Furthermore, all gas suppliers were to be guaranteed fair and transparent gas transportation tariffs in the network.

As the market was not developing fast enough and also because of allegations arising in relation to unfair barriers to entry the system network, the Monopolies and Mergers Commission (MMC, 1988) and the Office of Fair Trading (OFT, 1991) made explicit recommendations to take further actions with respect to the 2500 therms supply-threshold and the separation of transportation and distribution in the industry. The first recommendation was included in the 1992 Order of the 1992 Competition and Service (Utilities) Act, and the second was taken to Parliament in 1995.

Yet, as the industry failed to reach the market-split target and given that further complaints came up in relation to transportation issues, BG was referred again to the Monopolies and Mergers Commission (MMC, 1993). Recommendations, this time, included a directive to speed the complete abolition of the gas supply threshold and to split up the industry into production, transportation and distribution companies.

In the near future, industry environmental concerns will continue. Hence, as markets are expected to respond by making further shifts from coal fuelled technologies into gas based ones, this will increase uncertainties in the gas sector (because of uncertainties in incremental demand) well through the first decade of the next century. In this case, it does not seem unlikely that a major share of the gas supply to large customers will go via firms other than BG. Nonetheless, penetration of competition in the domestic market, corresponding to the largest proportion of the total gas delivered, is expected to progress much more slowly.

The proven reserves of natural gas in the UK should not be an impediment to the development of a larger market for at least a decade. As stocks may be depleted later, the European pipeline network will secure sufficient gas supplies well into the next century, although this might be at higher prices, with obvious repercussions on demand. This leaves some issues unresolved: general market uncertainties, international agreements on supply, performance of the gas pool mechanisms (being designed), evolution of competition and interrelationships with other industries. This chapter will partially address the last issue, especially in relation to arbitrage opportunities arising for strategic players.

4.1.2 The electricity industry

The electricity industry, the second in the energy sector to turn private, suffered a series of last minute adjustments, before being sold in 1991, when it was thought that part of the scheme under consideration by the Government would fail to go well in the stock market. This was mainly due to difficulties related to all the liabilities involved in the operation and dismantling stages of the nuclear industry. For political reasons relating to the set time-table for privatisation, the Government thus decided to leave the Nuclear sector public and go along with the rest of the blueprint as planned.

In the end three sets of packages, containing independent companies, were made out of the previously electricity monopoly (CEGB), dividing the industry into production, transmission and distribution companies. Thus, fifteen component companies were sold separately, except for the National Grid Company.

This new set-up aimed to bring about a competitive environment for electricity production. A pool was created so different companies would bid, in half-hourly periods, their respective operational prices for each plant. On this basis, electricity supply criteria to satisfy demand indicated that plants should be ordered according to merit and that those with lower prices should be dispatched. Fixed term contracts are allowed between buyers and sellers but all electricity is delivered according to the pool conditions. In this way, some trading between producers may take place to fulfil contacted obligations.

Transmission, constituted as a regulated monopoly business, was owned during the early days by the existing regional electricity distribution companies - RECs. All electricity transported over the grid has to be paid for according to a cumbersome, but well defined, wheeling formula.

Electricity distribution, comprising twelve companies, was originally designed as a regional monopoly to serve household customers. In the early days, large industrial consumers were only allowed to buy electricity from the pool, but in the near future they will be able to do so directly from the generators.

The system is far from stabilisation yet. From the markets' stand point, major problems arise on the generation and distribution sides. Pool prices do not always reflect reality as engineered volatility has been created artificially by the manipulation of some companies. Furthermore, there is a big question mark in relation to the evolution of the industry structure and distribution market. Weaknesses of the pool mechanism are explored further ahead.

4.1.3 The coal industry and others

For the coal industry different alternatives were being examined by the Government during 1994, and final agreements were reached when negotiations with a few buyers were settled by the end of December 1995. RJB Mining acquired most of the English mines, Celtic Energy got all the open-cast sites in south Wales but Scottish mines have not been sold yet. Green (1994) argues in favour of the protection of this industry and believes that under private ownership a further contraction should be expected.

Developments with respect to the nuclear industry are only now becoming clear. A special commission was set to enquire about the future of the industry in 1992, just after the privatisation of the CGEB, and was due to submit results by the end of 1994, but this only came to light in 1995. The Government decided then to sell its assets by mid 1996.

Renewable energy sources account for about 2 per cent of UK electricity (Rae, 1993) and the scope for these alternatives is limited in this part of the world. In spite of the fact that regional electricity companies in England and Wales are obliged to derive a specific amount of their electricity sold at premium prices via renewable generation, the short term target, to reach only 1 GW newly installed renewable-energy capacity by the year 2000, is not very ambitious by European standards.

4.1.4 Regulation

The regulation task has taken an interesting learning-by-doing approach in the energy sector. The gas industry has had a busier time with the regulator than other sectors, not only because it has been privately owned for a longer period of time but also as a consequence of being originally made a private monopoly, for the major part of the business. Because of this, the Office of Gas Regulation (OFGAS) has been forced into an more interventionist approach towards the industry, as it referred British Gas PLC to the MMC and the OFT, in a fairly short period of time, as explained previously.

While in the case of the electricity industry, the Office of Electricity Regulation (OFFER) has possibly taken a more dialectical, light-handed attitude, the electricity industry has not been excepted from criticism nor from threats of tighter regulation or MMC referral.

Although electricity prices have not gone up since the privatisation dates, Helm (1994) states that these should be somehow at a lower level - an issue that has been disputed by OFFER (Littlechild, 1994). In this debate, the Director General of OFFER can prove that his office has certainly undertaken some actions. He has challenged the structure and pricing conduct of the main fossil fuel generators, as Helm (1994) recognises, and he has also threatened to refer the RECs to the MMC commission if they do not stop moving towards vertical integration (Smith, 1994, and Smith, 1994b). Furthermore, he has asked National Power and PowerGen to sell 6 GW of generation capacity and has also opposed bids of these companies for vertical integration (The Economist, 1996).

The British approach to regulation has brought up a series of contributions to this important and, in many senses, new activity, as illustrated in Beesley (1995), Beesley (1994), Beesley (1993), Armstrong et al. (1994), Stelzer(1991), Veljanovski(1991) and Beesley and Littlechild (1989). These contributions point mainly in two directions: the Retail Price Index Minus X (RPI-X) cap formula for prices, and the institutional structure aspects related to the office of regulation itself along with the corresponding legislation. These ideas contrast with the long US experience with respect to this function, where interests centre on very detailed legislation on procedures, plus price controls on rates of return.

In general, the regulatory approach has followed the lines of a well thought out, independent and committed activity, and one that has been prepare to make continuous adjustments. In the years to come, however, much more is still expected to emerge, as many sectors will move more rapidly towards a much broader competitive environment and also as major reviews are due throughout the various industries.

In particular, energy regulation may be expected to suffer significant changes, as natural tensions between different social groups will build up over time. Some companies may probably benefit from gaps in the legislation or from the lack of co-ordination in the energy sector, this at a time when diverse social groups may call for a much faster decline in prices and for a stronger legislation in relation to environmental issues.

Further ahead in this chapter it will be possible to observe an example of how a company may benefit from acting in two different markets, and will most likely get away with making large profits during some periods of time. This is, partly because separate entities are responsible for the regulation activity for the electricity and gas industries and neither will be monitoring both markets simultaneously. The System Dynamics platform created to analyse these phenomena will show how useful it could be to study such eventualities.

4.2 A SYSTEM DYNAMICS FRAMEWORK FOR ENERGY ANALYSIS

As has been described in previous sections, the energy sector in England and Wales has been broken down into independently regulated industries, yet there are a number of interrelationships between them and, as no co-ordination has been considered, some questions arise.

4.2.1 A call for integrated analysis

First, let us discuss a few important overlaps that may be observed across the various energy industries:

- They compete in the same consumer market (e.g. electricity and gas as end-uses for cooking and for water and space heating), and from 1996 onwards there will not be a monopoly for distribution. Therefore competition is active not only for fuel choice but also for the supplier's selection.

- In electricity generation the main issue is related to the technology employed. In this sense, gas based plants such as Combined Cycle Gas Turbines (CCGTs), seem to outperform initially the coal based ones, such as the new Integrated Gasification Combined Cycle (IGCC) projects (Chester, 1993). In this case the evolution of gas prices will be a determining factor for the choice of either alternative. And even in the near future it will be very difficult to rule out completely the nuclear based options.

- Environmental issues must be examined across the different industries and effects have to be evaluated in an integrated framework. Major problems are considered all along the line from source development to final energy use, passing through the technologies involved in generation and the means used for transportation. There is some literature on these issues, such as Cartledge (1993), but very little has made use of an integrated approach, as intended in Newbery (1994) and Anderson (1993), and almost no paper has claimed to have considered synergy effects in its corresponding calculations.

- Efficiency issues should not only be considered hand in hand with environmental issues, but also when taking into account particular entry barriers, pondering carefully each particular problem. For example, internalising environmental effects will help the entry of cleaner technologies which, at the same time, will help to increase the rate of propagation of efficient energy end-use devices, mainly because of high energy prices. Efficiency has been a major concern in the energy world, especially in relation to electricity (Anderson, 1993), however Rook (1993) claims that it has been in the gas industry where major improvements have been accomplished.

In the light of these overlaps, it does not seem reasonable to continue analysing matters taken out of context, or isolated from the system where they 'naturally' belong, as side-effects, feed backs, delays, and non-linearities of the proposed actions will divert from what is intended in each particular case. Also, in this sense, analysts or policy makers might fail to identify some of the 'free rides' that may be gained in the process.

When an integrated approach is not undertaken by the Government, in a liberalised market, even when it is closely regulated, industrial and trader strategists may make use of unfair opportunistic advantages of the given circumstances. Some will consider taking actions towards:

- Maximising profits by intervening in several related markets at the expense of customers.

- Manipulating markets. For example, by creating price volatility, they may be able to charge high premia on long and medium term contracts.

- Collusive oligopolistic behaviour. This is also possible given the actual circumstances prevailing in all energy markets at the present time.

- Avoiding a serious commitment to DSM. A large number of possible end-use efficiency programmes will not be seriously pursued by the different energy companies. Hence more activity from pressure groups should be expected in the near future. Therefore, some of these efficiency programmes may be developed along with environmental ones, with potential for synergy.

- Inappropriate use of subsidies. Companies or individuals may misuse government support towards, for example, conservation or efficiency policies in electricity generation or in the household sector. This will show poor performance of Government programmes.

- Limited R&D investments. Several forms of R&D will not be undertaken by private generators and utilities. This is more evident when and where capital intensive technologies are involved and, specially, in the presence of long span returns on investments (of which there are many cases in the energy sector).

- Ignore national strategic issues. If indigenous coal or nuclear programmes are strategic for Britain, it may not be very wise to leave these exposed to market forces, as short term opportunistic behaviour may end up scrapping these completely. In this case, the long term costs will be very high.

- Disregard incentives to environmental impact-free devices. Product standardisation may be of help to ameliorate this behaviour.

Therefore Government, customers (via consumer associations), large producers and entrepreneurs will gain from an integrated, effective, analysis framework. The Government has shown genuine interest in engineering market environments where all players have fair opportunities but, at the very least, it is also probably aware that entrepreneurs will take advantage from any gap in legislation or from any competitive edge they may possess. This means that for different reasons all players may gain from system tools such as the ones proposed in this thesis. Furthermore, an individual, group, or company may benefit from an integrated analysis platform at the expense of a less strategic player, or a group with less potent analytic instruments.

4.2.2 A System Dynamics platform for the UK case

This section examines diverse aspects related to a System Dynamics platform proposed for the UK case, according to the requirements established in Chapter 3. It brings partial answers to the following questions: What is the motivation for creating it? (How does it arise?) What is lacking in alternative methodologies? (What is the gap?) What is the essence of the new methodology? In what circumstances can it be used? How can a major player benefit from it? What are the key components?

The new energy market environment specially engineered for England and Wales has proven, so far, to require continuous adjustments in order to fulfil the initial set goals, since the days it turned private. On the one hand, as 'market imperfections' have prevailed, regulatory institutions have had sustained close scrutiny of events to make the amendments required to achieve their task effectively. In this case, system tools may be important for supporting this task, as is shown ahead. Some results even suggest the necessity of bringing about some institutional redesign, in the form of greater co-ordination between regulators.

On the other hand, as this environment has created opportunities for independent companies, these have been alert to strategies for maximising profits through opportunistic behaviour, arbitrage, mergers, vertical integration, diversification, economies in scope (meter reading and billing) and innovation. In this case, the classical optimisation and econometric techniques have been shown to possess three main disadvantages: inadequate modelling of the dynamics, analytical constraints and lack of flexibility (Lee et al., 1990). However, although these techniques can represent many of the relevant dynamics of the systems, the complexities resulting in the corresponding formulation appear to have discouraged their widespread adoption by practitioners.

In this latter case, does regulation have to set a balance between what is within and what exceeds the limits? How much does each actor benefit from the present conditions? And, what are possible regulatory modifications and likely outcomes?

Powerful analytical tools for analysing these complex environments are scarce as the need for them has only arisen as a consequence of a completely new policy on state management, implemented in Britain since the middle of the 1980s. Separate intervention has occurred in each sector, taking special consideration for many of their particular identifying features, with no intention of following a single general rule or model.

Before moving ahead to address the next questions, it is important to acknowledge that each sector and each industry needs to be examined thoroughly on its own merits. The purpose is to consider specific structural characteristics and to take account of both novel features and possibly some earlier problems.

The System Dynamics platform proposed here have to prove capable of becoming a tool for policy support, as it will be argued below, to overcome some of the players' opportunistic behaviour discussed in section 4.2.1.

- In this environment, issues need to be addressed in a progressive, incremental and stage-by-stage fashion. It is intended neither that all issues be implemented simultaneously nor that they should await a universal plan to be fully formulated before proceeding to intervene in the system. In Figure 3.3, for example, some relevant problematic issues emerge clearly when examining a number of existing relationships. As the electricity industry changes from public to private ownership, questions related to the system margin arise; see Bunn et al. (1994). Yet this issue is related to the problem of technologies utilised for power generation as well as to the problem of appliances used by households, given that natural gas is an alternative for energy production and a fuel for end-use. Thus, the original model developed by Bunn et al. (1994) needs to be augmented to be capable of analysing concurrently issues related to gas and electricity. The following section illustrates this.

- When expanding electricity generation capacity, perhaps the most relevant issues are those relating to technology choice. Then a number of considerations emerge, such as: financial, environmental and strategic concerns. Here, the incremental approach becomes visible again. A component needs to be added to the model to focus on possible strategic manoeuvring of major players intervening in the system.

- Efficiency and demand-side management problems are very much connected to those of pricing, source substitution, environmental impact and technology choice. Nevertheless these issues are not examined as part of the British case as they will be considered in the following chapters.

When studying company strategies rather than government policies, it is not surprising to find that corporate and governmental interests diverge more often than not. However as they act on the same environment, most of the rationales needed to be represented in the core industry model may coincide. In what follows it is discussed in what circumstances a System Dynamics platform may be of help in exploring diverse strategic issues.

- A company does not necessarily win from diversification, except when synergy effects take place. This is possible, for example, when in-house expertise may be shared, the same distribution channels may be used and, economies of scope are possible and facilities may be commonly shared. But even in these situations, a close examination will be required to prove this to be feasible (Campbell and Sommers, 1992). In this chapter investigation is conducted to establish whether a major actor in both electricity and gas markets may benefit from strategic behaviour at the expense of consumers.

- Pool pricing is almost optimal under the recent privatisation scheme (Green, 1991), only when generators produce tenders at the marginal costs. It is not difficult to prove that in this case one "very good" strategy for the owner of a single power station will be to bid at the marginal cost (Vickery, 1964). But as the industry set-up differs greatly from the hypothetical case, other alternatives emerged as better candidates. In fact, Green (1994) shows that in the British case the major private generators could push up prices to undesirable levels. Also, simulation may be of help to determine whether major players benefit from manipulating markets by way of inducing price volatility in order to force large customers (i.e. RECs) to make agreements at higher premium values.

- Companies must be driven towards environment-friendly technologies, but sometimes they might just do it for strategic reasons, for example to discourage competition. At the eve of privatisation in Britain, companies decided to move into massive investments on CCGT technologies - the so-called "dash for gas". Part of the motivation had to do with environment and capacity margin questions, but many researchers and consultants believe that the main reason was based on strategic grounds, rather than on other motivations; Newbery (1994) and Lewington (1994) illustrate this point. On different grounds, an analysis platform may support investigation with respect to the likely benefits of close relationships between independent energy producers and RECs (to determine whether the former attain larger market shares).

- As stated before, on many occasions company strategies are not compatible with government policies. The case of the "dash for gas", for example, might have produced a clash of interest, had the government considered the indigenous UK coal industry to be of strategic importance. As is widely known, when electricity power generation started shifting towards gas-based technologies, a large number of British coal pits had to close as it became unnecessary to renew many long-term coal contracts. Simulations ahead (Section 4.4) investigates how much worse this may be if the plant generation mix follows an unlikely, but plausible, scenario where most of all new capacity would be based on gas technologies. But even projections of greater likelihood are little more favourable to coal (MMC, 1993). Furthermore, the British nuclear prospects may prove to be even more dramatic, if there is no government intervention.

4.2.3 Platform requisites to support strategy

As has been discussed previously in Chapters 2 and 3, the methodology developed in this thesis has to fulfil specific requisites. It is possible, however, to consider developing alternative frameworks to support strategy analysis but they will only be comparable on the basis of the following features:

- Learning. The methodology should enhance a double loop approach to learning - learning as a process of continuous adjustments. Superficial as well as deep knowledge should be possible. One induces the other.

- Facilitation of an incremental approach. After a problem has been identified, a policy or strategy may be studied and then, recursively, a new problem may be addressed. When the aim is system intervention, the system's behaviour should improve or else alternative policies should be examined.

- Modularity. The methodology should facilitate the addressing of a varied number of interrelated problems in a modular mode. No particular order should be required in the way the platform is developed; it should assist the progress of policy making and strategy analysis during the development stages.

- Flexibility and adaptability. Detailed or aggregated modelling should be possible. The methodology should help to transform the system and should be capable of evolving along with it.

- Long life span. The methodology's modularity, flexibility and adaptability should provide it, in principle, with a limitless life. In this sense, although it is never fully developed, the platform is designed to support policy or strategy in an incremental fashion.

- Non-linear, feedback and delay relationships should be part of the modelling approach. In most interesting systems, these relationships appear in a number of instances.

In this section only a few major issues favouring an integrated platform for energy analysis have been presented. Others are left for further research. The ones included here support the dynamic, flexible and incremental approach proposed in this and previous chapters. However, for reasons related to policy relevance in the UK and Colombia, some complementary issues are studied in some detail, in a different chapter. While company strategies are being studied in this chapter, DSM policies will be investigated in later chapters.

4.3 THE SD PLATFORM AND ITS COMPONENTS

The previous section explored the conditions under which a platform structure is required to support analysis in a competitive environment. It was noted that the model developed by Bunn et al. (1994) needed expansion to address complementary issues to those initially examined. Figure 4.1 shows the general architecture for the proposed platform and includes some of the most important information flows taking place. As can be observed company strategy depends on the supply, system's margin, price, and regulation. Additionally, it can be appreciated that the regulator's policy is a function of demand, system's margin, price and companies' strategy. Other relations are also represented.

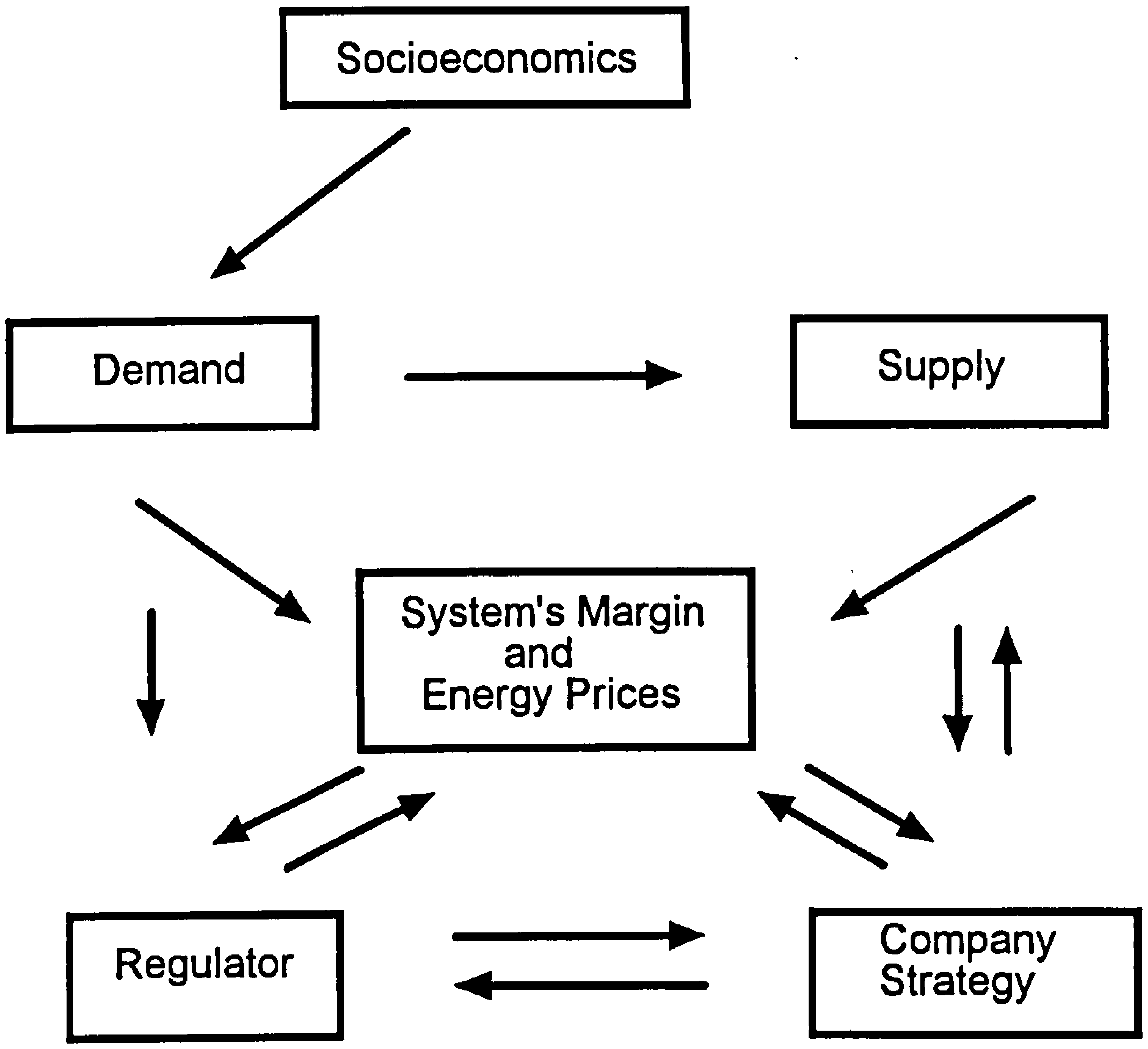

Figure 4.1 General platform structure

The platform designed for this purpose follows the specifications established in Chapter 3. Here, the system's margin and energy prices block is the core-component and all other blocks are peripheral components. It adopts the suggested structure, and particularly, in relation to model implementation, it observes the archetypes included in Section 3.2 on investment incentives and ownership. In this case, the system's margin and electricity price variables are part of the core component described in Figure 3.2; whereas, demand, supply, regulator and company strategy are peripheral components. This platform has to be capable of reproducing exactly the same conditions as in Bunn et al. (1994) and, furthermore, able to build upon it a new set of interconnected issues on an incremental basis.

As can be appreciated in Figure 4.2, the platform architecture incorporates the logic under which capacity addition takes place in the new privatised environment of the electricity industry in England and Wales. This is a re-interpretation of Figure 3.3 with focus on issues related to ownership and competitive markets, where long-term effects, such as demand elasticity to price, are not considered. Also observe that when examining Figures 3.3, 4.1 and 4.2 simultaneously, many ideas come to light. It becomes apparent that many connected problems may be studied if the model corresponding to Figure 4.2 is expanded to incorporate the appropriate features. On the competition side, strategy issues of many kinds become relevant: diversification may be a possibility for reducing risks, and integration an alternative for increasing revenues. On the environmental side, the selection between different electricity generation technologies or conservation legislation are other possibilities for consideration. On the efficiency side, alternative sources and end-use technologies, may be examined.

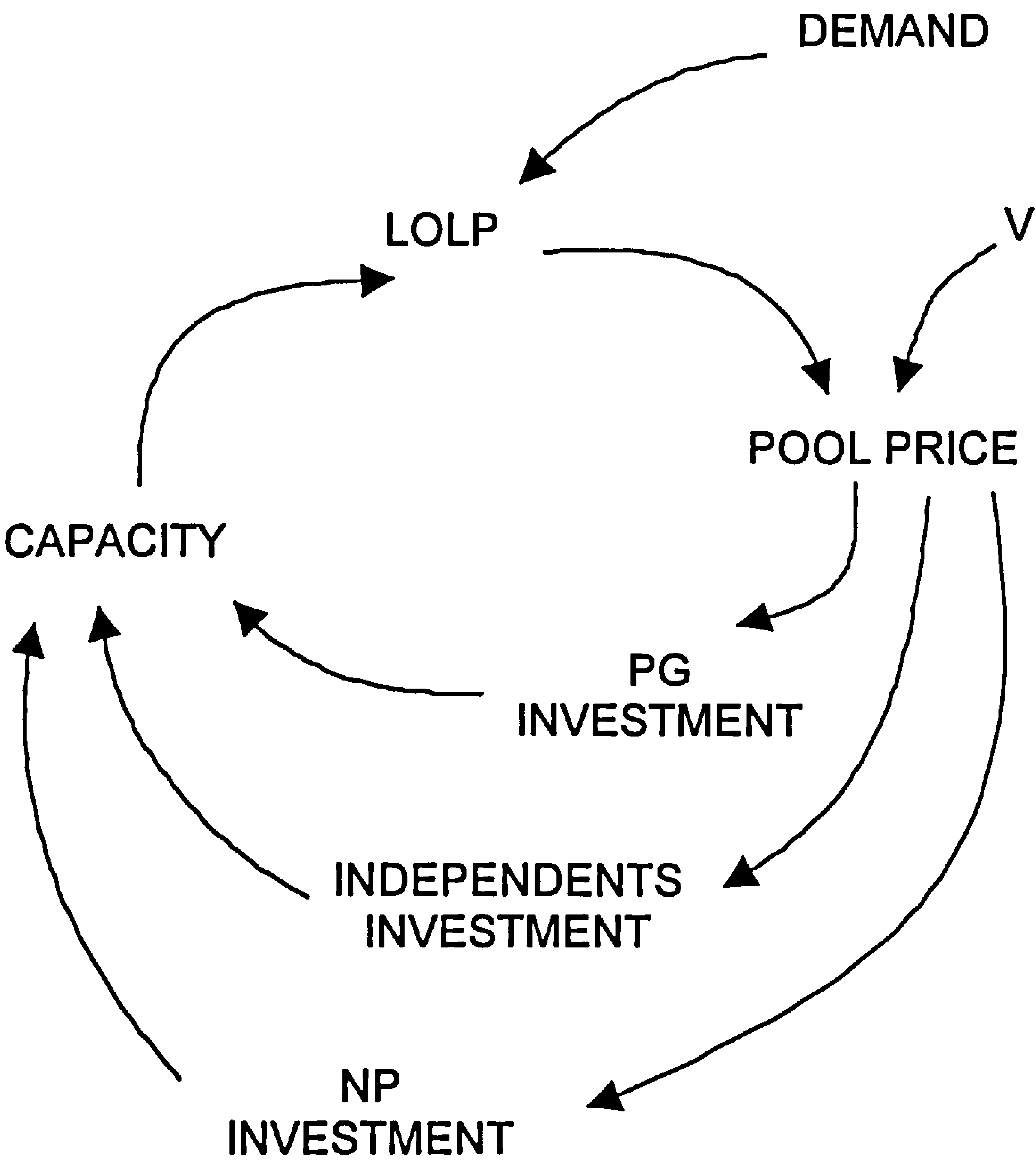

Figure 4.2 Dynamics of capacity investment (Bunn et al., 1994)

Many interesting problems become apparent when considering electricity and gas issues on the same analysis framework. The proposed platform could then be of value:

- To shift stress from isolated electricity problems to energy related problems. A systems approach is then appropriate. Also, along the same lines, general rather than specific issues are at stake.

- To include in the next stage of development the coal and/or nuclear sectors. This should be simple and attractive. In this case, the model will incorporate almost the totality of the non-transport energy supply in England and Wales.

- For strategy evaluation at the company level, when diversification or vertical integration are considered as viable options. And also, in terms of the technology choice for generation capacity when issues such as risk, environmental constraints and the creation of entry barriers provide a competitive edge over rivals.

- To examine links between electricity and gas markets. For example, gas as a fuel for power generation competes with other fuels at the supply side. And also, competition takes place for its application as an end-use source (e.g. in house cooking).

- To study future market interrelationships in distribution and retailing (e.g. sharing the same billing channels). To consider the prospects of companies intervening in electricity, gas and even in water markets.

- For policy making at the national level. In relation to fair competition (keeping it within bounds), system reliability (outages), prices for end users, subsidies, the support of R&D or the promotion of alternative energy sources.

- To assess a number of issues for regulation purposes. For example, breaking down an energy system into smaller parts, acknowledging the fact that the sum of optimal behaviours does not guarantee the overall optimum for the system.

- A better understanding of the integrated system dynamics and some likely strategic actions of the players involved, when opportunities arise due to the lack of legislation, will help regulators to intervene in the right direction, to avoid the collapse of the system. In this sense, it may support policy design in evaluating its possible effects and finding some likely loopholes through it.

- To incorporate environmental issues in future development stages which, by nature, require integrative structures. With not much effort, the platform should be able to take into account major global environmental effects as a result of energy generation and energy consumption, excluding the transportation sector.

- To incorporate efficiency and conservation as alternatives to energy generation. And to internalise environmental costs as attempted in many states in the US by means of integrated resource planning.

When considering the addition of another source (for example gas or coal) into the platform, the problem of establishing the amount of detail required turns out to be rather simple, as this depends both on some particular issues of concern to analysts and policy makers as well as foreseeable desired capabilities of the platform. However, this is not really a crucial matter as the software being used facilitates, with not much awkwardness, the re-engineering of any component of the model, according to needs.

Therefore from the systems analysis perspective, a step towards the incorporation of the gas industry should be the right move ahead, as this has been the fastest growing energy source during recent years, and will probably continue increasing its participation in the energy market, at least through the nineties and the first decades of the next century. In this case, the demand and supply side of the gas industry should contain as much detail as the electricity industry, but this will only be limited by information availability, ultimate research needs and particular features of this industry.

The purpose of this section is to develop the required platform to address some of the issues of concern. In this sense, on the one hand, it will be able to test conceptually the methodology proposed in previous chapters. And, on the other hand, assuming that the first stage is completed, it will be possible to pursue enquiries on the reality of, for example, arbitrage possibilities available to a major player for intervening in both electricity and gas markets.

4.3.1 The core component

In the British case, the core component is very simplified and incorporates an elementary demand sector for both electricity and gas. There are two main reasons for doing this: a) no policy will address demand-side matters, and b) no foreseeable economic factors have any significant effect on demand, except for gas in the power generation industry (which will be modelled in detail). Thus, as in Bunn et al. (1994), only a rate of growth is used here.

The core component also contains all information required for the purposes of assessing industry performance. The most interesting results in this case are those related to total sales and revenues of the electricity and gas industries, and the corresponding market share of diverse companies.

4.3.2 Power supply, regulator and price formation components

Power supply

When representing the power supply sector major notation changes have been introduced to: a) facilitate addressing additional policies to the ones already investigated by Bunn et al. (1994), and b) simplify and make more systematic the model building process. Vectors have been introduced to represent capacity according to technology (nuclear, coal and gas), as well as for all company information (present state and expected system evolution) and decisions on capacity investment.

The electricity regulator

The regulator component is almost identical to the original model, with only minor exceptions that have to do with the vector representation. Bunn and Larsen (1995) include a descriptive graph that illustrates major information flows between components and within important variables.

Price formation

The daily power-pool, operated by the National Grid Company (NGC), is the market place for buying and selling electricity. Although various contracts and options are set up between generators and suppliers, these are just hedges against pool price fluctuations. Every day generators submit offer prices for power available from each generating unit in their company for the following day. The NGC produces a schedule for generating power in the cheapest way over the next day. For every half hour, a System Marginal Price (SMP) is computed, which is the offer price for the most expensive plant needed and available for loading at that time. NGC also computes, for each half-hour, the Loss of Load Probability (LOLP) which takes into account demand uncertainty and the stochastic nature of generating unit failures. Together with Value of Loss of Load (VLL), which is a measure of the price that pool customers may be willing to pay to avoid loss of supply, this product (VLL-SMP) * LOLP is the "capacity element" which generators receive in addition to SMP.

The initial Bunn et al. (1994) model was created to focus only on the capacity element. In this thesis the SMP element is also included. Figure 4.3 shows the increasing nature of SMP (in pence/kWh) with available capacity (compare Green, 1994). Demand varies from a minimum of about 20 GW in the summer to a peak of about 48 GW in the winter (Electricity Association, 1994). This has to be thought of as a dynamic function changing over time, as plants are continuously retiring as well as coming on line. Thus, for example nuclear, gas and coal may be defined uniquely during one specific day for the capacity intervals [0,8), [8,19) and [19,60], respectively. These dynamics are captured in the model by extrapolating tendencies of generation price due to both technology innovations and technology obsolescence. In this case sensitivity analysis may be required to observe the relevance of this dynamic function to final strategies being considered.

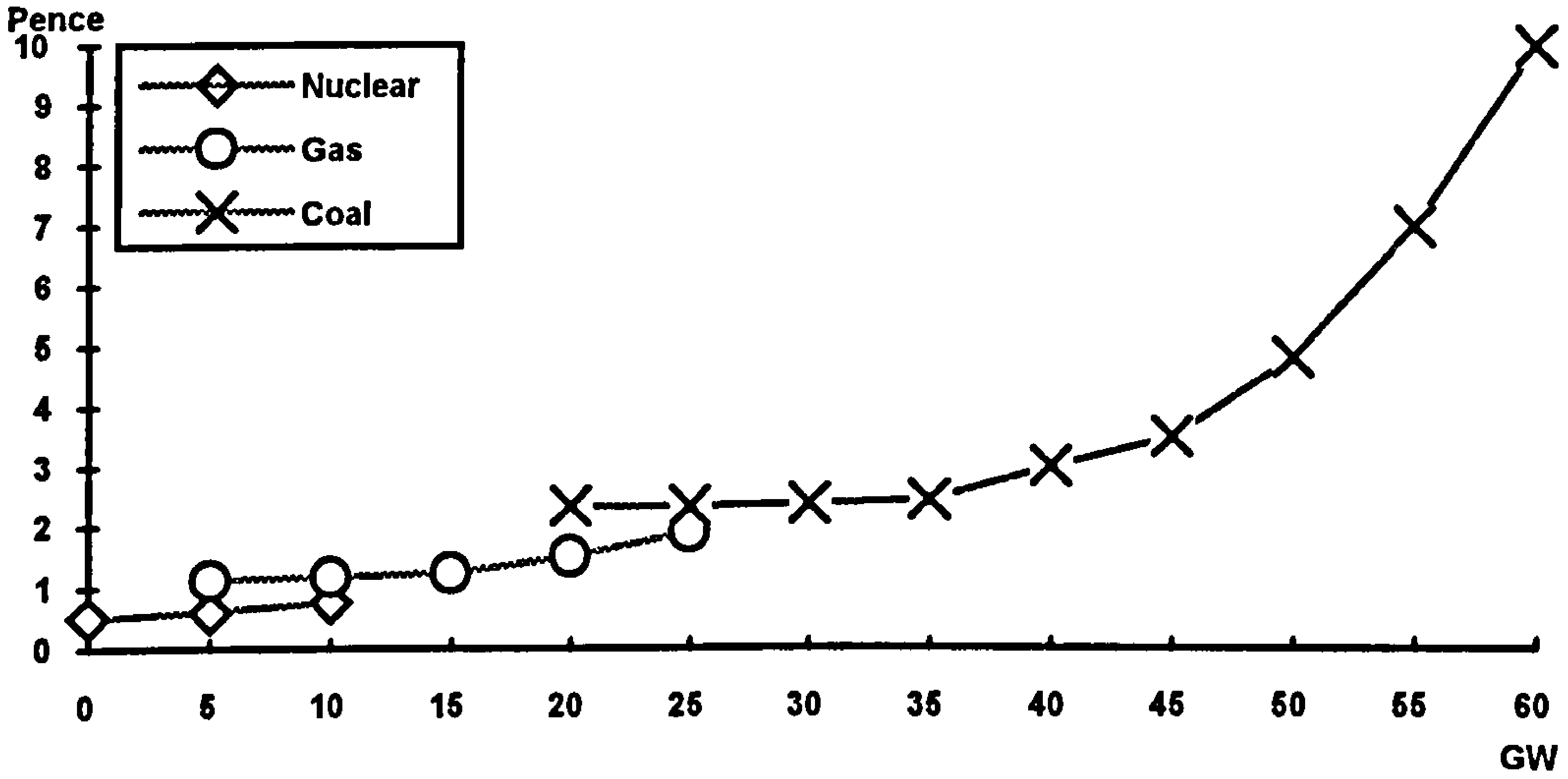

Figure 4.3 Price as a function of generation capacity (pence/kWh vs GW)

4.3.3 Company strategy component

The rapid introduction of CCGTs into the capacity mix has, in fact, been one of the remarkable features of the first five years of privatisation. Although it was the relaxation of European Union legislation on the use of gas for electricity generation which facilitated what has been referred to as the "dash-for-gas", the higher cost of capital following privatisation and the RECs' strategic need to co-invest with Independent Power Producers accelerated it (Bunn, 1994). In all, close to 10 GW of new CCGT plant has been planned for introduction during the decade from 1990 (on a system with about 65 GW installed capacity, and 45 GW peak demand). Many of these CCGT plants were covered by 15 year "back-to-back" gas supply and electricity sales contracts.

With regards to the status of the UK gas market itself, we have already observed that, although British Gas was privatised a few years before electricity, it was not originally split up. Only now, following new Government legislation designed to introduce more competition, is the company being divisionalised and a new gas spot-market created. Depending upon the depth of the gas spot market, the electricity generators could be a significant influence. At least several different situations could arise:

- *Non-scheduling of Available CCGTs*: As more CCGT plant is introduced onto the system, there will be times when it becomes mid-merit and therefore not necessarily scheduled for use on the day. Initially, this will be a seasonal effect, but in time will become more common throughout the year. Under such circumstances, gas may have to be unloaded onto the gas market, possibly at short notice.

- *Planned and Unplanned CCGT Unavailability*: Maintenance arrangements, plant or system failure could all create a need to sell off gas on the market.

- *Strategic Arbitrage across Both Markets*: A large generator with a portfolio of plants may find it profitable to withdraw some gas plant from time to time, selling the gas, in the knowledge that such a move will increase the electricity SMP (because the plant will be replaced with higher operating cost plant) from which the generator will benefit on its remaining scheduled plant. Furthermore, to the extent that such action may induce greater volatility in electricity prices, it will increase a consumer's propensity to contract, from which the generator may earn more rents from the premia in the contracts.

- *Fuel Cost Moderation through Arbitrage:* In contrast to the above situations, which could all be considered to have destabilising effects, the existence of a spot market will provide a transparent reference point for gas contracts, and should make them more efficient. Also, as more generators buy from the market, seasonal arbitrage to the extent that it is possible could likewise provide more efficient seasonal prices for gas-fired electricity generation.

Only the third situation indicated above gives rise to a regulatory issue. This issue is focused upon by seeking to analyse its potential feasibility. Figure 4.4 shows general behavioural relationships as a causal influence diagram. It can be observed that if price uncertainty (volatility) is created by a major electricity supplier this will have an effect on the pool price as well as on the quantity of contracts induced and on the corresponding premium paid. Excess gas is sold at discounted prices.

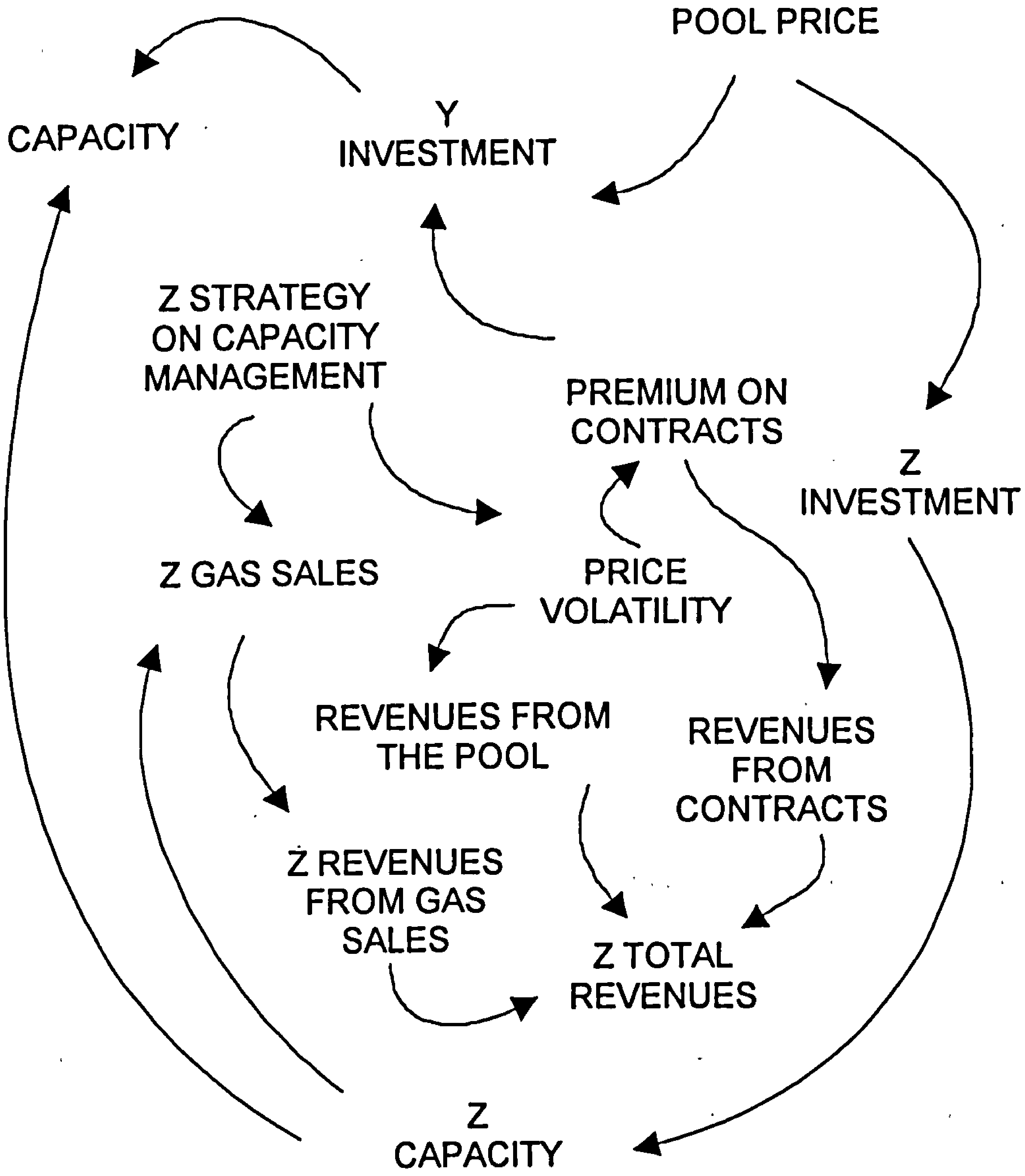

Figure 4.4 Strategy of electricity supplier to create price volatility

Note that other companies, such as IPPs (represented by Y in Figure 4.4), may also benefit from this strategy, thanks to the extra revenues obtained as a consequence of the induced volatility. However, as peaks do coincide for both electricity and gas markets, IPPs have no assurance of possessing sufficient gas for electricity generation during these periods (most gas supply contracts are agreed on an interruptible basis).

Hence, a possible strategy for a large player may be as follows: during the non-peak hours a large generator will try to run his CCGTs on alternating basis (all spare gas may be sold at discount prices); while, for the peak hours, he will choose to run them most of the time, as he will out-compete coal plants. Yet, this strategy will not lead necessarily to large profits considering that it depends on several factors:

- Amount of price volatility created
- RECs' risk aversion utility functions
- Premium as a function of price volatility
- Capacity to sell remaining gas at a 'reasonable' price
- Getting away with not being penalised by regulators.

4.3.4 Simplified gas industry component

Figure 4.5 illustrates a simple scheme for the operation of the gas sector. The main feature here is the effect on prices caused by dumping of gas, due to strategic manoeuvring in the electricity market.

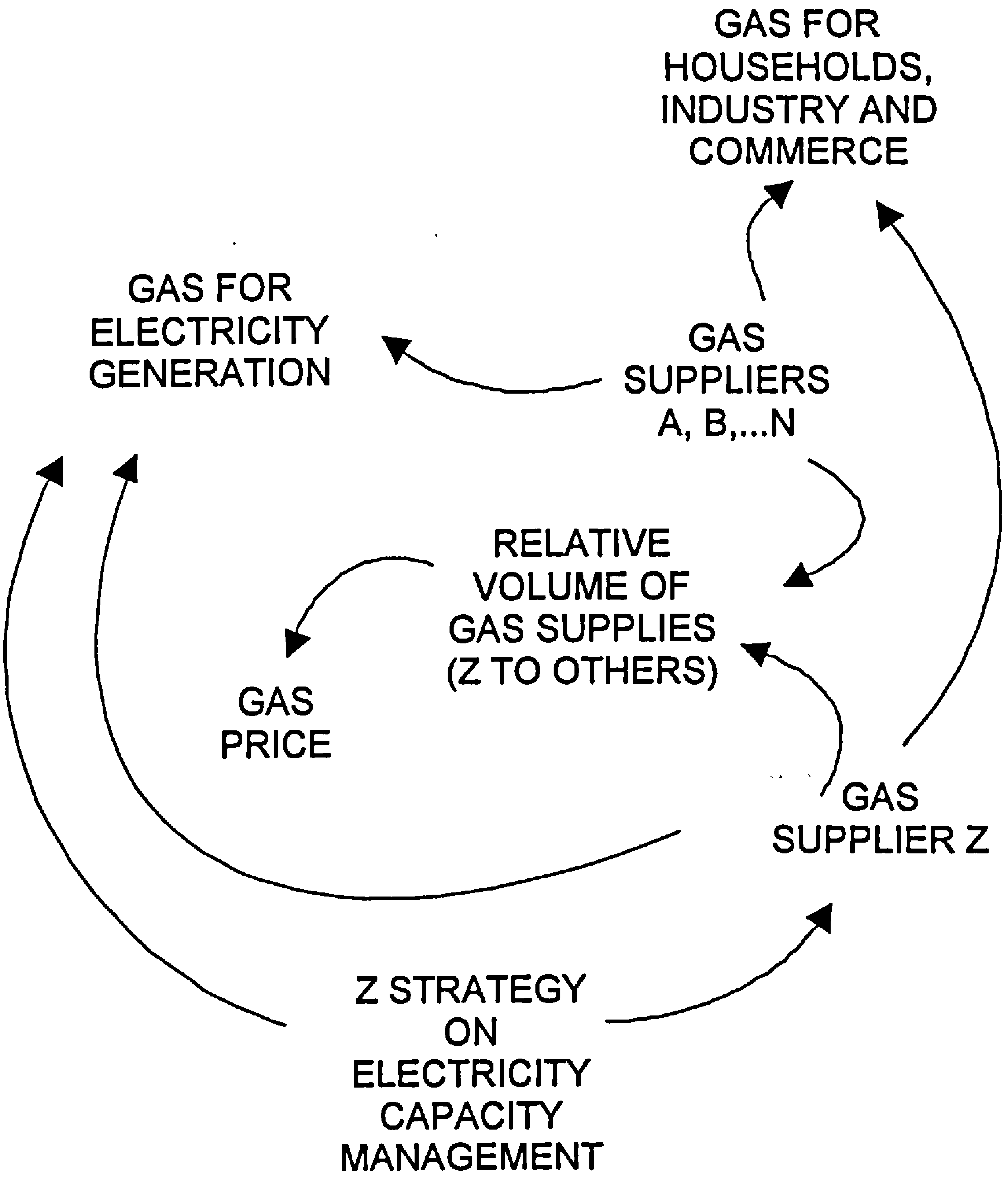

Figure 4.5 Simplified gas sector

4.3.5 The calculations

The main platform components have already been described. However, it is still necessary to describe how to carry out the most delicate calculations in the platform. Note that the total net revenues for the major player depend basically on the following factors:

- Annual pool price as a function of the demand

- Willingness to contract as a function of the price volatility, and
- Premium paid as a function of the price volatility.

The pool price formation as a function of demand and capacity has already been discussed above. Figure 4.6 represents the corresponding utility functions for willingness to contract and for premium paid. It can be inferred that induced volatility in the SMP will encourage electricity suppliers (e.g. RECs), who purchase from the pool, to increase their hedging of price risk though extra contracting with the generators. As volatility increases, it would be reasonable to expect both the fraction of power under contract to increase, and the risk premium paid over average SMP to get larger. For example, in the initial years of the pool, when ex ante price uncertainty was greatest for the RECs, their risk aversion encouraged contracting of about 90% of required power at premia of about 40% above average SMP, whereas more recently with temporary price capping, much lower levels of contracting and risk premia have emerged. Therefore a function was proposed going up to 90% of power to be contracted, as the excess deseasonalised price variance over 'normal' variance (about 0.3 p/kwh^2), computed over the previous year goes from 0 to 0.3 p/kwh^2, with a risk premium going up from zero to 50% over the same volatility range. This is clearly a speculative view on the risk aversion of the suppliers and was the basis of extensive sensitivity analysis. The base-line assumption was of contracts running yearly, but this was also sensitivity-tested.

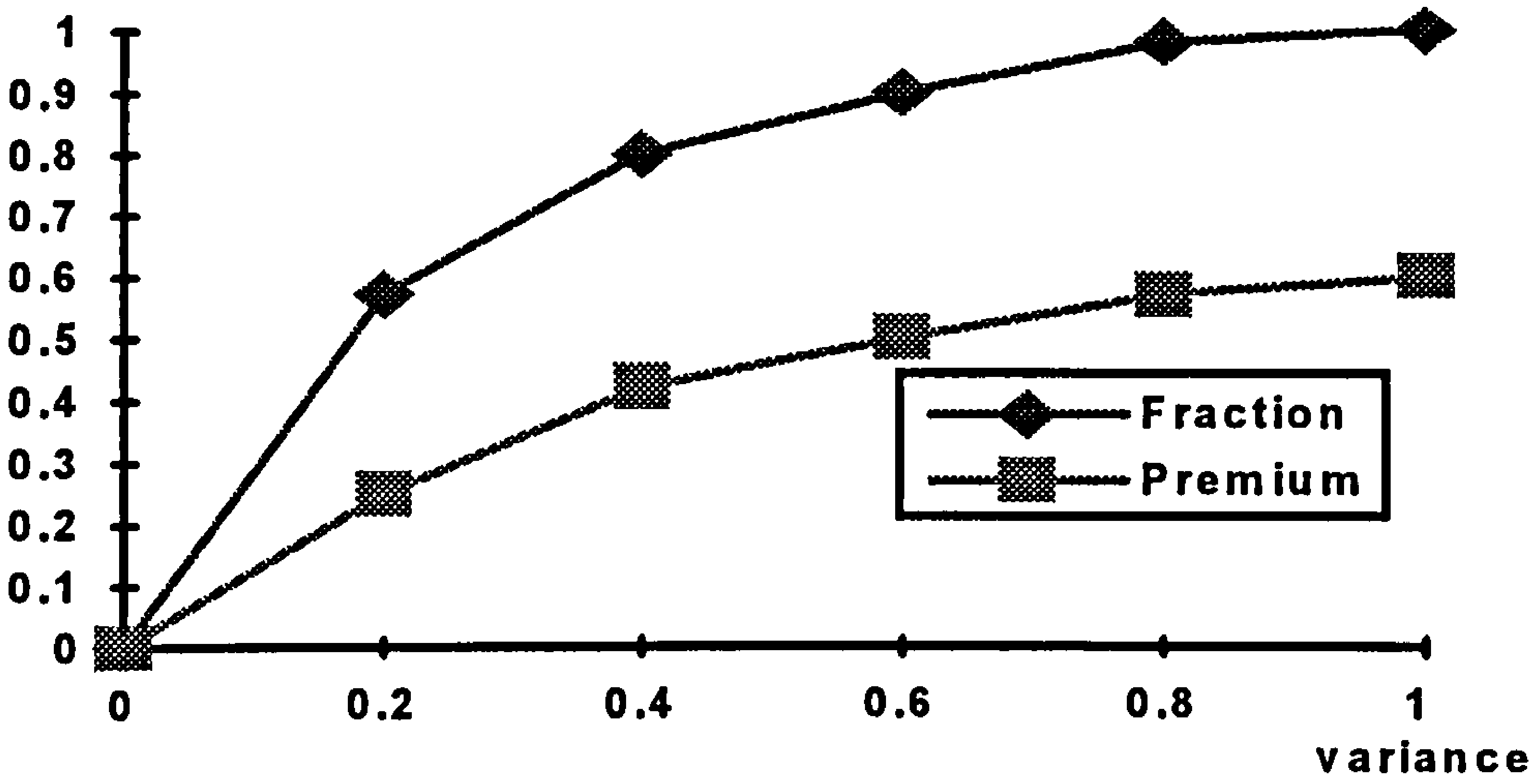

Figure 4.6 Fraction of customers contracting and premium they are willing to pay as a function of the price variance.

With these pieces of information, it becomes rather simple to calculate, within the simulation platform, the major revenues accumulated by one of the major players. This is compounded of three terms: pool revenues, revenues through electricity contracts and gas revenues.

Therefore, when X represents electricity demand (in terms of capacity) and ΔX represents the capacity of CCGTs not made available, to establish the electricity price it is the same as if in Figure 4.3 there was a further ΔX demand in capacity on top of X, at a particular time. Thus, in functional terms, for a company engaging in this strategy:

◊ Revenues from pool (RP):

$$RP = X * P_{X+\Delta X} * (1-f) * f_a$$

◊ Revenues from contracts (RC):

$$RC = X * (P_{X+\Delta X}+\text{Premium}) * f * f_a$$

◊ Revenues from gas sales (RG):

$$RG = \Delta X * C_g * P_g$$

And, the total revenue (R) turns out to be:

$$R = RP + RC + RG - (P_{X+\Delta X} - P_X) * \Delta X$$

Where

X is the electricity demand at a particular time,
ΔX is the capacity of CCGTs not made available,
f is the fraction of electricity contracted,
f_a is the market participation of the major electricity producer,
P_X is the price of electricity when demand requires capacity X,
$P_{X+\Delta X}$ is the price of electricity when demand is equivalent to $X+\Delta X$,
P_g is the price of gas, and
C_g is the gas needed to fuel 1 GW of a CCGT.

Some of the effects produced by the strategy are tangible, using previous calculations; however, some others are not. Yet the strategy has to be under close scrutiny to prove its merit. Thus the strategy proves to be worthwhile only when:

- Net accumulated revenues in the electricity and gas markets are larger than those obtained in the case that no strategic action is applied.

- It helps to maintain a dominant position.

- It will dissuade new entrants.

- Survival will be much more likely as a diversified company.

- It will make the company more flexible.

- Learning will be much easier.

- It contributes to the understanding of energy issues, rather than just electricity ones.

- It will have the advantages of an early entrance.

However, a major generator will also be required to examine RECs' responses as they may defend themselves against his strategy by:

- Contracting electricity with independent producers (leading to feedback cycles).

- Referring the generator to the MMC on several grounds related to unfair trade.

- Referring generators to the OFT on the grounds of unfair trade.

For this, the support of the simulation platform described here, which has been built following the methodology presented in Chapters 2 and 3, will prove to be of utmost importance. As has been discussed earlier, this is enhanced with modular and adaptable features. It, has also been shown that it may be developed in incremental stages. Appendix I contains a complete version of the platform components.

The next section will examine in depth how a strategic player will have arbitrage opportunities in the electricity and gas markets, based on general conditions of the technology mix of capacity additions and on broad assumptions about the utility functions for contracting and premia. Appendix I contains a full version of the platform for the British case.

4.4 POLICY ISSUES AND PLAYERS' STRATEGIES

The platform developed here facilitates simulations of the system behaviour when this is under the influence of policies and strategies which may be considered by the different actors involved. In this way, it may be possible to investigate new market structures as yet untested. The platform may also assist researchers and analysts to construct- and concept-test diverse strategic issues which could be of concern to players in the system.

4.4.1 Scenario 1

Let us first consider a scenario under which a major company might try to diversify and follows a strategy addressing the following factors:

- Technology mix for generation: gas, coal and gas-oil.
- Run CCGTs at the base and the rest at the peaks.
- Not all CCGTs are made available during the peaks.
- Gas not used for generation during peaks is sold in the gas market.

In this case it is assumed that new capacity brought on line marginally favours gas-based technologies over all others. Also, the initial scenario intends to assess the effect of a strategy that makes 25% of the CCGT capacity unavailable every third period (month). Curve 2, in Figure 4.7, shows monthly revenues as a consequence of the engineered volatility, and Curve 1 exhibits simulation results when no strategic playing is being conducted.

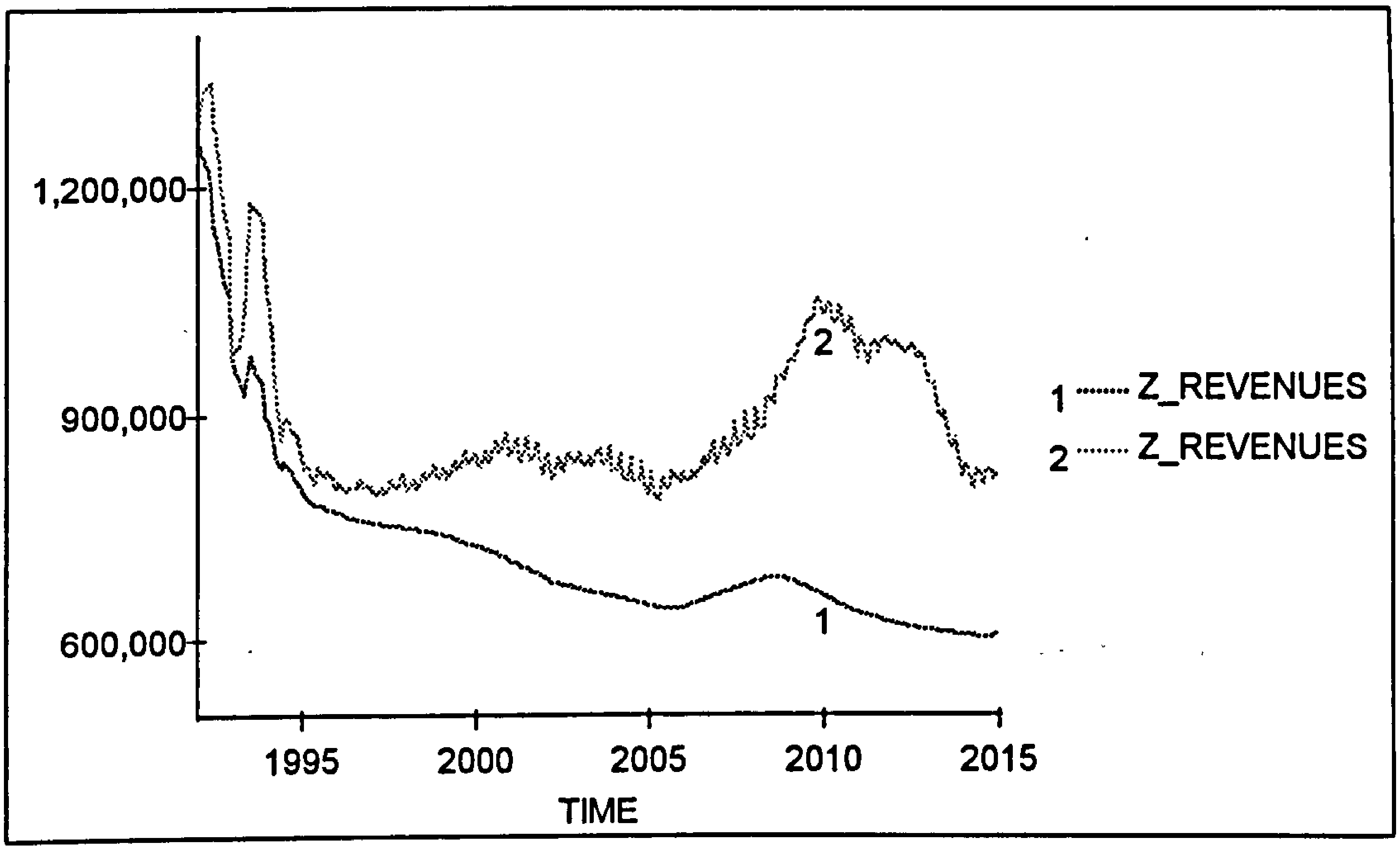

Figure 4.7 Revenues: 1) bidding at operational costs, 2) under strategic bidding

Additional profits in this case amount to more than 50%, during some months when enough gas capacity is available in the system (in this scenario gas-based technologies present a high penetration rate). A major player withdraws on average 4 GW of CCGT capacity, on an intermittent basis, during the 20 years of simulation. Even though this strategy has achieved a significant increment on revenues during the simulation, it is possible to stretch this percentage even further.

Hence a non-extreme scenario, in terms of the amount of CCGT made available, already brings sufficient price volatility as can be observed in Figure 4.8. Here, the variance grows continuously at different rates until it reaches a maximum value of about 0.4 at the year 2010. Then it falls down to nearly 0.25 by the year 2015. This contrasts with values lower than 0.005 for the same variable in the absence of any strategic behaviour. The large values observed during the first years are due to stabilisation problems related to initial conditions.

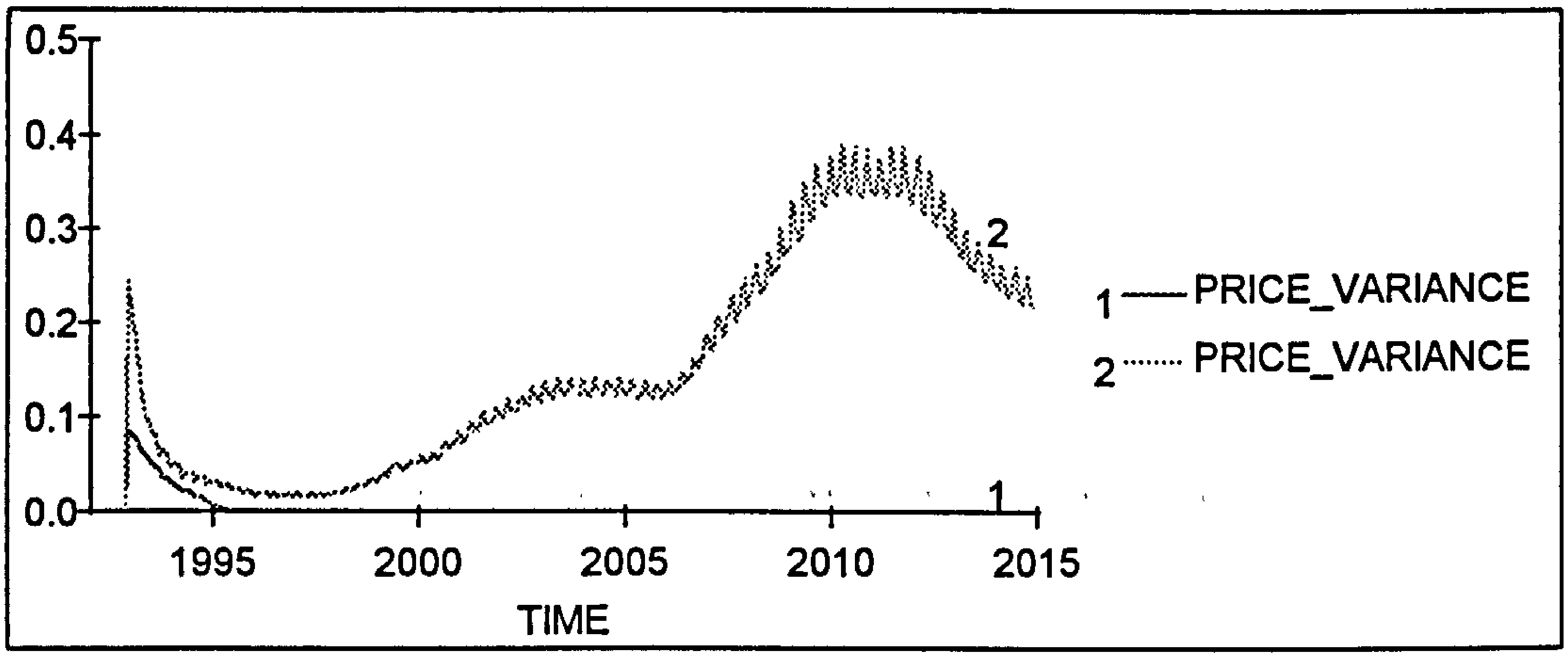

Figure 4.8 Price variance corresponding to scenarios simulated in Figure 4.7

This scenario already shows a plausible way for some major players to manipulate markets, trying to optimise returns, just following the proposed operational rules previously described. In simple terms, larger returns are attained as electricity is traded at higher prices than needed (because of the engineered uncertainty) and gas will be sold at slightly discounted values. It is important to note, at this stage, that this analysis incorporates deseasonalised data.

However, utilities may defend themselves by way of contracting electricity with independent power generators, avoiding in this way having to pay excessive premium values. The causal diagram, Figure 4.3 above, illustrates this argument. Thus, if 50% of premium is transferred to the customers and the other half is used to discount investments of new electricity plant, under the conditions of the scenario discuss above, simulation results show how independents may increase their market share by as much as 3%. This can be observed in Figure 4.9, where calculations have considered only purely economic investment perspectives. Here, however, two factors have to be acknowledged: a) this basic scenario shows a rather optimistic market share evolution for the IPPs, and b) the new generation capacity mix brought on line during the simulation may differ from what will happen in reality (depending on technology evolution and source prices).

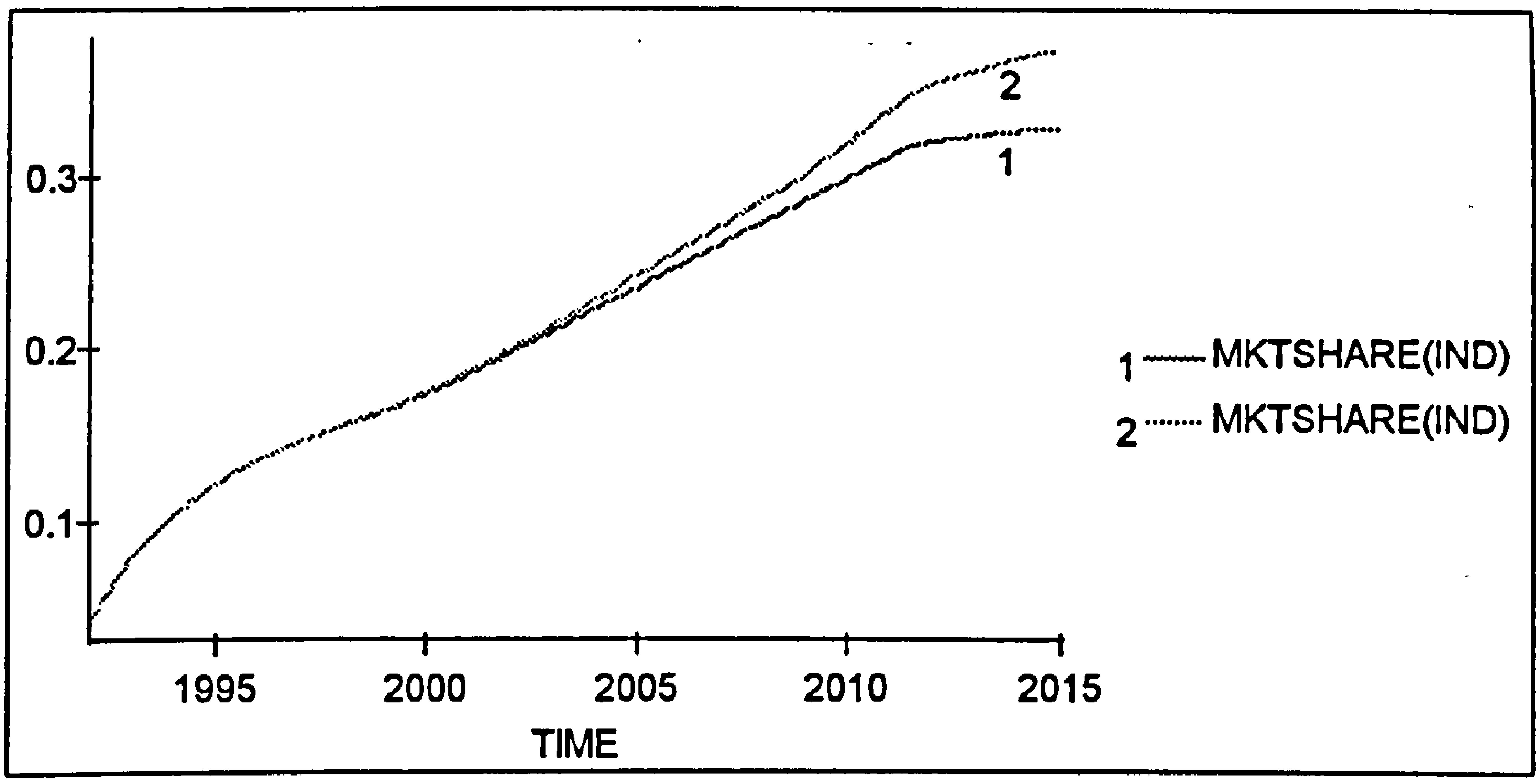

Figure 4.9 Independents' market share: 1) not splitting profits, 2) splitting profits

4.4.2 Scenario 2

Suppose now that a major player may try an alternative strategy to create price volatility in the electricity market by, for example, not declaring CCGT's capacity at certain random-like instances. For instance, every period he considers withdrawing 12.5% of his capacity, randomly, with probability 0.333 (e.g. on average not making available 0.8 GW capacity every third period). Figure 4.10 shows exactly the same simulation results obtained under the previous scenario (1), which may be compared with this new random strategy scenario. In this case, revenues fall only slightly with respect to the previous strategy, even when withdrawal capacity has been dropped by as much as one half. Yet profits remain over 25% higher with respect to the no-manipulation-strategy scenario for most of the simulation period.

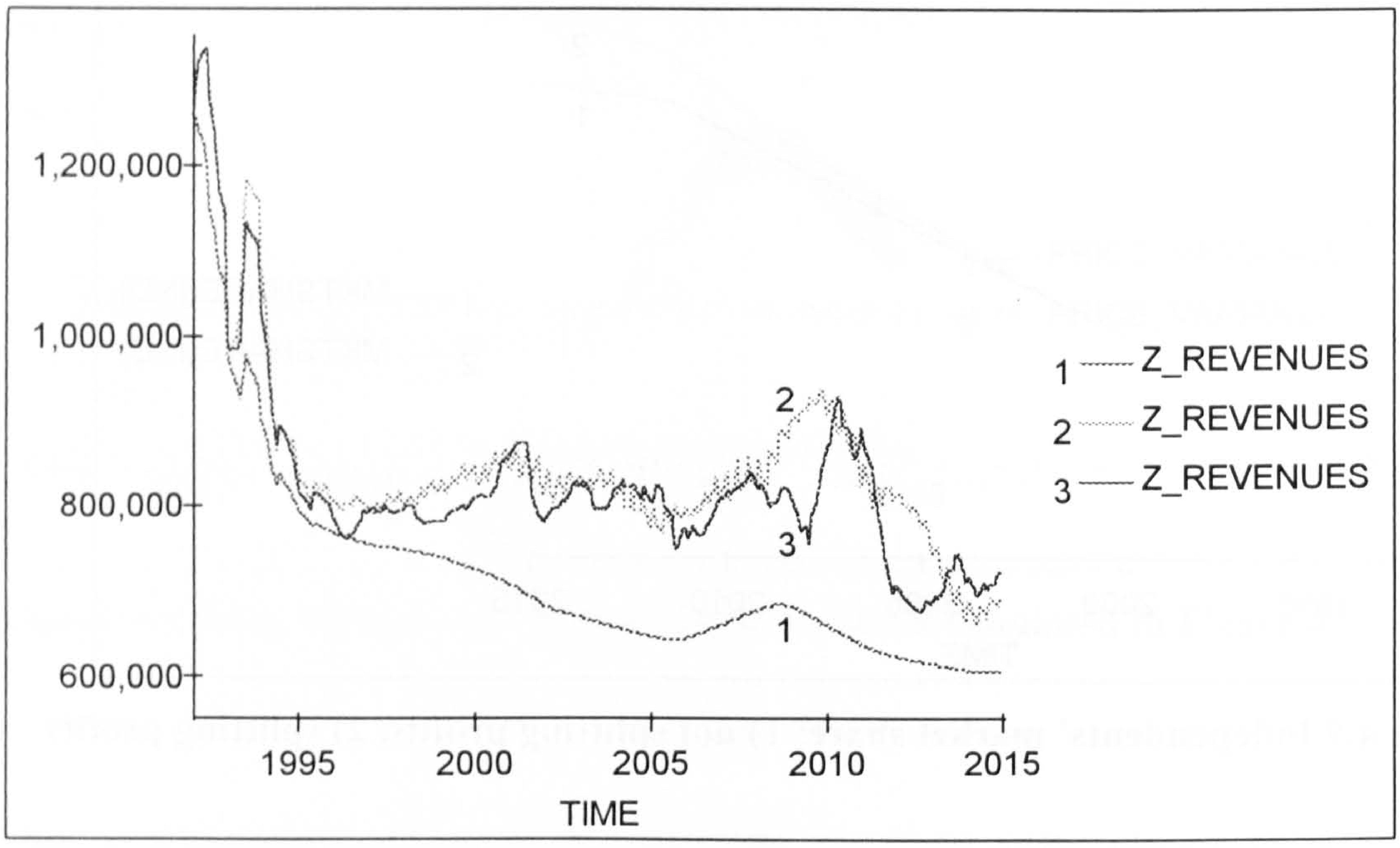

Figure 4.10 Curves 1 and 2 are the same as in Figure 4.7, and curve 3 represents a random strategy.

4.4.3 Scenario 3

A different strategy, which depends on previous results, is explored in Scenario 3. Here, every fixed or randomly selected period, a major generator compares the current volatility with the average volatility over the last few periods, and creates an index I given by:

$$I = \frac{V(t)}{y^{-1} \Sigma_z V(t-z)}$$

where y is the time over which the earlier volatility is smoothed. The index is then linked to a graph function intended to deceive the regulator in terms of how much capacity is to be withdrawn. In this case, capacity is withdrawn each randomly selected period with a probability of 0.333; y=5 and the amount withdrawn varies according to a logistic function from a minimum of 7.5% to a maximum of 15% of the CCGT's capacity. This simulation yields slightly different results from the ones under previous scenarios. Figure 4.11 illustrates this point. The most recent strategy performs marginally better, even when withdrawing marginally lower quantities of CCGT capacity. Hence, this strategy could be considered to improve the previous one as: a) the amount withdrawn is not fixed, and b) it takes a dynamic perspective which improves decisions.

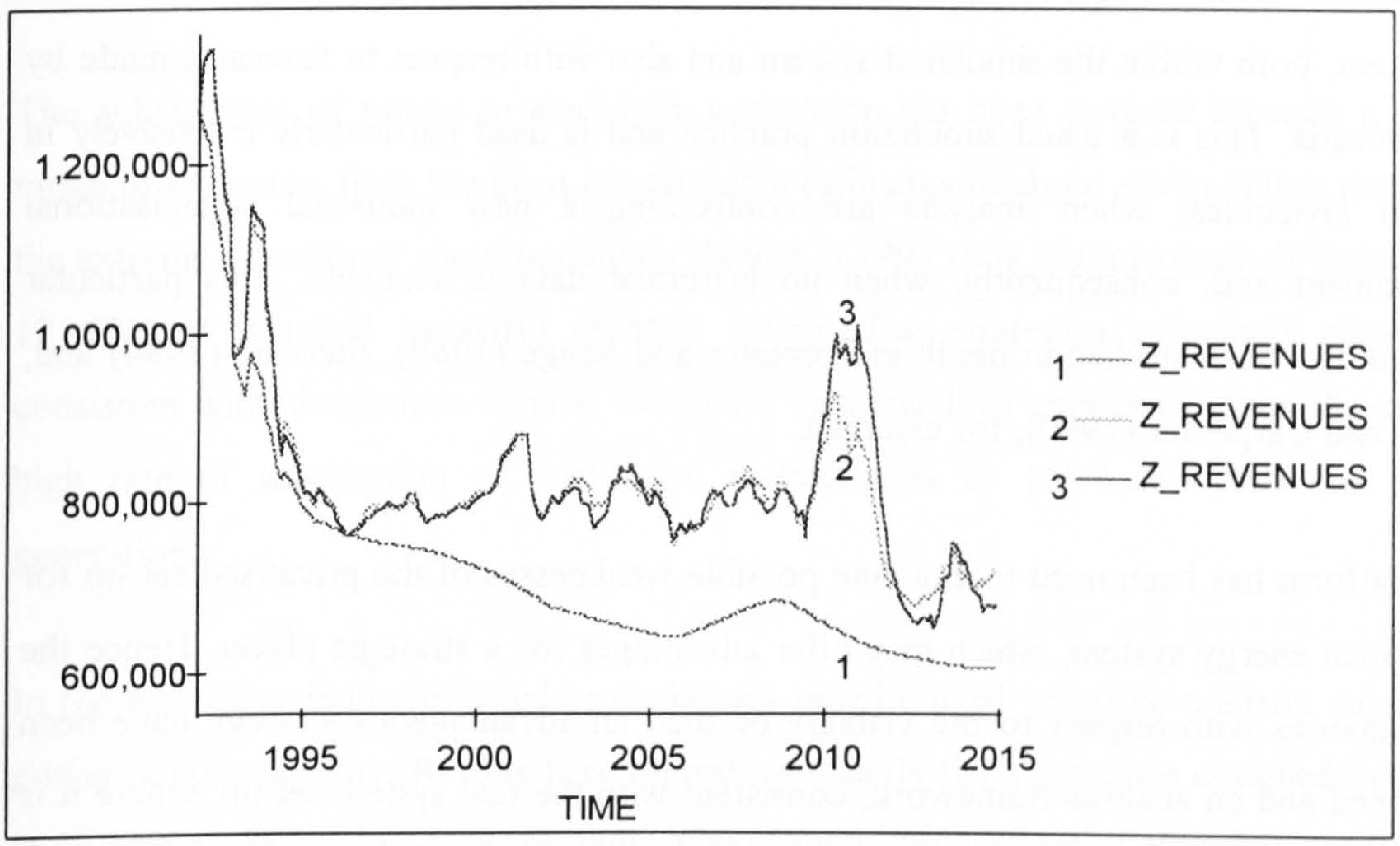

Figure 4.11 Curves 1 and 2 are the same as in Figure 4.10, and curve 3 represents a mixed strategy.

Although it is assumed that all economic actors strive towards maximising individual benefits rather than the global system optimum, it is not intended to design the 'best' strategy for any particular one of them. The aim is rather to illustrate the use of the SD platform built in this thesis for the purpose of strategy design.

Before moving ahead to address another issue it is important to mention the regulators' side, even if only tangentially. From their perspective, it seems likely that better system behaviour may be attained by co-ordinating actions, leading to a better control of the system as a whole rather than through this artificially overlapping split of the energy sector. Regulatory policies will be better understood by making use of an integrated analysis framework as the one proposed here and would more easily counteract some undesirable players' behaviour.

4.5 CONSISTENCY AND SENSITIVITY ANALYSIS

One of the aims of this section is to establish whether results obtained here are consistent, both within the simulated system and also with respect to forecasts made by other means. This is a usual simulation practice and is used particularly extensively in System Dynamics, when analysts are confronting a new industrial organisational environment and, consequently, when no historical data is available. This particular question has been studied in depth in Forrester and Senge (1980), Sterman (1984) and, Barlas and Carpenter (1990), for example.

The platform has been used to examine possible weaknesses of the privatised set-up for the British energy system, which may offer advantages for a strategic player. Hence the initial queries with respect to the viability of such an advantageous strategy have been confirmed and an analysis framework, consistent with the real system set-up, where it is possible to test conceptually a non-trivial hypothesis, has been found. The hypothesis is basically as follows:

> *it is feasible for a large player to create volatility in the electricity pool and profit from arbitrage manoeuvring in both electricity and gas markets.*

In general terms, the argument follows this logic:

- In the new system design there is a potential, and apparently desirable, for companies to trade both electricity and gas.
- Interruptable contracts encourage time-of-day management, which will help to allocate, and flatten demand loads for both, electricity and gas.

- As a result of this, arbitrage opportunities will arise and, consequently, the volatility created is very much imbedded in the system structure.

In terms of the energy traded during the simulations, there seem to be no constraints as most scenarios examined tended to be rather conservative. The indigenous gas market seems to be capable of growing at the same rate as the expansion of demand, at least, until the end of the century, and well into the next century considering the formation of the European market (Odell, 1994).

The substitution of source in electricity generation has been covered through a whole range of scenarios, from the most conservative estimates of about seven billion therms to the extreme scenario of about ten billion therms in 1998 (this is approximately from 12 to 17 GW of installed capacity) (MMC, 1993). The strategies examined above are consistent with simulations results. These are very much as expected, given the current high rate of substitution of coal-based technologies by gas-based ones for power generation.

In the electricity industry, simple calculations may be used to prove realistic values for power supply capacity. Results here reproduce exactly the same ones obtained in Bunn et al. (1994). Furthermore, as previously explained, the amount of electricity contracted with respect to total sale coincides with the values reported by the Electricity Association (1994).

The three scenarios discussed in the previous section already show little sensitivity to strategy variations. Further sensitivity analysis is pursued below with respect to what are perhaps the most important non-linear relationships contained in the platform (presented in Figure 4.6). This will establish the importance of these functions (shape and slope) for the purpose of strategy design. Figure 4.12 shows how, as risk aversion to contract is brought down by over 10% on average, and premium on volatility by about 10%, revenues fall only marginally in some cases.

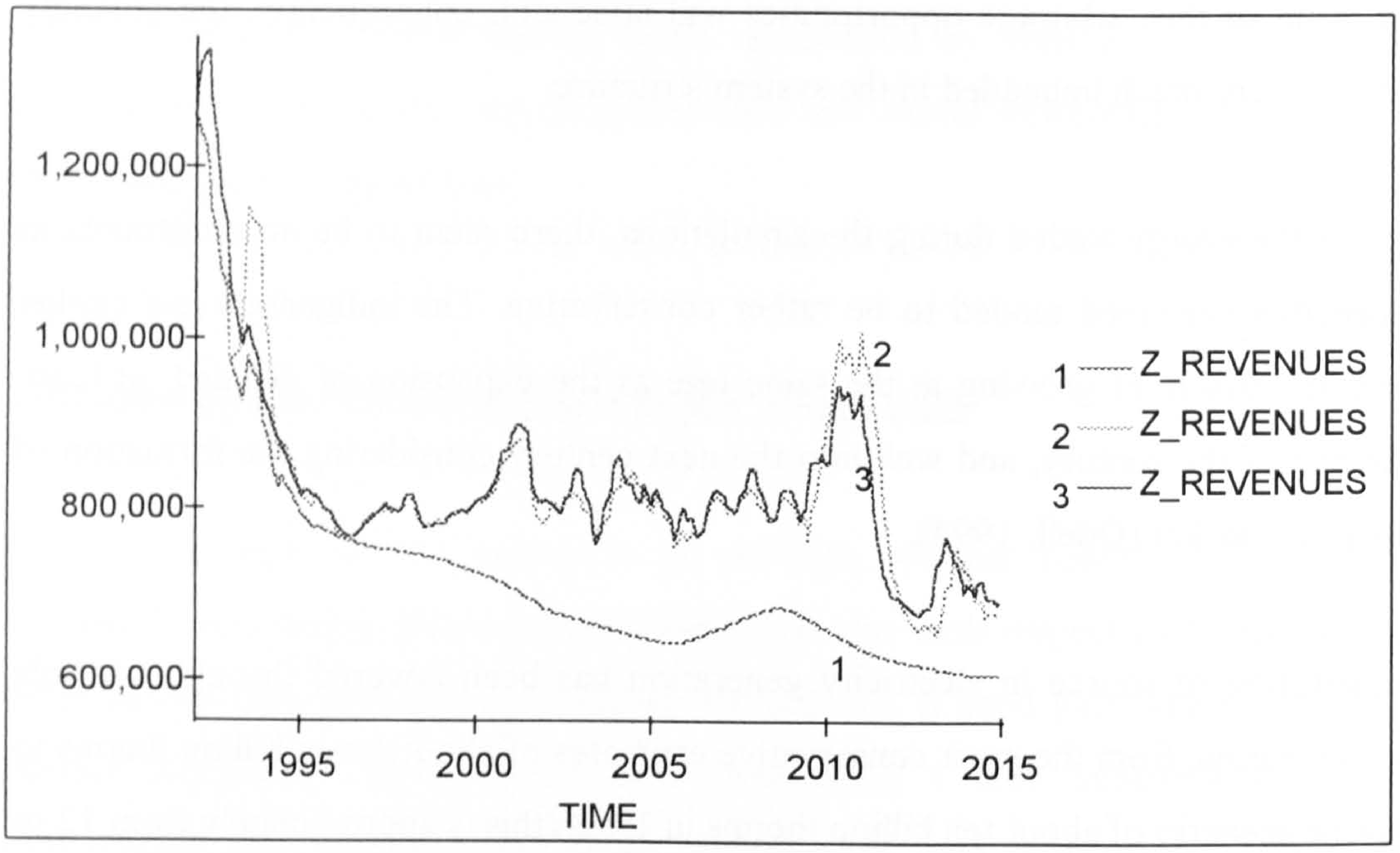

Figure 4.12 Sensitivity to contracting and premia. Curve 2 represents revenues under scenario 3 and curve with less risk-averse customers.

Finally, let us consider lower pool prices than those of Figure 4.3. Assume both that a) the slope of the SMP function reduces prices by about 20% on average, and b) customers as less risk averse, as has just been discussed above. Simulation results exhibited in Figure 4.13 illustrate that the proposed random strategy will reduce revenues dramatically during the first 8 years, when no significant gas-based technologies are available. However, in spite of lower prices and less contracting, the strategy seems to work fairly well when much more capacity is available and, hence, it is possible to create large price volatility.

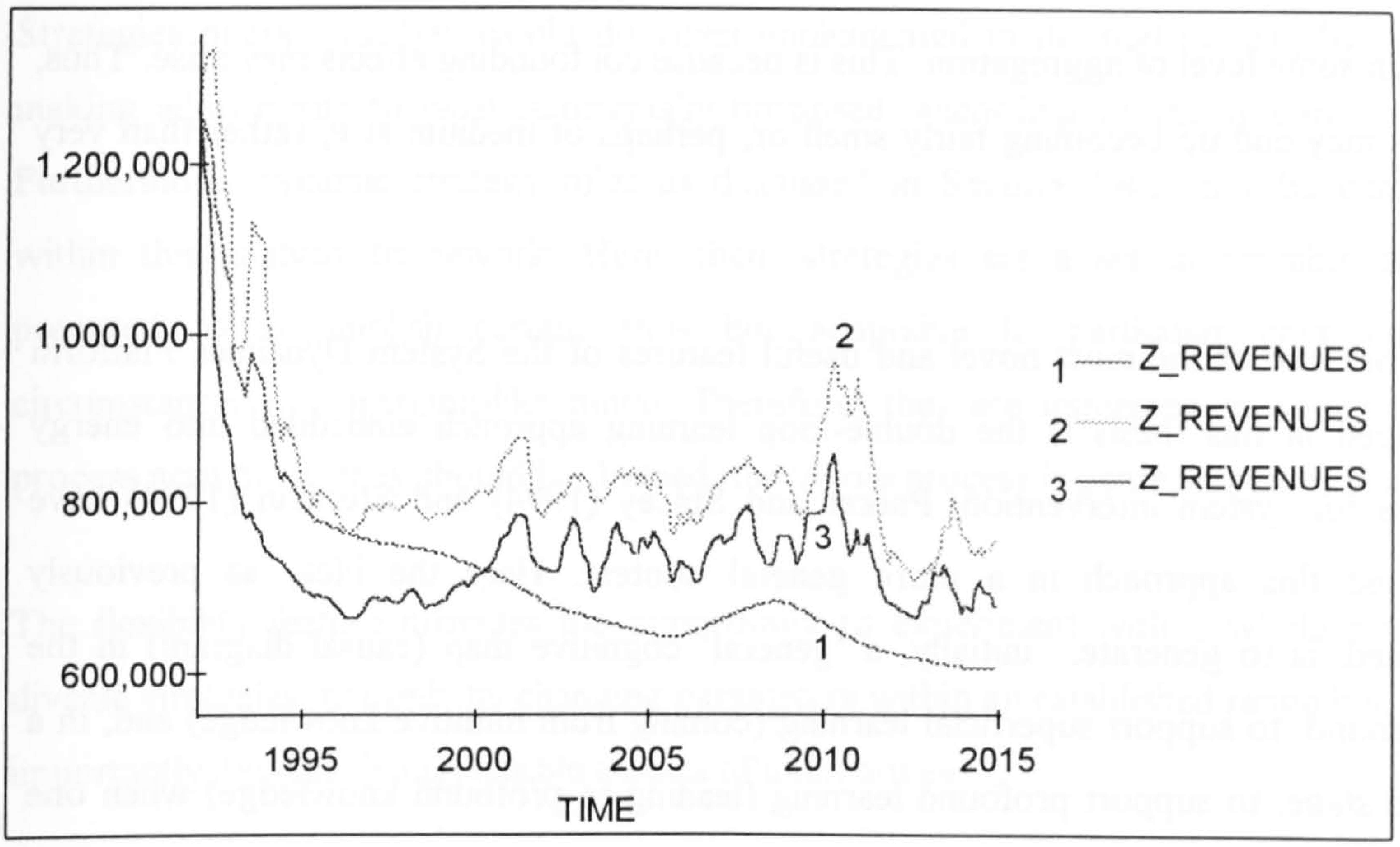

Figure 4.13 Sensitivity to pool price effects. Curve 2 represent revenues under scenario 2 and curve with 20% lower pool prices.

4.6 SUMMARY AND CONCLUSIONS

The findings of this chapter can be summarised in terms of methodology, strategy formulation and policy making/regulation:

Methodology

The System Dynamics platform proposed here enhances a methodological approach that can be described as follows: the general causal diagram provides preliminary insights into some intuitively understood system relationships (particularly major dilemmas), but after a problem is selected for investigation, further relationships are explored using stocks and flows (as in the SD tradition). This two stage approach considers: first, superficial evaluation and then, through further exploration, a more profound investigation is undertaken.

It must be understood that the model development process does not always imply the preservation of the very detailed features already introduced in previous stages, but instead, sometimes, depending on the issues being considered, it may be convenient to maintain some level of aggregation. This is because confounding effects may arise. Thus, models may end up becoming fairly small or, perhaps of medium size, rather than very large.

Therefore one of the most novel and useful features of the System Dynamics Platform developed in this thesis is the double-loop learning approach embedded into energy analysis for system intervention. Parker and Stacey (1994) and Sterman (1994) have discussed this approach in a more general context. Here the idea, as previously explained, is to generate, initially, a 'general' cognitive map (causal diagram) in the background, to support superficial learning (coming from intuitive knowledge) and, in a second stage, to support profound learning (leading to profound knowledge) when one or more issues are examined in depth through the process of detailed model building, validation and simulation.

Platform for strategy formulation

The new environment for system analysis presented here may benefit the major actors involved in the various organisations - companies, government and regulators. The particular platform, developed in this chapter, facilitates strategy formulation, as well as construct- and concept-test ideas, in a rather different way from the tools utilised by main stream strategy analysts, using well-known statistical methods (namely, regression analysis), or the game theoretical approach. Although Porter (1991) argues that his 'frameworks' differ from the classical statistical techniques, they posses similar drawbacks in what refers to the lack of dynamics.

Here the approach is modular, dynamic and flexible. Modularity for strategy formulation is a feature very much imbedded within the methodology explained above. Strategy effects can be either isolated or examined within the system context. This will help to clarify synergies and non-linearities.

The dynamic characteristic contains a variety of attributes. It tends to reflect the activity that takes place within the system, as captured by delay and feedback mechanisms.

Strategies operate as they would do when implemented in the real system, by way of making adjustments to what is originally proposed, according to the system reaction. Furthermore, dynamic strategy rules as discussed in Section 4.4.3 may be examined within this analysis framework. Here, then, strategies are a set of possible actions prepared to accomplish certain ends but adaptable to particular environmental circumstances in a learning-like mode. Therefore, they are implemented as a learning process activity, as they should be. Indeed, the whole process is geared towards learning.

The flexibility feature provides the opportunity to experiment with a whole range of diverse strategies, not only by changing parameters within an established range but, more importantly, by examining possible classes of alternatives.

Policy making and regulation

Even though it was not intended to analyse policy making in depth for this particular case, as this will be exhibited elsewhere in this thesis, the platform designed here makes a clear contribution in relation to the support of research on untested new market structures.

It could also render assistance to regulators for both the electricity and gas industries, for example in relation to co-ordinated policies. For example, it was shown above how companies may escape the regulators' scrutiny by intervening in both markets simultaneously. Thus, it could also aid in the investigation of further alternatives, to avoid wrong practices.

State planning is losing importance within the market framework. Also, short-termism is believed to be appropriate under a more dynamic, market oriented structure, although some negative points have also been exhibited here. Thus some sort of light-handed (indicative) planning or co-ordination seems to be indicated, for example, within the regulation framework or, alternatively, at the government level.

5 A SYSTEM DYNAMICS PLATFORM FOR THE COLOMBIAN ENERGY SECTOR

The recent Colombian Public Services and Electricity laws (The Colombian Congress, 1994a and 1994b), have created a completely new environment for the Colombian energy sector. These laws confer on the Ministry of Mines and Energy special functions for regulation, planning co-ordination and evaluation of all activities related to the public services of electricity and gas. They also define criteria to harness energy resources (under integrated, efficient and sustainable management) and to promote efficient and rational energy end-use.

These laws are wide ranging in their aspirations and propose a delicate balance between: a) promoting a gradual evolution of free markets which provides for a regulated framework to protect end-users from market "failures", and b) retaining some key aspects of planning with respect to environmental abatement matters, promotion of generation capacity projects to satisfy demand, and allocation of sufficient resources to meet subsidies to the lower income socio-economic groups.

In this and the following chapter the feasibility and mutual coherence of these ambitious laws are tested. Experimentation, using the System Dynamics platform, explores major issues, programmes and codes which are derived from these laws. This is conducted with

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Results of this chapter have been included in: i) a paper presented in the opening plenary of the 1996 System Dynamics Conference held in Boston in 1996, and ii) a chapter of the forthcoming book "Systems modelling for energy policy", edited by D. Bunn and E. Larsen (Wiley, 1996).

the aid of a new construct to support energy policy in Colombia, which is based on the methodology described in Chapter 2. It will be shown that the platform structure proposed in Chapter 3 meets the requirements in this particular case.

The following section provides an overview of the Colombian energy sector; policy issues are investigated in Sections 5.2 and 5.3, and the need for support tools for energy analysis then emerges; a platform structure which aims to fulfil the support requirements for energy analysis is described in Section 5.4; and finally its experimental implementation is reported, finishing with some concluding remarks.

5.1 AN OVERVIEW OF THE COLOMBIAN ENERGY SYSTEM

The Colombian energy system has been going through a very dynamic period and has achieved major structural transformations since the oil embargo of 1973, as has occurred in many of countries around the globe. During the early 1970s the dominant scheme considered independent policies for the different subsectors and experimented with various alternative management models. The oil industry, for example, pursued a trial and error process for the design of association contracts, ending up with arrangements that seem acceptable to most national experts and multinational companies in this field. In the coal sector, apart from the traditional concessions to independent investors, the administration adopted experiences from the oil industry for the open cast Cerrejon project, in the north of Colombia, and created a large company, half publicly owned with the other half held by EXXON. Yet the electricity sector, by comparison, evolved almost exclusively within the public ownership framework, but with the formation of separate national, regional and local enterprises.

As expected, results have been mixed. In the area of hydrocarbons there are promising outcomes, since production should reach the one million barrels per day mark by the end of the century, according to BP experts (Mortished, 1995). Nevertheless, in the coal industry results are less satisfactory, which is partly due to very low world market prices. The electricity sector is a different case altogether. In spite of a well qualified and technically capable work force, it has produced regrettable mistakes. The most important ones are the intermittent electricity blackouts suffered by Colombians during several months in 1981 and again for over a year between 1992 and 1993. However, some analysts partly blame politicians for these unfortunate happenings, as the latter continuously neglected investment recommendations for planning, maintenance and expansion.

In general, during the late 80s the tendency was towards greater integration between industries. Initially, the National Energy Commission was created and, a few years later, this led to the formation of the Planning Unit in Mining and Energy, within the Ministry of Mines and Energy. Even though the latest Public Service and Electricity laws, passed in 1994, envisage both market forces and regulatory intervention, these laws also confer importance to the planning function for the purpose of policy co-ordination. This is being achieved by means of both a specialised Unit for this purpose and a team of energy regulators. The new framework arrangements, while incorporating some of the British and Chilean experiences, also intend to establish conditions specially adapted to the Colombian idiosyncrasies and stage of development. In what follows, a description of the main features and components of the Colombian energy system will be presented.

5.1.1 The electricity sector

The electricity sector is characterised by both diversity with respect to ownership and homogeneity in relation to technologies used for power generation. There are over 20 public generation companies, six of which account for about 89.5% of the system's net capacity (ISA, 1995, and UPME, 1995). It is important to note that almost 10% of the total capacity will be private by early 1997, as new gas-fuelled capacity is being built, at the time of writing, by IPPs in the Caribbean and Southwest regions of the country. Furthermore, after examining proposals and current applications for environmental licences, it is possible to infer that no less than 15% of the total power generation infrastructure could be privately owned by the end of this decade, even if no national assets are sold. Note that the present technology mix consists of 78% hydroelectricity and 22% thermoelectricity, although most new capacity proposals are gas-based.

Table 5.1 shows the ownership status and the percentage capacity of each company (N stands for national, R for regional and M for municipal). There are more than 30 regional distribution monopolies with similar ownership structure to the one in the generation industry. The main difference is that the former possess a slightly smaller share of the market than the latter. The notation used for the distribution companies in Table 5.1 actually represents a conjunction of regional companies under the influence of a major production-distribution company. For example, EEB Distribution includes the Cundinamarca and Meta utilities, and EPM Distribution includes the Antioquia and Choco utilities. The transmission business is largely owned by the nation. The 550 kV line is completely government owned, while almost 70% of the transmission assets over 220 kV belongs also to the central government, with a small participation of the large regional utilities.

PRODUCTION CAPACITY	**DISTRIBUTION**	**TRANSMISSION (>220kV)**
ISAGEN .... (N-27%)	EEB................. (24.2%)	ISA.......................... (69.5%)
EEB..................... (M-21.9%)	EPM................. (19.3%)	CORELCA............... (7.7%)
EPM.....................(M-16.8%)	CORELCA........ (19.3%)	EEB............................. (7%)
CORELCA........... (R-11.4%)	CVC.................... (13.7)	EPM......................... (6.3%)
CVC........................ (R-7.4%)	NORTHEAST..... (8.2%)	CVC.......................... (5.4%)
CHB.......................... (N-5%)	CHEC............... (6.3%)	Others....................... (4.1%)
Others....................... (10.5%)	Others.................... (9%)	
TOTAL................ 10.08 GW	**TOTAL 39161.85 KWh**	**TOTAL............... 8173 Km**

Table 5.1 Generation, distribution and transmission companies according to capacity and market share. (N stands for National, R for Regional and M for Municipal).

Since the late 80s demand in this sector has been growing at about 6% per annum. The interconnected service covers at the present time almost 80% of the population, but all government plans always aim for extensions of the network to remote rural areas of the country. During a time span of less than 12 years Colombia suffered two major periods of electricity rationing, namely in the middle of 1981 and between 1992 and 1993. The first period was not very dramatic and was primarily caused by delays to the power generation expansion plan and also to a below average hydrological yield. The energy required then could have been supplied by a 135 MW thermoelectricity plant.

The second period of electricity blackout was much more severe and lasted for over a year, reaching a maximum discontinuity of service of about 25% per cent during some weeks in 1992. This was caused by a combination of events: planning problems, delays on some projects, poor maintenance of thermoelectric plants, political constraints on financing, terrorist attacks on the transmission infrastructure and sabotage on some power generation installations (Sanclemente, 1993).

5.1.2 The gas sector

World-wide, mainly through the 90s, natural gas markets are being associated more closely with electricity markets for two main reasons: 1) because currently developed power generation technologies make efficient use of gas sources, and 2) because both compete at the end-use level in the household sector primarily in cooking, and space and water heating activities.

Colombia had over 8.3 Giga cubic feet of proven reserves of natural gas in 1993. Recent discoveries associated with the search for oil deposits almost double the natural gas availability (Mortished, 1995), and this further suggests the possibility of abundant undiscovered reserves still existing in the country.

In the early 90s Colombia initiated a large scale gas plan for household consumption, expecting to increase the coverage from 8% in 1995 to 50% by the year 2010. It is also expected that the gas used for electricity generation will expand from 10% in 1995 to over 35% by the year 2010 (UPME, 1995). This plan includes construction of the pipeline system, the most significant part of which should be concluded by early 1997.

5.1.3 The coal sector

Since the 1980s coal mining has become an important export activity in Colombia. With one of the most modern open-cast mines in the world, the aim of EXXON and the Colombian government, through the Cerrejon enterprise, has been to capture about 10% of the world market. Nonetheless, domestic consumption is limited, as the share of coal in electricity generation only amounts to about 10% of the total, and this is expected to decrease even further according to the reference expansion plan for electricity (UPME, 1995a) which sees almost the totality of new power being generated by hydro and gas.

5.1.4 The oil sector

The oil industry has evolved in an interesting way during recent decades. From self sufficiency in oil during the 60s and early 70s, Colombia became a net importer by the late 70s and early 80s, and is now turning into a medium-sized oil exporting nation. Production reached 600,000 barrels per day in 1995 and is expected to rise to the one million mark by the end of the century. While production is now achieved through association contracts and the distribution activity takes place via a very competitive market arrangement, oil refining is still a national monopoly.

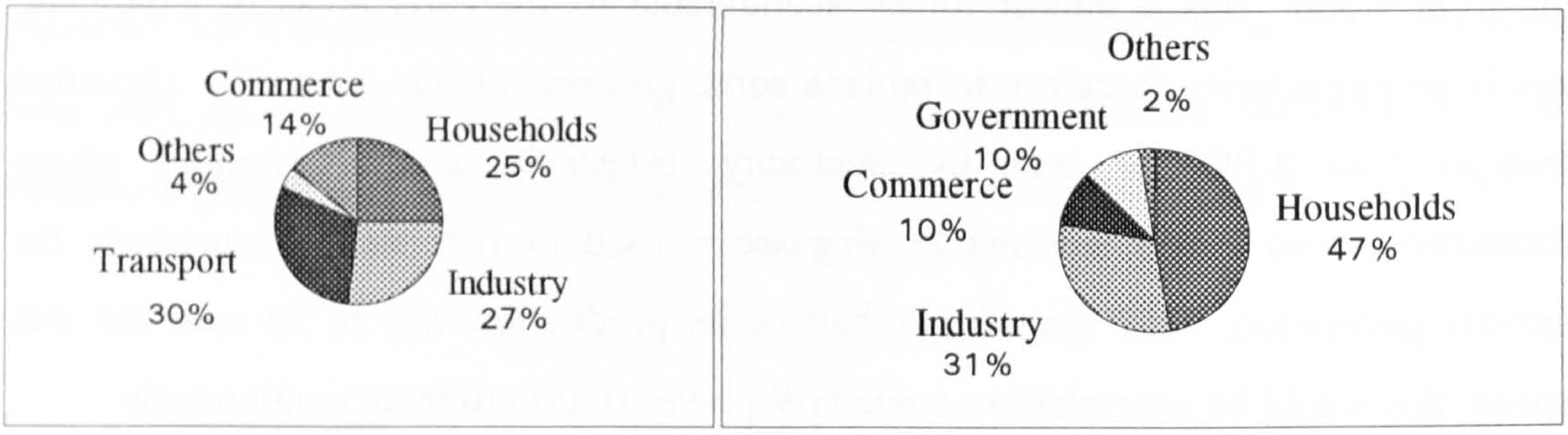
5.1.5 Other sources

Apart from wood and some bagasse (waste in sugar manufacturing), the use of other renewable and non-renewable energy sources is very limited in Colombia. In the residential sector, although it is hard to ascertain, about 60% of the energy used may come from wood. This is almost totally accountable to the rural areas of Colombia. There is an opportunity therefore to replace some portions of this source by Liquefied Petroleum Gas (LPG) or even by electricity, especially in those regions where deforestation is no longer sustainable. Bagasse is used in very small proportions for electricity generation. Note that if only half of its production was to be used for this purpose, this would be equivalent to a one GW power station running continuously.

5.2 THE POLICY AGENDA

Final energy consumption in Colombia grew at about 3.4% between 1975 and the early part of the 1990s, and was basically driven by significant economic and population expansion dynamics. Although GDP exhibited growth-rates above 5% per annum during the 60s and early 70s, they dropped down to slightly less than 4% on average, between 1975 and the early 90s, to rise back again to over 5% a few years later. Meanwhile, the population grew at a steadily declining rate, from 3% in the 60s to 1.7% in the early 90s. Although these figures are not universally acknowledged, here are given perhaps the most widely accepted ones across government and research sources. The differences, however, do not have a dramatic effect at a global level of analysis.

Figure 5.1 (a) and (b) shows the corresponding total energy consumption and electricity demand split between the different socio-economic sectors. It can be observed that the residential sector accounts for about 25% of the total energy consumption and for nearly 47% of the electricity used, while the industrial sector accounts for 27% and 31%, and the commercial sector for 14% and 10% respectively (UPME, 1994).



(a) **(b)**

Figure 5.1 (a) Energy consumption and (b) Electricity consumption, by socio-economic sector.

Figure 5.2 shows the evolution of energy consumption by source in the domestic sector, highlighting the importance of wood. Figure 5.3 (a) shows the share of electricity consumption according to end-use, and Figure 5.3 (b) the <u>energy</u> consumption by different appliances both in the residential sector. Note that cooking is by far the single most electricity-intensive activity in the household sector, following closely the machine operation activity in the industrial sector.

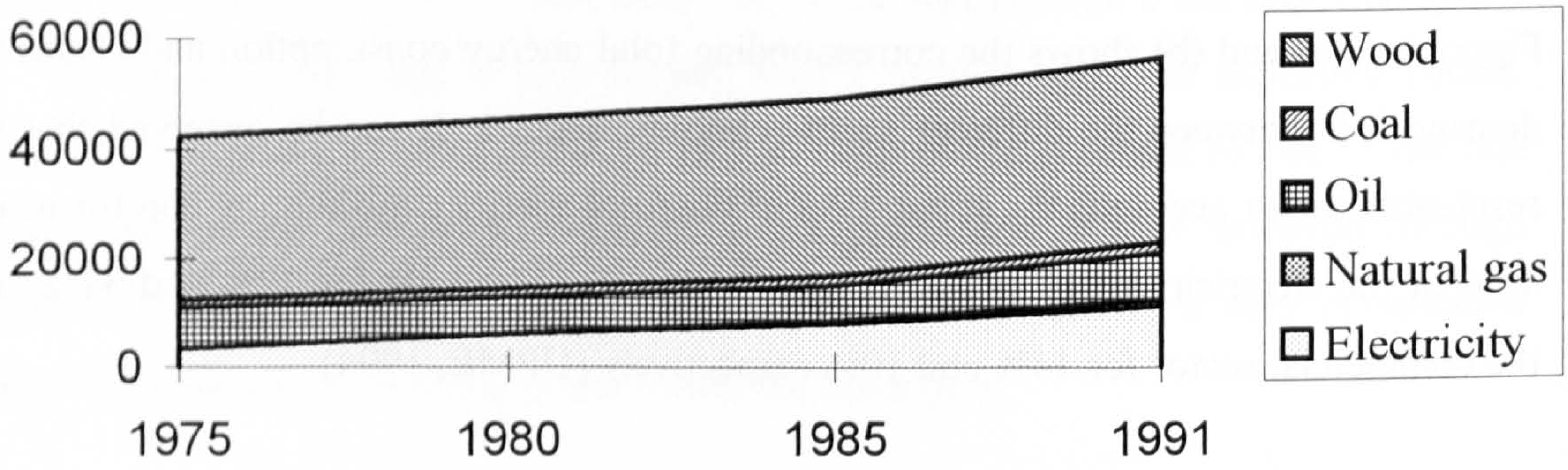
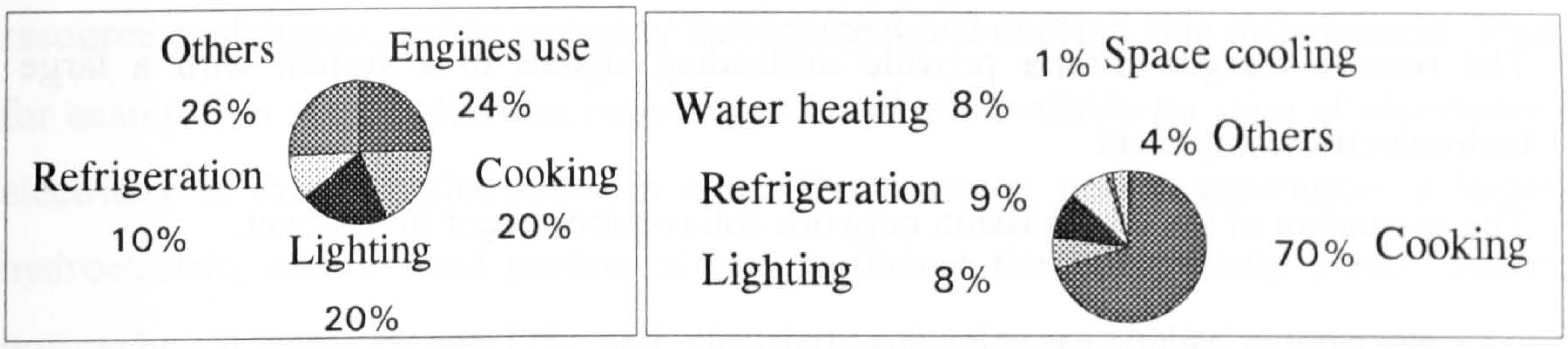


Figure 5.2 Evolution of energy consumption (in teracalories) by source, in the domestic sector.



(a) (b)

Figure 5.3 (a) End-use electricity consumption across all sectors, (b) Household energy consumption according to end-use.

Briefly, a number of issues arises when making an overall assessment of the Colombian energy sector. On the supply-side it can be established that:

- The country possesses abundant energy resources
- The development of resources has had an uneven evolution over the years
- The supply of sources is unbalanced within and across sectors
- Wood continues to be an important source, especially in rural areas
- Electricity has been very much a monopoly in the residential sector
- The large scale gas plan is only going through the initial stages
- Coal supply to the national market is insignificant
- Energy exports (oil and coal) will be growing at a significant rate during the near future.

In particular, some of the problems that have an important effect on the power generation sector are:

- Power generation depends heavily on hydroelectricity
- Hydrological uncertainty plays a very important role
- Thermoelectricity is very inefficient
- Planning for new capacity has shown deficiencies (blackouts)
- The country is on the verge of another period of electricity deficit
- Heavy non-technical losses are endemic in the system

- The reserve margin criteria provide misleading signals in a system with a large hydroelectric component
- The expansion of the transmission network still requires major investment.

Historically, the energy sector has been driven by supply-side management criteria. In actual practice this has meant that the central government has played an omniscient role in the specification of required resources. However, the Colombian demand-side now raises a number of issues:

- Energy markets are very underdeveloped
- The electricity pool started operations in July 1995
- The variety of fuels supplied to industry has been limited
- The domestic sector has not had sufficient energy alternatives either
- Cross subsidies exist in the domestic sector for electricity, according to income
- No rational energy use programmes have been implemented yet

Interrelationships within and across industries, and across supply and demand sectors result in the following peculiarities:

- Planning and policy making is intended to function along with market approaches
- Co-ordination of government actions does not seem a simple task
- Regulation should procure competition and price cross-subsidies
- Political intervention has been frequent
- Management has had an important technical-engineering component
- Economic and system thinking for analysis have played an insignificant role
- Management support instruments and tools are very limited.

The complexities manifested in the Colombian energy sector are immense and require major intervention from different perspectives. Although economic growth has been an encouraging factor, energy policy has shown weaknesses in supporting the overall developing climate from the supply perspective, with respect to: alternatives, expansion, security and efficiency. These have created distortions within this sector in relation to resource exploitation, public company management and demand side management. Thus, for example, in most Colombian regions gas is still not available (in spite of abundance); electricity is the only alternative in some Departments; power generation is largely hydroelectric, with a small portion of very inefficient thermoelectricity plants; electric non-technical losses exceed 12%; and, electricity subsidies are applied extensively.

In the future, co-ordination between public policy and private initiatives should have a much more positive and widespread effect on the whole system, as a consequence of recent legislative developments, the new governance structure set-up, and initial indications of private investment plans. As a result of these, competition, planning and regulation should work together to correct some major system malformations. For this, the country would probably have to both develop its own strategies and learn from experiences taking place in the UK, Chile and other developed and developing economies around the world.

In this sense, there is no obvious recipe to follow, as a number of crucial interlinked problems arise: selection of programmes, scheduling and prioritisation of projects (seeking possible synergies), incentives for private investors and market regulation, among many others. The incrementalist approach may serve the policy purpose to solve these problems. This approach, along with some co-ordinated action, in search for positive feedback elements for development, could prove to be fruitful as discussed in Arthur (1990), but needs to be investigated in this particular set-up.

5.3 ENERGY POLICIES AND PROGRAMMES

One of the aims of the platform proposed in this thesis is to contribute to the analysis of demand- and supply-side policies and programmes. Both The Energy Law (The Colombian Congress, 1994b) and The National Plan for Rational Energy Use (The Department for National Planning, 1995) established the need for demand-side policies and programmes. Both, however, discussed these issues at a very general level. Hence, it is necessary to study these issues in greater depth and to build capabilities for evaluating policies and programmes at a more detailed level, if these laws and plans are to stand a chance of success.

5.3.1 Demand-side policies and programmes

The National Plan for Rational Energy Use intends, in the first place, to determine the most technologically feasible set of end-use appliances and then find the potential savings within each socio-economic group in Colombia. In the residential sector this potential amounts to about 160 MW and 990 MW in refrigeration and lighting, respectively, by the year 2005. In the industrial sector the potential electricity savings may reach only 140 MW in the year 2005, whereas in the commercial sector these savings could approximate 22 MW in the year 2005. In total, potential savings at peak times will be about 1300 MW (i.e. about 13% of current capacity, excluding the effect of electricity substitution by gas) by the year 2005.

The Plan for Rational Energy Use establishes four strategies: 1) Publications, exhibitions and education on rational energy use issues, 2) tangible actions to reduce electricity demand in the short-term, 3) electricity substitution by gas, and 4) rational energy measures for the medium and long-term.

Apart from some specific actions on the education side (no estimates are made on the impact of these actions), it proposes two specific projects for the short term in the area of substitution of light bulbs: a) in the public sector, and b) in the residential, commercial and industrial sectors. The first project, which represents savings of approximate 205 MW, costs some US $130 million (some of which has been budgeted already) and will take nearly three years to be implemented. The second project consists of promoting substitution of some of the light bulbs in the non-government sectors. Its aim is to substitute 2 million units, reducing demand at the peak period to about 70 MW, at a cost of approximately US $16 million, and taking approximately six months for completion. Excluding the gas plan (where nothing specific is proposed) seven different actions are intended for the medium and long-term: Change of light bulbs in buildings, normalisation of electric appliances and equipment, installation of condensers in the distribution grid, DSM in industry, solar building design, co-generation in industry and adjustment on prices and subsidies.

In this research, additional efforts have been made to structure policies and programmes on rational energy use, or DSM, and to evaluate preliminary projects complementing those discussed above. Policies on rational energy use may be classified in the following categories:

SUBSTITUTION
EFFICIENCY
CONSERVATION

Apart from the above DSM policies, other overlapping categories which may be broader in scope are considered:

TECHNICAL LOSSES
PRICES, SUBSIDIES AND NON-TECHNICAL LOSSES
ENVIRONMENTAL ABATEMENT

Figure 5.4 exhibits an interesting feedback loop between DSM policies and prices. The differences between economic and conservationist approaches have created an interesting debate (Sutherland, 1995). On the one hand, the current liberal economic trend argues in terms of market-force pricing to attain economic efficiency. In this case, if external factors have an important influence on prices, it seeks to make some adjustments, internalising some societal cost, perhaps through taxes. On the other hand, the conservationist/engineering tradition, maybe more inclined to DSM programmes, aims to bring down some existing market barriers (for example those related to information or financial asymmetries). As long as these two antagonistic positions prevail, prices and DSM will go up as indicated in the figure.

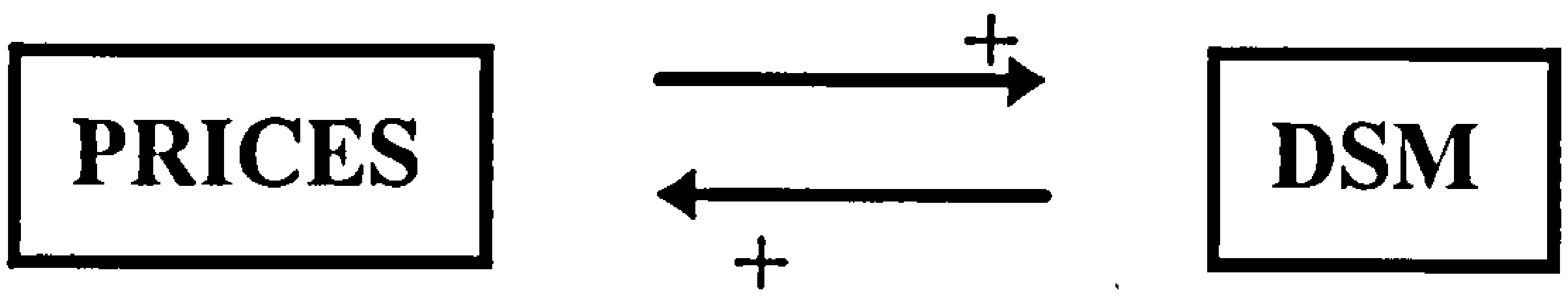


Figure 5.4 Relationship between Pricing and DSM

The specific DSM programmes initially considered to addressed with the support of the platform designed here, include:

Substitution

Programmes on substitution are primarily oriented to seek the use of the most efficient sources, when there are no effective market mechanisms to do so. It is important to supply fuel alternatives to households and industry. The supply of, for example, natural gas as a source for end-use will release some pressure from the power generation sector and will create a more competitive environment. Detailed modelling to support the penetration of gas in the household sector is one of the most important goals of this research. Policies and programmes related to this subject may then be examined. These will have implications specially with respect to the substitution of appliances for cooking and water heating.

Efficiency

Programmes in this area are geared towards replacing appliances, equipment and other devices by more efficient ones. They aim to introduce new, more efficient, technologies for lighting and space cooling in all sectors, and for cooking in households.

Conservation and energy losses

Programmes on conservation and energy losses intend to promote the appropriate use of appliances and equipment within each socio-economic sector. Also, problems related to losses in connections or installations are addressed here. The means utilised should include education campaigns, publication and diffusion of written material, industrial audits, TV and radio advertisements, and exhibitions. The most significant areas for action will be in the cooking, lighting and fabric pressing functions.

Pricing and non-technical losses

Programmes on pricing and subsidies are a delicate matter in Colombia. There are at least three different angles from which to observe this problem: the social, the political, and the economic. In Colombia there are broader differences between the rich and the poor than in most countries around the world. A portion of the population cannot pay real electricity prices and this fact is acknowledged in the Constitution and Electricity Law, by establishing cross subsidies to help the less well-off sectors of society. Furthermore, it is important to note that non-technical losses or pilferage are as high as 12% in Colombia. Therefore, under these circumstances handling the economic perspective is not a simple issue. In the past the Tariff Commission in Colombia set tariff goals to reach the long-term incremental costs of electricity. However, both political and economic circumstances worked against these. Not only has there been political opposition against such measures, but also economic obstacles (namely inflation) have made things slightly more complicated than initially suspected. Yet tariffs are showing a moderate upward trend during the 90s. The future challenge will be, without doubt, to handle simultaneously a competitive market environment along with guaranteed price subsidies to the poorest communities. The platform proposed here will require additional research efforts to address these specific problems.

Environmental abatement

Environmental issues are only addressed tangentially in this research. Nonetheless, DSM policies have a clear effect in reducing the need for energy, which impacts pollution problems positively. With the aid of the platform discussed in this thesis, it is thus possible to measure the savings on electricity generation, facilitating preliminary calculations of environmental benefits.

By and large, the Colombian policy on energy demand seems to be ambitious and raises many questions. How much of it is realistic? Under what conditions, can goals be attained? What financial incentives are required? What is the weight of energy prices vs.

financial incentives? What is the average energy-bill increment expected by customers in the years to come? What would be the effect on regional utilities? None of these queries can be answered without a quantitative support tool that examines the combined effect of the multiple issues being considered.

5.3.2 Supply-side policies and programmes

The Colombian Electricity Law (1994) provides a new framework for the activity of supplying energy services. The inauguration of the wholesale market took place on July 20, 1995. Its operation, similar to the British pool (Bunn et al., 1993), required producers to submit, one day ahead, hourly bids. Note that the Colombian pool does not consider yet any compensation for capacity availability to producers, principally because it has been argued that the system margin does not have the same meaning as in a highly biased thermoelectricity structure. The Colombian electricity set-up, as mentioned before, is predominantly hydro (80%) but is being affected significantly by severe unpredictable droughts during the dry season (due to the Niño phenomenon). These uncertainties are creating shifts in the power generation technology composition, because thermoelectric plants outperform the hydroelectric ones, on the grounds that they: reduce construction time by a third, lessen capital cost involved by more than one half, decrease construction uncertainties, abate environmental problems during construction periods, and last but by no means least, eliminate completely hydrological uncertainties.

At the time of writing, the system is characterised by some unfavourable conditions: low tariffs, large debts across the industry (with very few exceptions), commonplace inefficiencies, tight system reserve margin, and no clear incentives to newcomers. This environment creates difficulties, restrictions and barriers, and poses serious threats for the future system evolution.

To make things slightly more complicated, the Colombian gas plan is going through its initial phases and some delays are expected. This is critical to some gas-based power generation projects, specially in the Valle Department, in the Southwest of Colombia, and has a deleterious effect on the time-table of the indicative expansion plan at a crucial moment. Furthermore these delays will also have a significant impact on some of the electricity substitution programmes in the household sector.

As in the previous section on DSM, additional efforts have also been made to structure policies and programmes on Supply-Side Management (SSM). In this case, however, as yet there is no corresponding CONPES document from the Department of National Planning. Therefore the ideas following are intended to help in ordering the analysis. Policies on SSM may be classified in the following categories:

TRANSMISSION
COMPETITION
PRIVATISATION
ROBUSTNESS
ENVIRONMENT

The policies on SSM examined in this thesis do not address specific questions on efficiency, rather it is approached by means of competition and privatisation. This is precisely what Figure 5.5 illustrates. Here, productive and allocative efficiencies (Armstrong et al., 1994) are targeted by way of market forces and regulation.

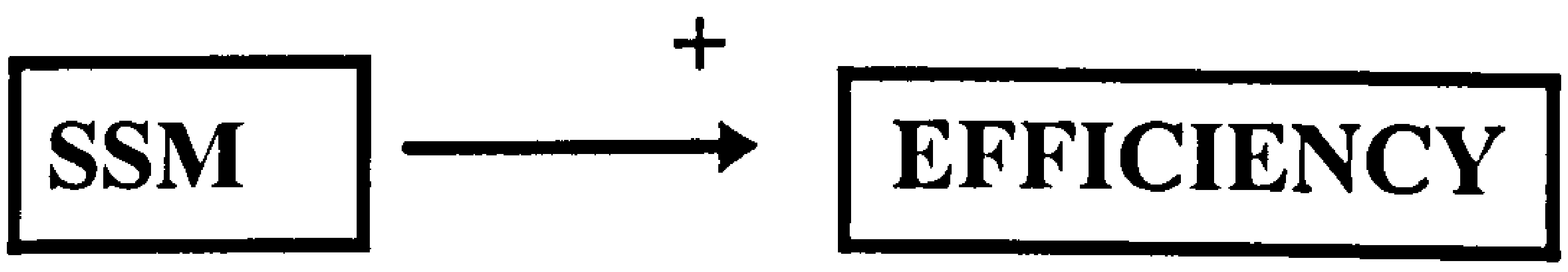


Figure 5.5 Effects of supply-side management policies on productive and allocative efficiencies.

Some specific SSM programmes, policies or actions may be structured with possible support from the platform, as follows:

Transmission

Several programmes on electricity transmission are a matter of concern to the Colombian authorities. In the first place, as previously discussed, the plans for the grid expansion to remote rural areas have always been part of every government's development plan. Thus it will be important to assess the impact of these programmes on the energy system, with the aid of the platform developed in this thesis. In the second place, renewal and maintenance of primary and secondary networks need monitoring. However, especial features to address these monitoring situations will not be implemented in the platform in the near future.

Competition

Specific regulatory actions to promote competition are not simple to model and their effects often take time to show results, as they may imply structural changes in a specific industry. At the generation end, for example, the daily pool mechanism has many alternative designs to provide appropriate incentives for capacity building. In Britain the challenge has been to bring more competition into the system, whereas in Colombia, although some competition already exists, the main concern is to guarantee sufficient capacity. This is undoubtedly to avoid electricity rationing and to take as little risk as possible to this end.

Limited research has been pursued on this area for the Colombian case. Note that in Chapter Four some of these issues have already been explored for the British case. In the Colombian case, however, research has been limited to examining the effect of a) electricity pool pricing on customers' demand, and b) DSM policies on the likely delays required to be introduced into the indicative expansion plan for power generation. In this case other questions related to, for example, the modelling of risk aversion factors or political intervention behaviour are left open for further investigation.

Competition between the different regional companies and newcomers is also an open question but this is being investigated at the present time under the framework developed in this thesis (UPME, 1996).

Privatisation

In general, although privatisation processes of some public assets are taking place in Colombia, these have been moving at a very slow rate, particularly in the electricity industry, where broad announcements on selling intentions have been made but with no specific action being taken yet. The Colombian government had been studying this possibility for some years until it was advised to go ahead with it in November 1995. Regardless of these considerations, independent producers are already entering into the system. About 1.3 GW of gas-based power production should be starting operation in early 1997, apart from some 30 proposals for new plants which are going through different stages within the lengthy licensing process required in Colombia (environmental licences are taking over a year for approval - the maximum allowed by Law).

Robustness

The Colombian energy system has shown some imbalances and major weaknesses. Although resources are varied and abundant, consumption exhibits unique patterns, for example, at the household level. Furthermore, electricity supply displayed definite reliability faults, as evidenced by the 1981 and 1992-93 blackouts.

If economic incentives are correctly designed for capacity building, it is likely that a number of uncertainties will be reduced, as more gas-based plant seem to be attracting the attention of both public and private companies for electricity generation. In this sense, the system will be more robust and less vulnerable to unfavourable hydrological situations.

Robust policies on the supply side will guarantee a sufficiently large reserve margin, an appropriate technology mix for production, and a fairly smooth evolution of capacity building. These characteristics, which will be examined in next chapter, should overcome some of the adverse initial conditions observed in the system, which have been discussed earlier in this section.

Environment

Environmental policies and programmes are coming to the forefront since the creation of the Ministry for the Environment in 1993. Colombia has had a variety of laws on environmental matters but their enforcement has been limited in the past. The electricity generation and transmission projects are going through close scrutiny and the evaluation of proposals is taking around one year for approval at the present time.

The Colombian policy on energy supply seems ambitious given that the starting conditions are far from ideal. As in the demand case then, how much of it is realistic? What can the expected outcome of competition on prices be? What would be the combined effect of pool prices and DSM policies on customers' energy bills? How robust are these policies? These questions cannot be answered without a quantitative support tool that considers the combined effect of the multiple issues being considered. This problem will be addressed next.

5.3.3 Support requirements for policy analysis in Colombia

There is a recent tradition of using the ENPEP energy model (Buehring et al., 1991) for policy analysis in Colombia. This has posed major limitations from both theoretical and technical perspectives. Firstly, as has been discussed in previous chapters, ENPEP follows a general equilibrium economic approach. Also, as balance takes place on a yearly basis, policies on technology penetration for five years, or so, will show awkward short sighted effects. For example, creating high price-volatility or source scarcity, which may not match reality, given the regulatory intervention on prices. Secondly, although a weaker criticism, the ENPEP PC-version has a very limited capacity for supporting either a large enough model or stochastic uncertainties.

Furthermore the results obtained by this approach are rather different compared with those provided by an SD-based one. The SD methodology is more suitable for exploring bounded rational agents and transitional systems, whereas general equilibrium methods are more appropriate for studying rational agents and ultimate limit situations.

Hence the need for a framework for analysis capable of handling breadth and depth. Breadth in terms of being able to address a number of connected policy issues. Depth in terms of supporting analysis at a detailed level, as in the case of specific DSM programmes.

Moreover, an incrementalist approach needs to be built into the methodology, both for the analysis of the implementation of programmes and projects as well as for the purposes of policy making. For example, in the 18 month period since this research started to focus on the Colombian case, the pool price mechanism was introduced and some DSM programmes were devised. Overall, the modelling requirement is one that provides a platform for simulation, scenario analysis and policy evaluation. It has to focus as much on global strategic issues as on some fairly detailed financial analysis. This approach addresses the features of scale and modularity required in the platform design, discussed in depth in Chapter 2.

In many aspects, with respect to data not yet available in Colombia, the modelling approach needs to make use of experiences from elsewhere. For example, in imposing upon Colombia the UK-like power pool, can we incorporate as "archetypes" re-customised versions of the SD-type models that have been developed to understand the UK system (Bunn et al; 1996a, 1996b) and thereby investigate whether similar behavioural properties will be exhibited in Colombia? So much of the world-wide trend to re-structuring has been promoted by <u>analogies</u>, that a platform to verify whether the analogies will transfer to new contexts is needed. Similarly, can the insights from consumer choice models such as in ENPEP be assimilated and assessed in this context? These dilemmas are addressed in the next section.

Thus, one of the primary functions of such a modelling platform is as a workbench for testing analogical reasoning upon which so much of the advice given to the energy sector is based.

Also, as a context testing framework, the platform construction process has to evolve through the adaptation of changing circumstances, including new components to address a variety of complementary and dynamic issues. Furthermore, transferability of the platform between different groups of modellers requires a modular and transparent structure. End users also need to be trained to use their "own" platform in order to develop it further as new policy issues emerge.

Summarising, the methodology needs to be capable of handling, for the Colombian case:

- Scale and modularity
- Adaptability
- Incrementalism, and
- Transportability and transferability.

In the following sections we will examine how well these features can be integrated into a systems platform, proposed in Chapter Three, which needs to be constructed specifically for the Colombian national case to aid both policy making and the evaluation of programmes and projects.

5.4 A PLATFORM TO AID POLICY ANALYSIS IN COLOMBIA

The platform design to support Colombian policy analysis, at a global level, included a prioritisation strategy for the most important problems involved. Rational energy-use programmes, the large scale gas plan and the indicative power generation expansion plan are at the top of the agenda. These are very much interrelated and required immediate attention as energy demand is growing at a significant rate and the system margin is being reduced dramatically.

Figure 5.6 shows the general platform structure in terms of its main components and the corresponding interrelationships. This follows closely the design proposed in Figure 3.2 and also preserves the structure of the archetype in Figure 3.3. One can see that supply is driven by demand but that the former may impose restrictions on the latter; also that some endogenous variables, such as prices, interact dynamically with both supply and demand; and additionally that external forces, including the energy policy, have a strong influence on the system. While the following subsections discuss the main platform components, the next chapter examines whether this design facilitates the analysis of plans and programmes mentioned above.

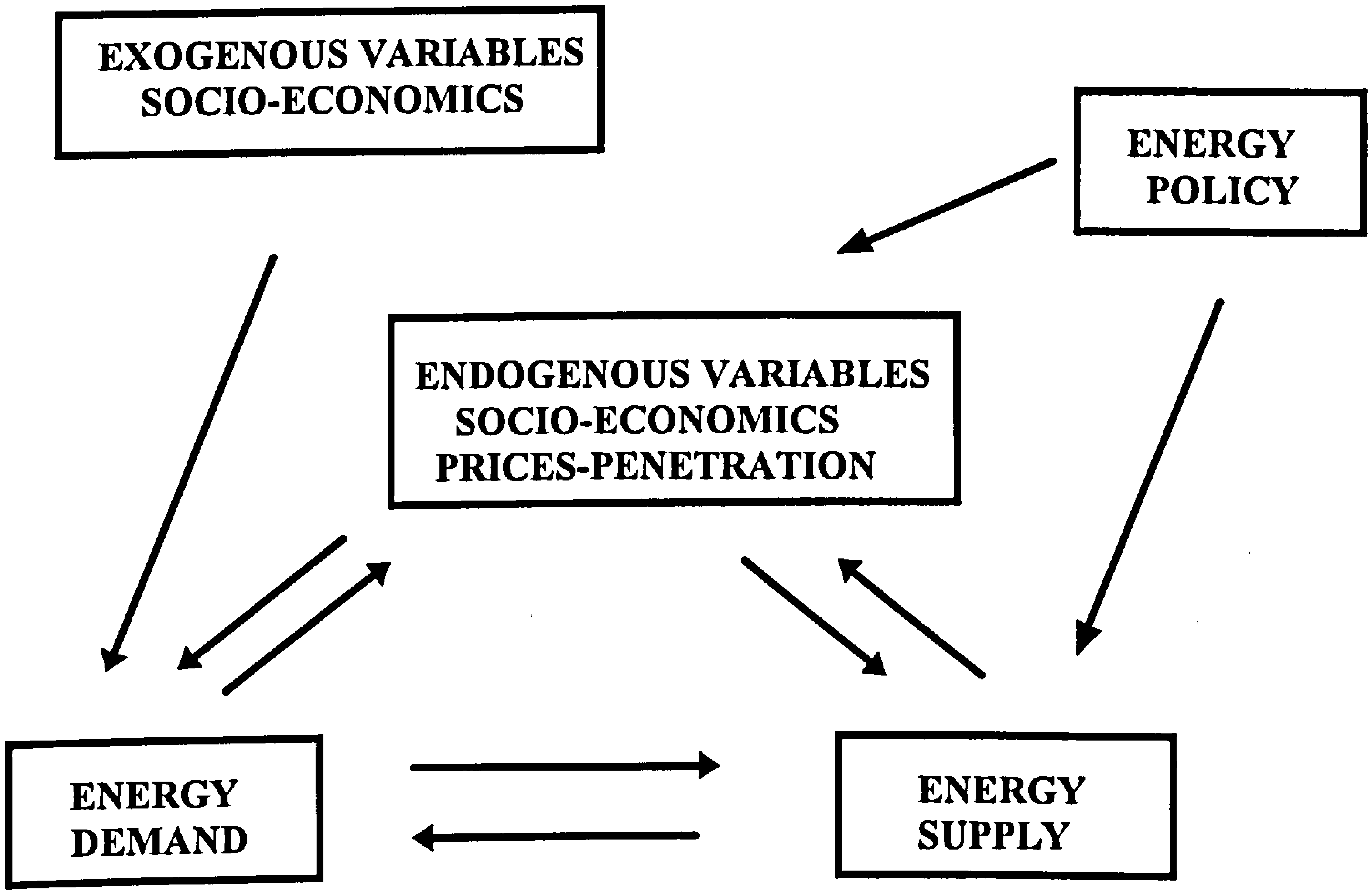


Figure 5.6 General platform structure

5.4.1 Socio-economic modules

The most relevant exogenous variables considered included GNP, GNP per capita and population. Also, some pertinent causal relationships between these variables are exhibited in Figure 5.7. The actual equations used to represent the corresponding interactions are standard in the literature, except perhaps for the house-building component. Household construction is modelled here endogenously as a function of accommodation requirements, GNP per capita, and income distribution.

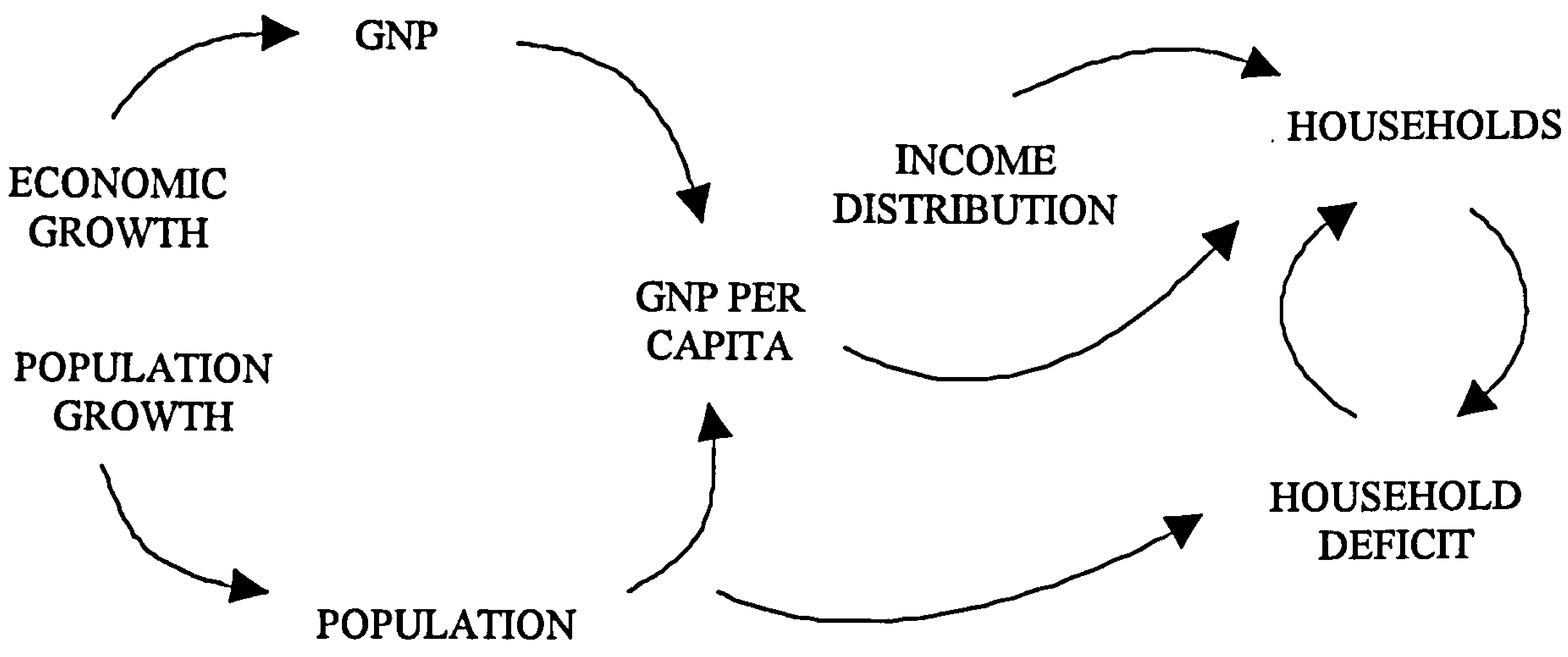


Figure 5.7 Socio-economic module

Modelling the house-building activity requires careful analysis, as there is an overwhelming perception in Colombia that this activity grows at constant or increasing rates, in spite of evidence showing the opposite. This has had important repercussions, possible leading to exaggerated electricity demand projections such as those exhibited in UPME(1995).

It is important to examine this issue closely. In the first place, population growth has shown a steadily declining rate since the early 70s, as discussed earlier in this chapter. And, secondly, Colombian governments have managed to reduce major housing deficits and deficiencies since the late 70s, as can be appreciated from Table 5.2. Some inconsistencies in these figures, due to diverse interpretations of the concepts 'deficit' and 'unsatisfactory conditions', have only minor effects on the connections to the electricity grid.

President	Period	Housing deficit*	Unsatisfactory conditions	Intended constructions
Turbay	1978-1982	850000	-	188529
Belisario	1982-1986	615000	-	442000
Barco	1986-1990	300000	1000000	-
Gaviria	1990-1994	800000	1700000	539000
Samper	1994-1998	-	1994000	606000

Table 5.2 Government house building plans during the period 1978-1998 (DANE, 1993)
*** Estimated housing deficit at the beginning of presidential period.**

Note that in urban areas Colombia had about 5.2 million houses in the year 1993. Thus, since the early 80s the average housing requirements have been growing at decreasing rates, as reported deficits have been declining in relative terms. There is further evidence to support this fact. Figure 5.8 shows a reduction (in terms of the trend) in new connections per year as a percentage of total domestic connections to the electricity grid. This is a good proxy for construction activity, given that only a very small fraction of houses are not covered by electricity services in urban areas.

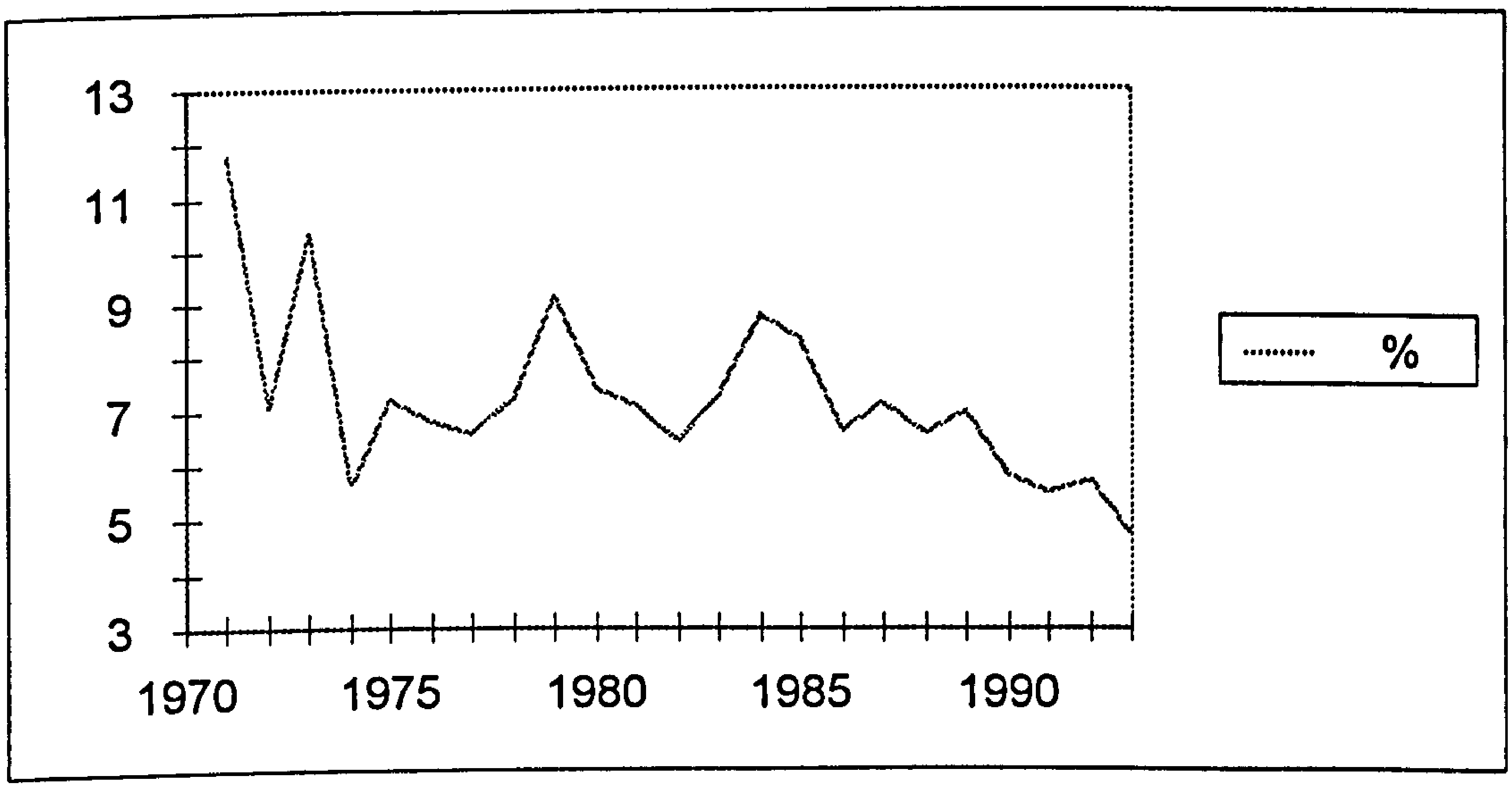


Figure 5.8 New connections per year as a percentage of total domestic connections to the electricity grid, UPME (1995).

Hence the simplified model chosen to represent the household building activity for the platform actually requires some balancing (negative feedback mechanism) to describe the reduction in the rate of household connections. Figure 5.9 shows the differences between the declining trend of household connections and the projections obtained using the model (simulation). In fact, the model initially exceeds the fitted trend in order to account for the specific phenomenon that occurred during the 1992-1993 blackout (unfulfilled latent connections due to blackout). The fitted trend shows the relevance of the platform component.

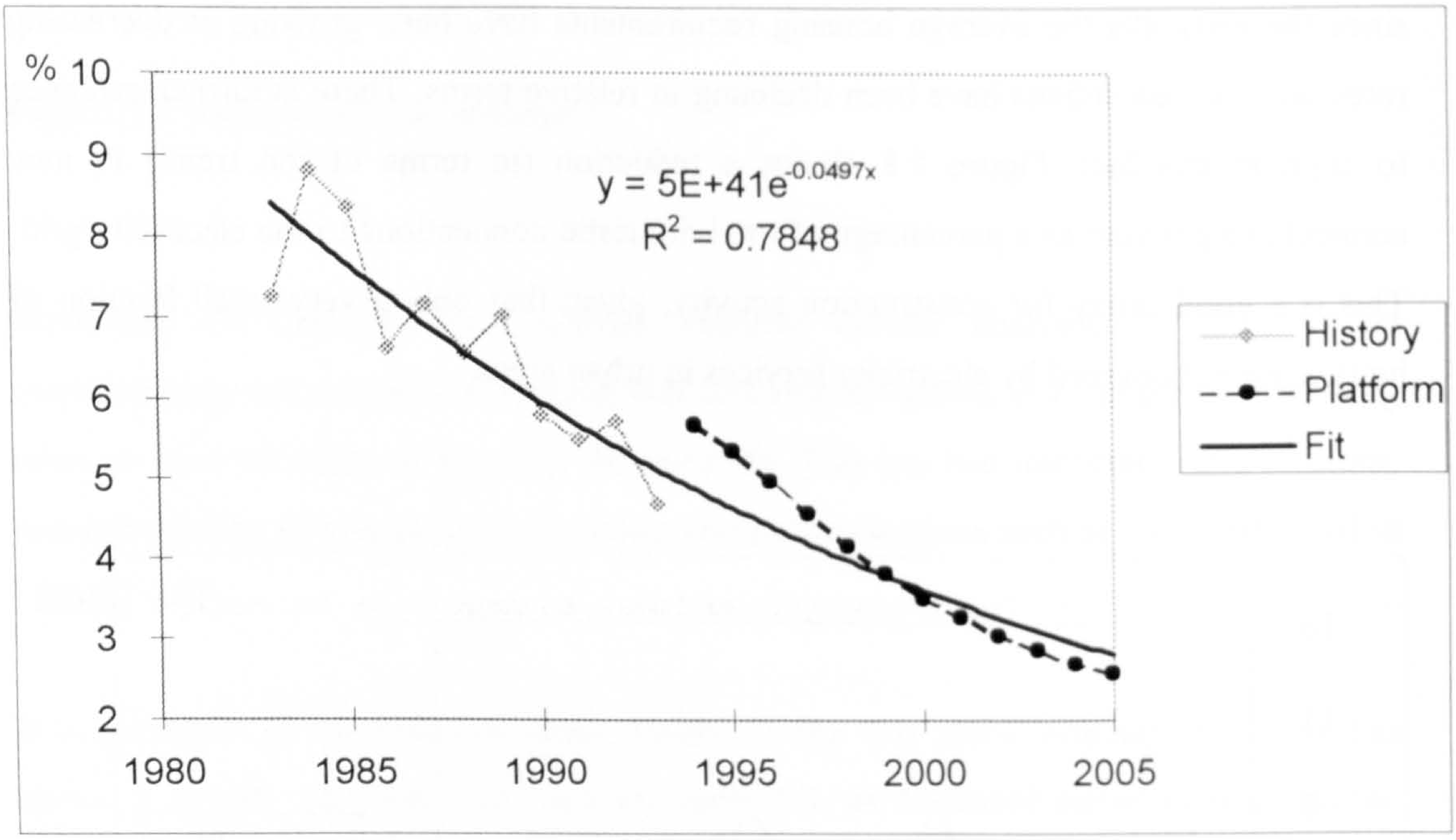


Figure 5.9 Fit of new connections per year as percentage of total domestic connections to the electricity grid.

Finally, the residential component was disaggregated into its urban and rural components to account for both the grid expansion plan aimed at the poorest regions, in remote territories (in the country-side, and in order to be capable of focusing on major DSM programmes. Fuel and electricity prices are overwhelmingly regulated, and so were initially represented as exogenous variables. Equipment and appliance prices were represented as functions of technology penetration. These can be appreciated in the following section.

5.4.2 Energy demand modules

The demand modules include the following sectors: residential (disaggregated into its urban and rural components), industrial, commercial and government. Individuals or groups, within these sectors, use diverse energy sources by means of different appliances, equipment and artefacts. As the platform keeps an account of energy use by these alternatives, it aims to facilitate the formulation and evaluation of policies, especially with respect to DSM programmes on rational energy use. This makes possible the investigation of the impact of programmes on energy conservation or policies intending to stimulate the substitution of appliances by more efficient ones, from both economic and energy perspectives.

Figure 5.10 shows some of the most relevant driving forces influencing end-users' decision making processes for appliance acquisition. This behaviour is considered to depend on the equipment annual equivalent cost and on the economic and population growth. The annual equivalent cost is represented here as a function of the equipment price, the corresponding fuel price to run it and its life cycle. It is important to note that the penetration speed of a new technology has an influence on other customers (its acceptability), which has an effect on price reduction (economics of products) and eventually closes the cycle, thereby making it more accessible to newcomers.

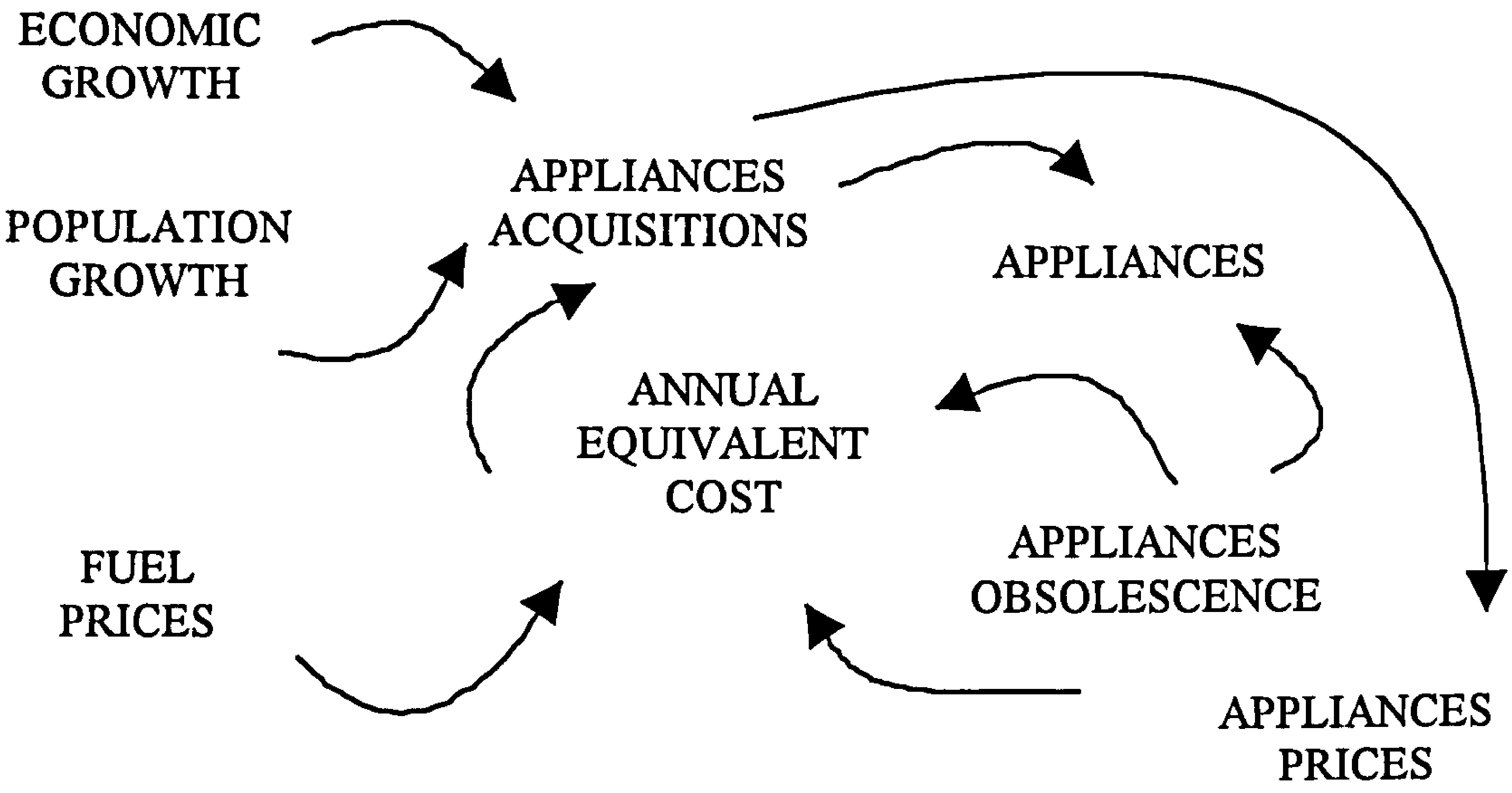


Figure 5.10 Driving forces within the appliances acquisition dynamics

The dynamics of price and income elasticities, as a partial explanation for electricity consumption, are also considered in this platform. These factors have proven to have an effect on demand when prices increase significantly (Haas and Schipper, 1995). Table 5.3 shows short-term price elasticities reported in three of the most reliable studies in Colombia, which may be contrasted with values found elsewhere in Westley (1991). It is important to note here that the decline in income elasticity is explained by the fall of GNP per capita growth-rate during the 80s (less than 3.5% during some years). Thus, as GNP per capita is expected to start growing again at rates over 4%, income elasticity should recover moderately. Also note that the average electricity price growth-rate of about 3% during the 70s was moderate compare to that observed (above the 6% mark) during the 80s - over double the rate. Hence, as prices should continue to grow at significant rates, price elasticities should continue their declining trend - although this may be more smoothly than in the past. Note that ENE (1981) and CNE (1992) are major studies which were undertaken by the Ministry of Mines and Energy between 1979 and 1981 (MINMINAS, 1981) and between 1990 and 1992 (CNE, 1992).

	ENE (1981)	CNE (1992)	UPME (1994)	WESTLEY (1991)	
	COLOMBIA	COLOMBIA	COLOMBIA	COSTA RICA	MEXICO
Price elasticity	-0.27	-0.44	-0.41	-0.50	-0.47
Income elasticities	1.40 - 1.64*	-	0.76	0.20	0.73

Table 5.3 Price and income elasticities
*** Value depends on region**

Elasticities in Colombia have shown notorious changes over the years. These instabilities have also been observed in other Latin American countries (Westley, 1989) as well as in Europe and the US (Haas and Schipper, 1995). Historical evidence explains how, during a period of electricity tariff increments, as income (GNP per capita as proxy) has grown by 60%, price elasticity has dropped by about 50% (Mexico's GNP per capita is about 30% higher than Colombia's). When a logarithmic function is adjusted to these values, projections decline slowly (i.e. giving a projected value of around -0.7, at the corresponding GNP per capita growth, which may be reached by about the year 2009). Figure 5.11 shows how price elasticity decreases, as GNP per capita grows, according to the following logarithmic adjustment:

$$y = -0.2951 \operatorname{Ln}(x) + 3.6056.$$

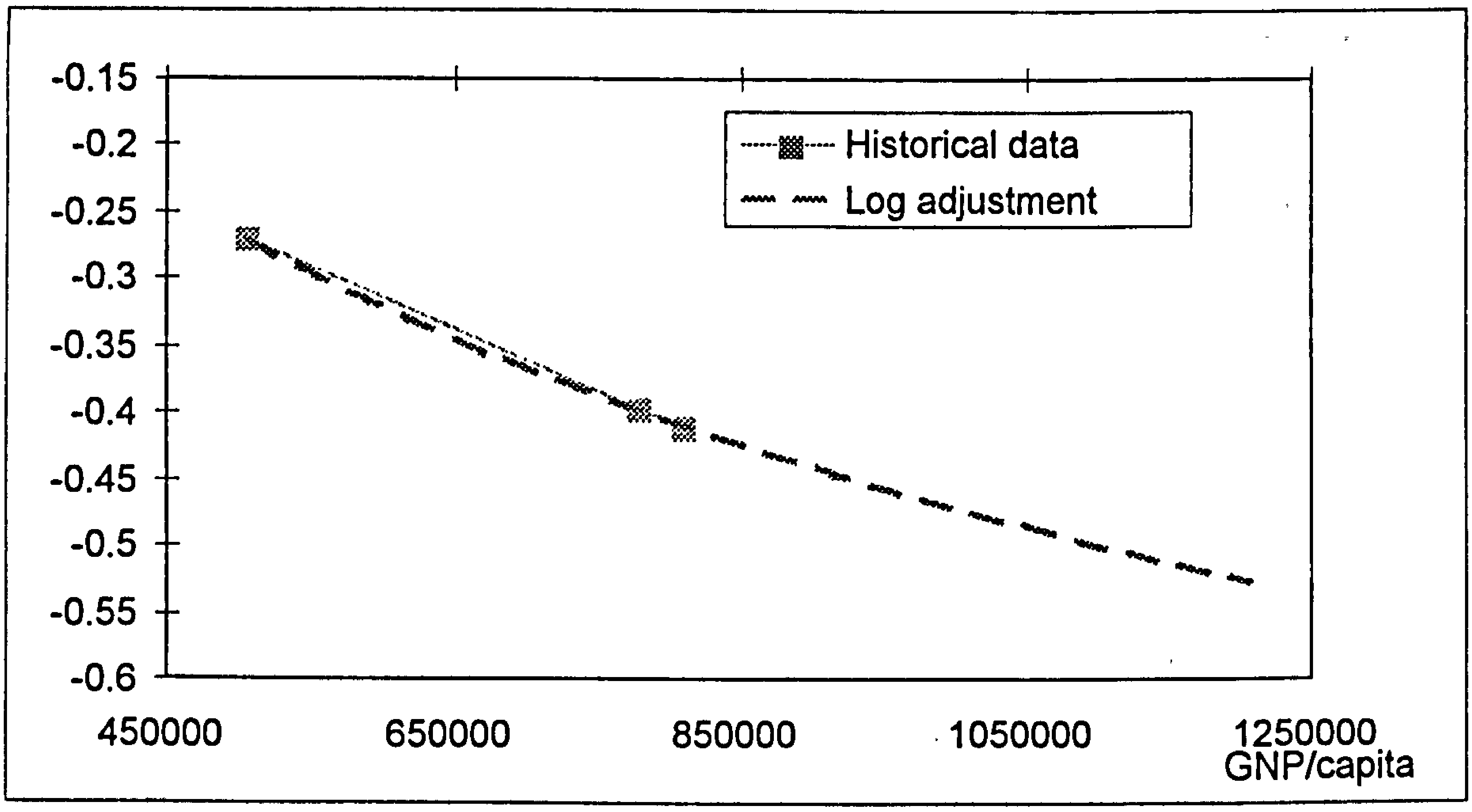


Figure 5.11 Historical price elasticity as a function of GNP per capita (Colombian $)

Similarly, consistent with investigations elsewhere (Westley, 1989, and Haas and Schipper, 1995), it has been assumed here that income elasticity will increase during a period of significant GNP per capita growth. Thus Figure 5.12 represents the way income elasticity should recover smoothly as GNP per capita growth grows to over 4%, while population drops (yielding increments in GNP per capita), until reaching stability. This is done according to projections for GNP and population growth. Also note that: a) as per capita growth rates increase by half of one percent (from 3.5% to 4%) income elasticity goes up by over 15%, and b) as Colombia approaches Mexico's GNP per capita (about US$ 3100 in 1995), income elasticity rises by about 10%. These formulations of price and income elasticities will provide interesting insights into policy analysis.

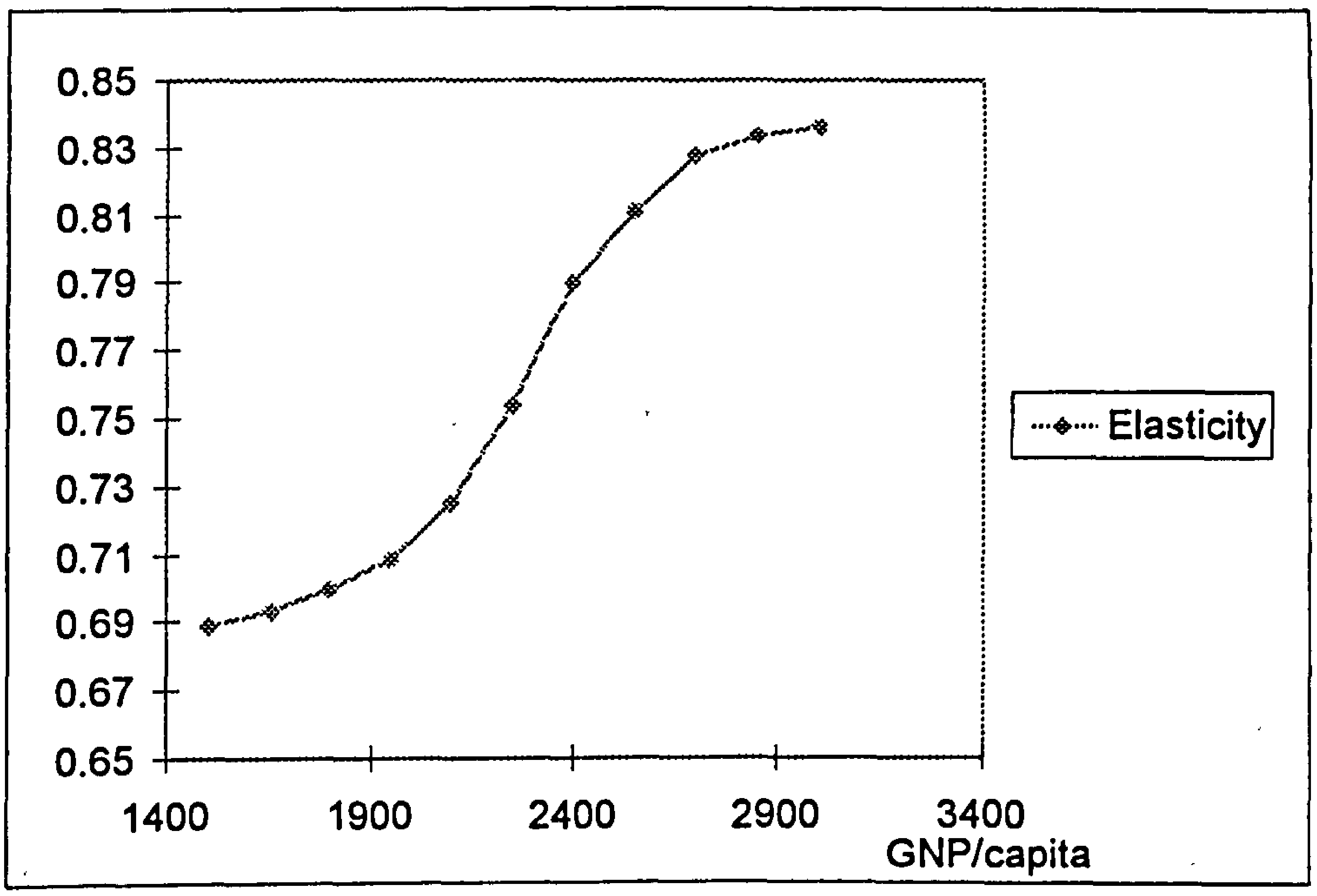


Figure 5.12 Projected income elasticity as a function of GNP per capita in US $

The price dynamics of appliances is also investigated here. This is required in order to appreciate more clearly the penetration of efficient technologies. Figure 5.13 exhibits historical data and the corresponding polynomial adjustment found for cumulative sales of domestic manufactured electricity cookers (in thousands), with respect to prices, since the year 1971 (DANE, 1993). In this case

$$y = 4188\, x^{-0.1853}$$
$$(R^2 = 0.7794)$$

provides a good adjustment to historical data. Although similar results were found for lighting equipment, these are not being used here, as price evolution depends more on external factors related to technology improvement in the industrialised world than on domestic market conditions. Furthermore, in this particular case it is more interesting to check the viability of Colombian programmes on lighting equipment rather than other medium or long-term issues concerning technology propagation.

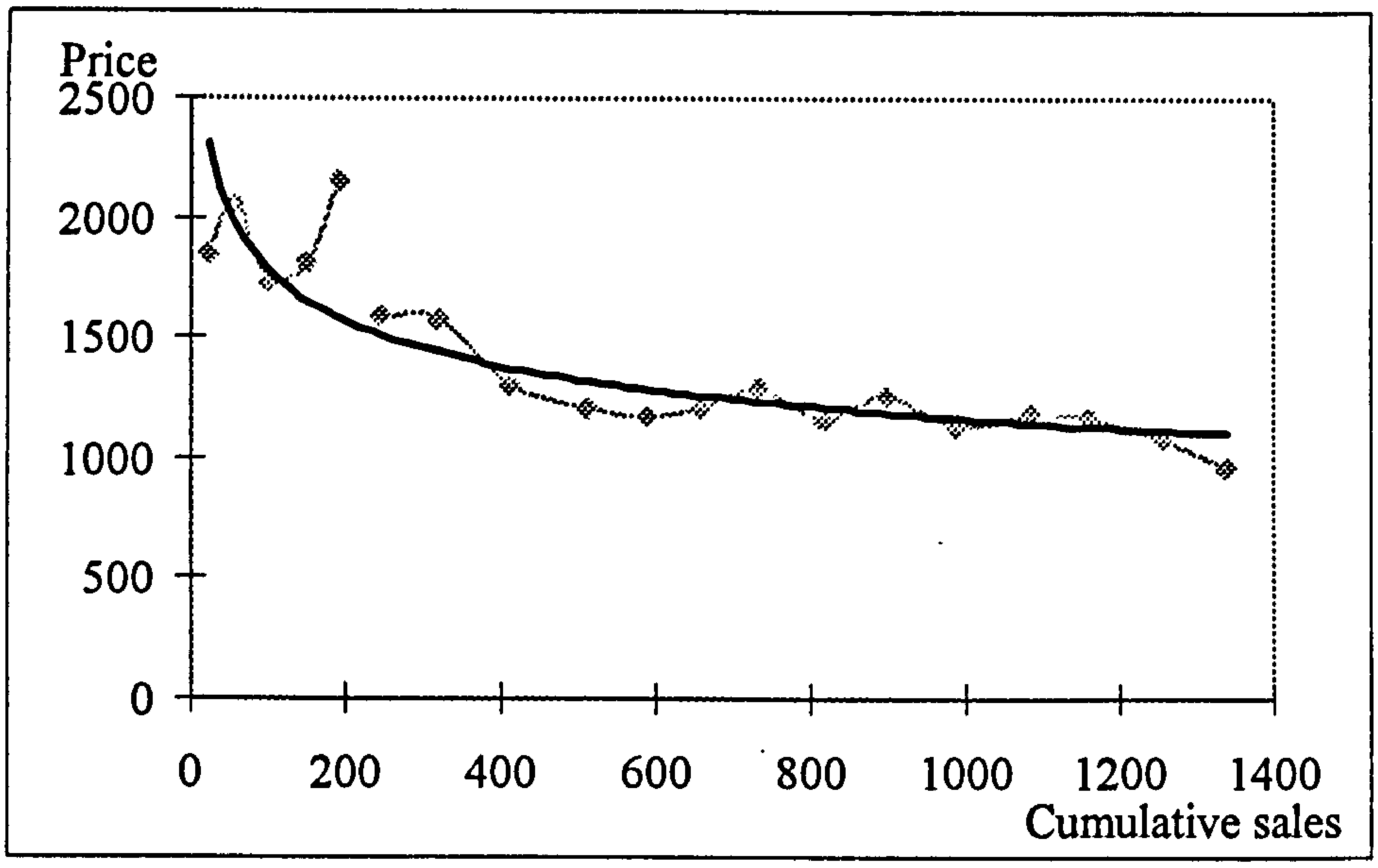


Figure 5.13 Cumulative sales of households cookers (in thousands) as a function of price, since 1971.

Figures 5.14 and 5.15 show the specific logic used in the platform design to represent the end-user motivations for appliance acquisition in the residential and industrial sectors. This rationale is also extended to commerce and government. Acquisition decisions for the various appliances and instruments in these sectors are based on two fundamental criteria: a) fulfilment of new requirements, and b) substitution of an obsolete appliance within a household or company.

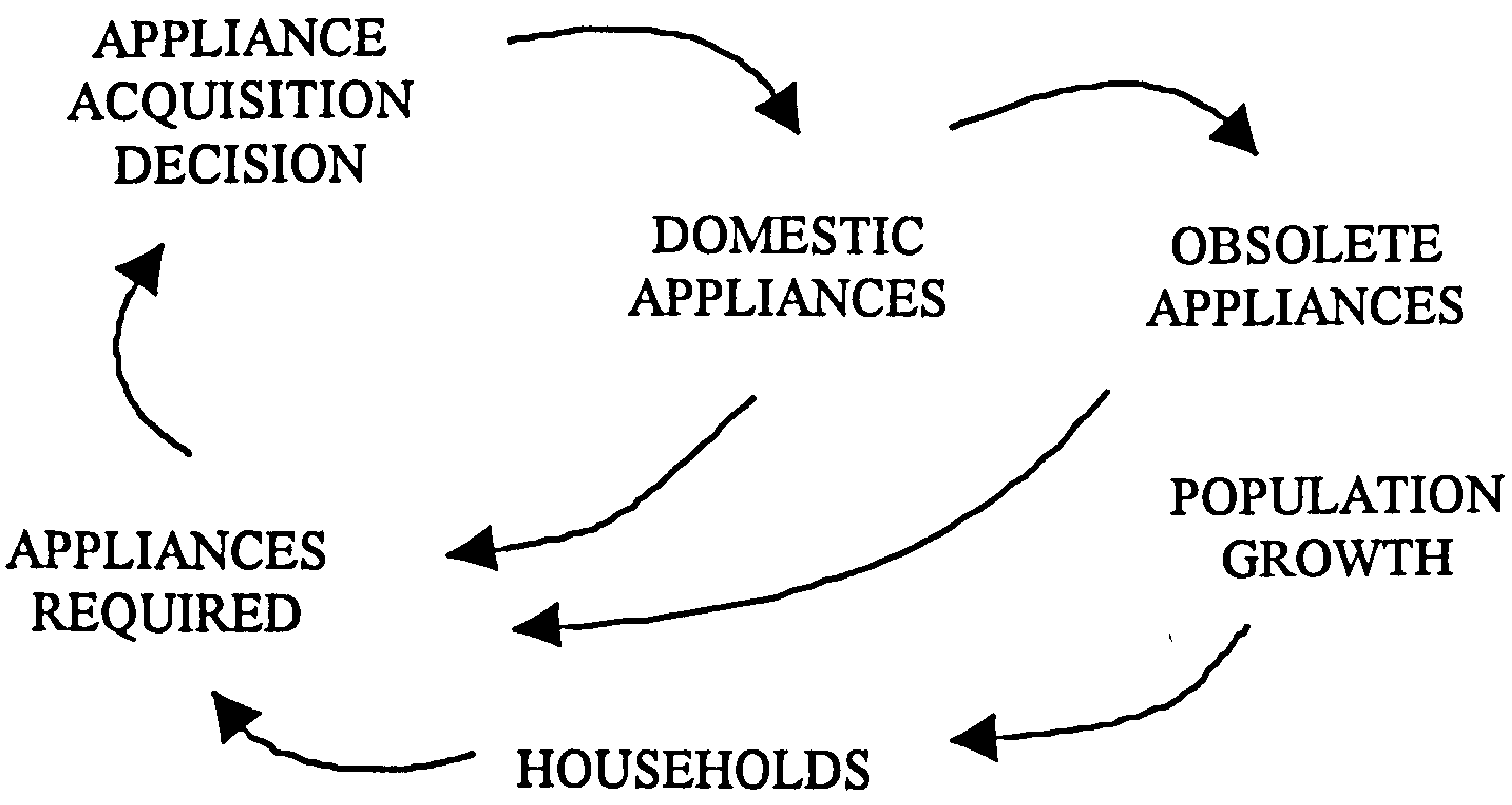


Figure 5.14 Appliance acquisition in the residential sector

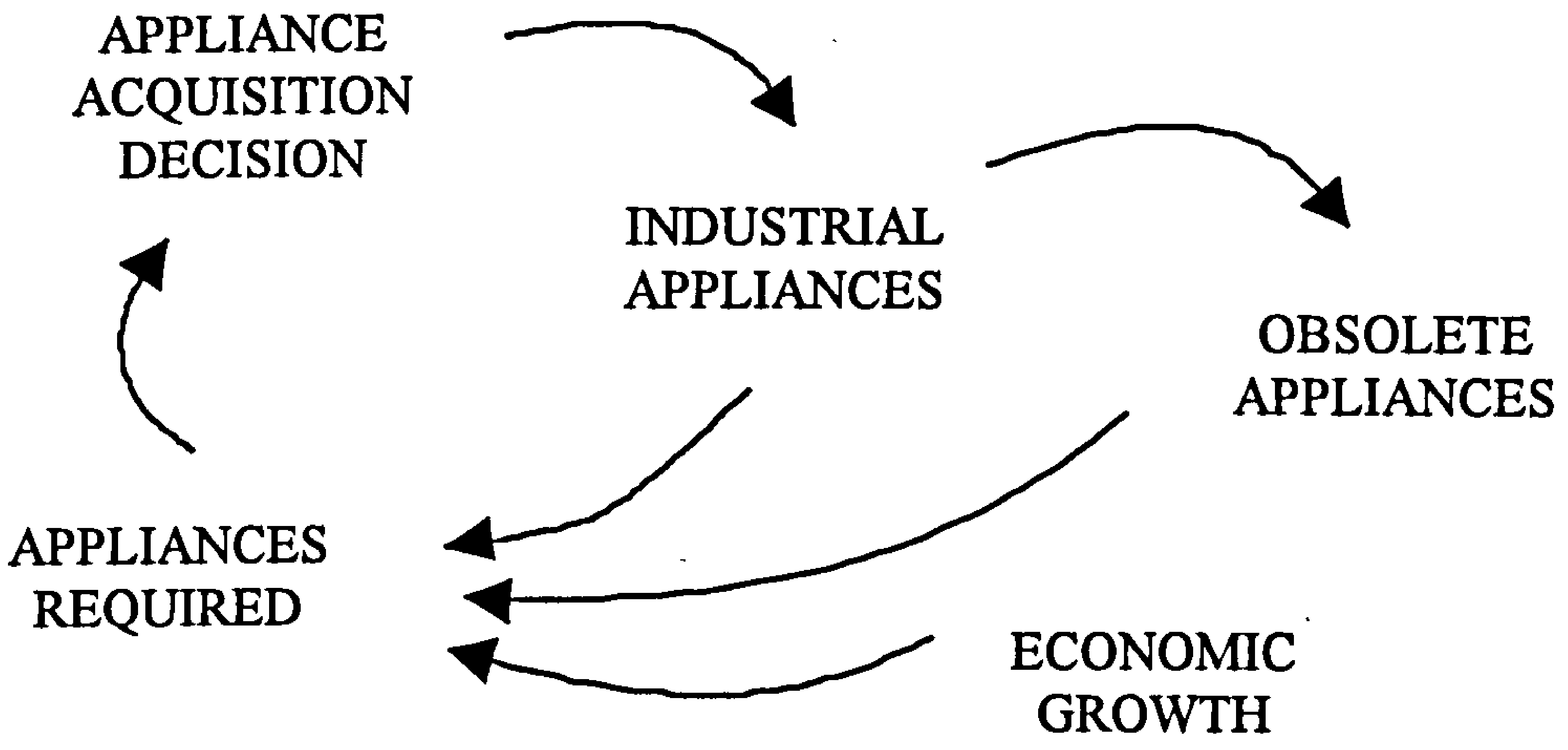


Figure 5.15 Appliance acquisition in the industrial sector

Figure 5.16 shows how, once a requirement is established, the final decision and acquisition of the corresponding appliance, depend primarily on the following factors: the quantity of appliances supplied, their annual equivalent cost, the financial incentives and other policy factors that may benefit end-users.

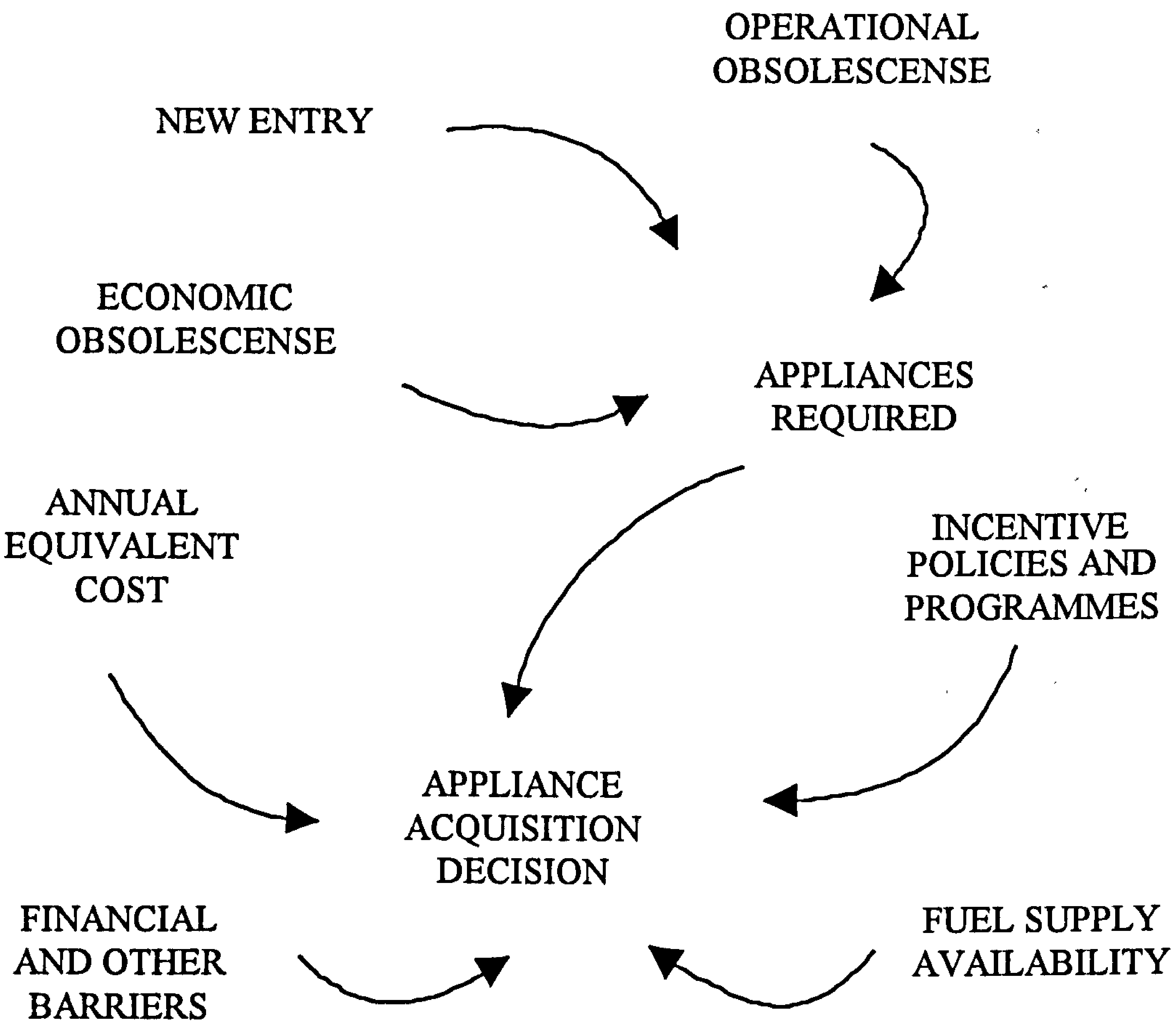


Figure 5.16 Final decisions for appliance acquisition

To determine the consumer's choice between k different appliances, equipment or artefacts, the platform makes use of the Logit model:

$$S_i = \frac{AEC_i^{-\gamma}}{\sum_j AEC_j^{-\gamma}}, \qquad i = 1, 2, \ldots, k,$$

where S_i represents the proportion of appliances of type i being chosen, out of the total, and AEC_i represents the annual equivalent cost of operating this type of appliance during one year. The parameter γ (>0) is a measure of consumer's preference for appliance i with respect to other alternatives. Large values of γ indicate that the decision maker is more readily inclined to choose appliance i, when AEC is the smallest. This Logit model, with or without minor variations, has been widely acceptable for discrete choice situations in a variety of contexts (e.g. Buehring et al., 1991; Backus, 1994; Swann and Tavakili, 1993; and Train, 1986).

It is important to note that the generalised consumer choice model defines the probability, P_{in}, of a decision maker (DM) n, choosing alternative i, by

$$P_{in} = f\,(Z_{in}, Z_{jn}, \forall\, j \varepsilon J_n \text{ and } j \neq i, S_n, \beta),$$

where,

Z_{in} is a vector of characteristics of alternative $i \varepsilon J_n$ observed by DM n,
S_n is a vector of characteristics of DM n,
β is a vector of parameters,
f is a function.

In this research customers are characterised by their income distribution, which in some cases becomes a barrier for appliance acquisition. Financial incentives may then be a solution to this problem. This issue is carefully investigated for policy purposes in the next chapter.

Alternative i is here only differentiated from the others by its price. Reliability, safety and performance criteria are not taken into account specifically, as research in this thesis aims to appraise DSM policies and programmes in broad terms and not to policies related to other industrial problems. Once these policies seem viable, from an economic perspective, diffusion of alternatives and their marketing may be encouraged and further research will indeed be required to assess in depth consumers' preferences and their implications.

Hence, even though the Logit model presented above is very simple, this particular formulation has been selected in this thesis for the following reasons: a) the parameter γ implicitly contains both product and DM characteristics, b) some relevant attributes are considered, in explicit form, externally to the formula, and c) there is no need for a more sophisticated model at the policy level discussed here.

To determine the total energy needed during any period of time, it is required first to calculate the specific energy requirements of all appliances within each socio-economic sector. And then, to consolidate these figures into a final energy demand.

5.4.3. Energy supply modules

The platform incorporates three basic energy supply structures. Power supply capacity dynamics, grid expansion to rural areas and the gas coverage plan. The first one offers two alternatives: the government indicative plan and an adjustment to the plan due to postponements of some projected plants, given the success of DSM policies and programmes.

Figure 5.17 shows a template of a construct considered to represent the power capacity dynamics in the platform. The reader may observe that capacity building depends on investment incentives, which are created by the electricity requirements needed to satisfy demand. The capacity required is a function of the systems capacity (existing and being built), the short term demand, the system security margin and the lead time for plant construction. This is a simplified version of the British model discussed in earlier chapters. For the Colombian case, however, three alternative supply constructs are tested to assess additional power capacity requirements:

a) The Government's indicative expansion plan (exogenously defined),
b) One construct which brings capacity on line to maintain a pre-defined system's margin, and

c) A construct that makes endogenous adjustments to the Government's indicative expansion plan (according to a specified system's margin).

These modelling structures aim to support the investigation of questions related to the postponements of the Government's expansion plan, as this plan will be affected by the various DSM schemes now under consideration. Furthermore, as part of the distributed modelling strategy, complementary research to this investigation aim to extend these ideas to account for the dynamics of capacity building under a liberalisation environment (Smith and Montoya, 1996). This is being design as a major construct to be added onto the platform to test the economic signals leading to "appropriate" investment.

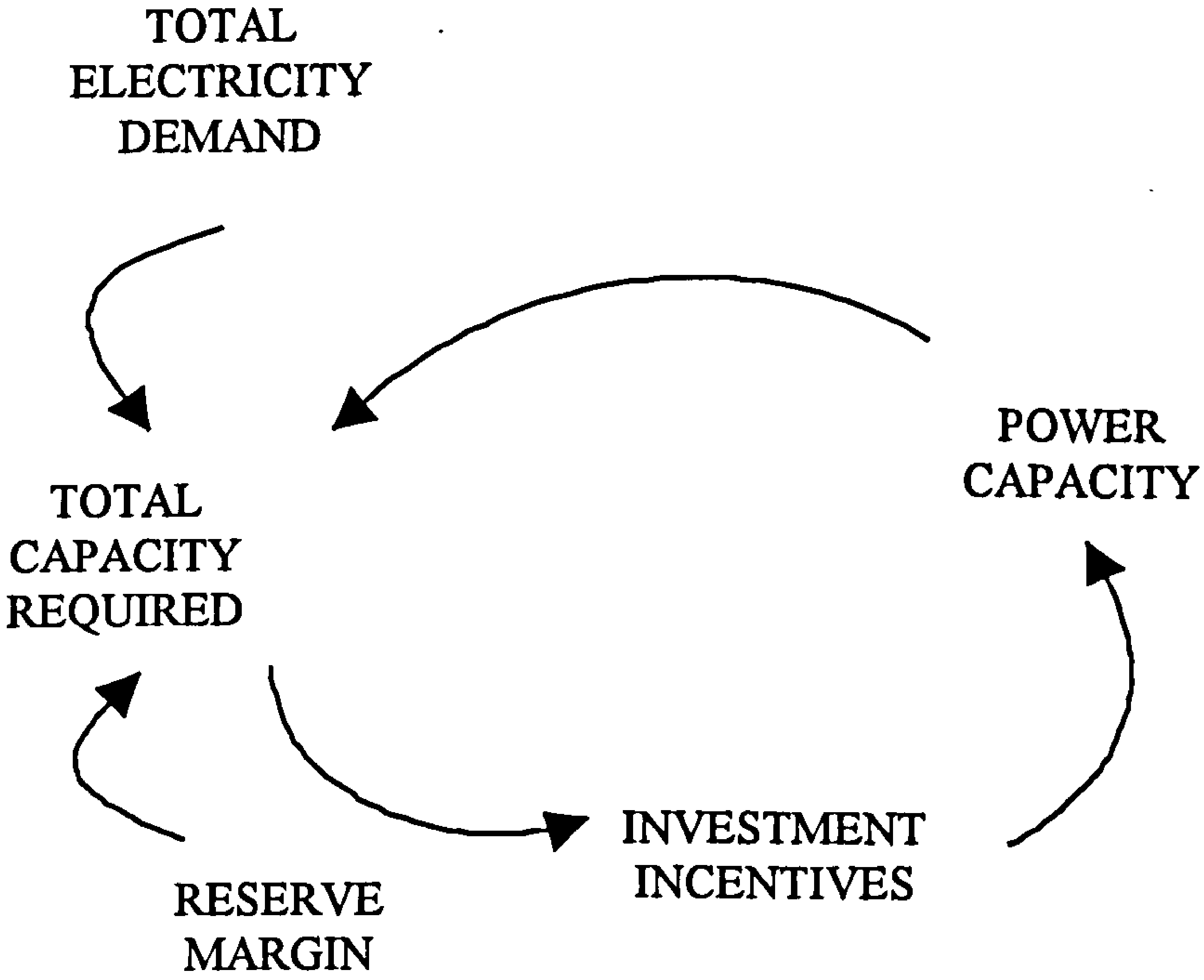


Figure 5.17 Power building capacity dynamics

Figure 5.18 illustrates how the effects of the gas plan are undertaken in the platform. In this way, it is possible to evaluate the overall consequences on the energy sector for insufficient supply of natural gas. A similar approach is followed to model the expansion plan of the electricity grid.

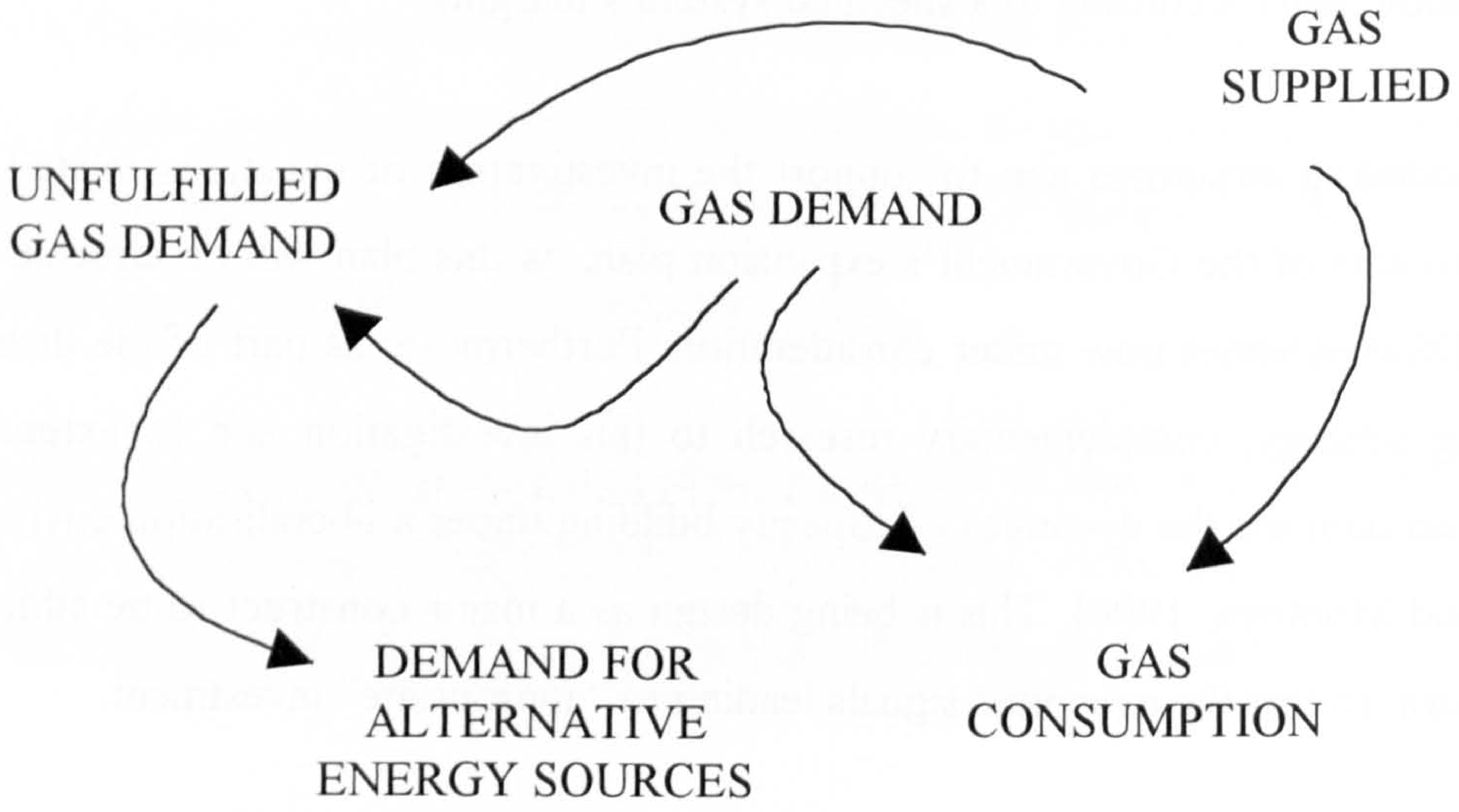


Figure 5.18 Effects of the gas plan

5.4.4 The Colombian electricity pool

The actual design of the Colombian electricity pool followed very much that placed in operation for England and Wales in 1990. Perhaps the most important initial differences included a) no payment incentives have been created for capacity availability, and b) the day-ahead bidding was made hourly, instead of half hourly. Nevertheless, a study is being conducted at present to modify the first of these differences.

Figure 5.19 shows the ordered generators' bidding for the critical hour on December 12, 1995, according to technology. This pattern has proven to be typical for the dry season since the pool started operations in July 1995. The SMP has climbed up to about US $ 0.18 per kWh during the driest days, but has remained below US $ 0.02 per kWh for most days during the wet season. Cubic or logistic functions fit very well the actual observations as can be appreciated in the figure.

For modelling purposes, the patterns are preserved and extrapolations are used exactly in the same way as in the British case (Figure 4.3). Thus, in this sense the pool module has been transported across from the UK case to the Colombian case, but the actual estimation considers the initial evolution of the Colombian system.

In this case, the platform needs to be enhanced with a construct to concept-test this new pool-price device which has been inserted into the Colombian system. Specifically, this construct intends to assess the likely price evolution resulting as consequence of important changes in the power generation technology mix (hydro-gas), which would most likely be influenced by deep transformations in ownership structures (similar to the "dash for gas" in the UK).

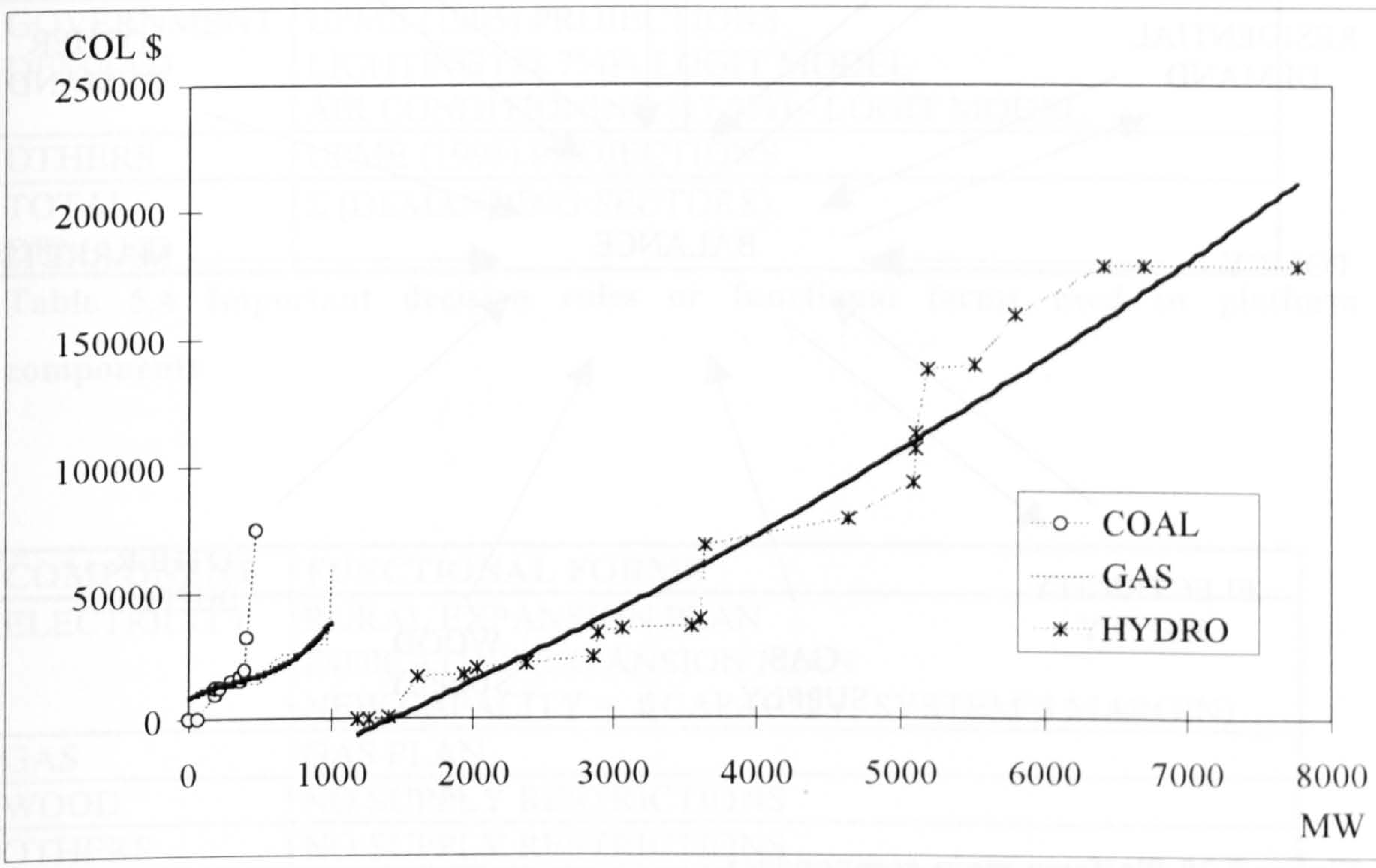


Figure 5.19 Pool bids as a function of cumulative capacity

5.4.5 A platform overview

Figure 5.20 contains some of the platform main components. It can be appreciated how the different demand sectors affect energy balance, which may a) pose restrictions on demand and/or b) provide investment signals to the corresponding supply sectors. Note that capabilities have been built into this analysis framework to enable experimentation with alternative policies in order to investigate the impact on energy balance and to assess the corresponding consequences for the different economic sectors and industries.

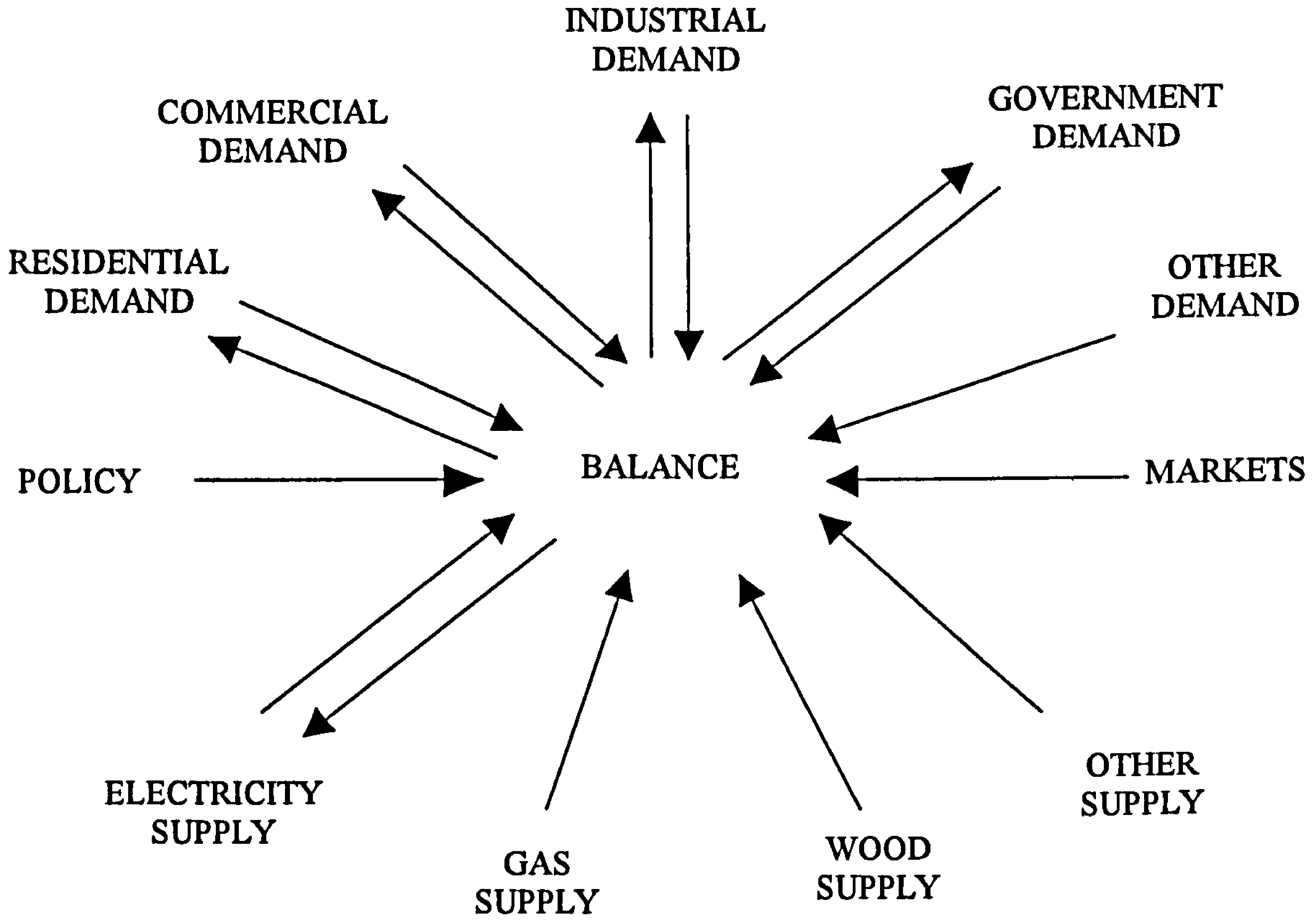


Figure 5.20 Platform main components

Tables 5.4, 5.5 and 5.6 indicate the most important functional relationships, decision rules, and policy alternatives considered within the most important components in the platform.

COMPONENT	FUNCTIONAL FORMS OR DECISION RULES
HOUSEHOLDS	HOUSEHOLDS = dt*BUILDING BUILDING = f (DEFICIT, INCOME, GNPXCAPITA) DEFICIT = f (POPULATION, HOUSEHOLDS) POPULATION = dt*POPULATION_GROWTH
DOMESTIC DEMAND	INTENDED DEMAND - LOGIT MODEL FINAL CHOICE SUBJECT TO AVAILABILITY
INDUSTRIAL DEMAND	UPME (1995) PROJECTIONS LIGHTING (5%) - LOGIT MODEL
COMMERCIAL DEMAND	UPME (1995) PROJECTIONS LIGHTING (18.6%) - LOGIT MODEL REFRIGERATION (26.8%) - LOGIT MODEL AIR CONDITIONING (20.8%) - LOGIT MODEL
GOVERNMENT DEMAND	UPME (1995) PROJECTIONS LIGHTING (31.7%) - LOGIT MODEL AIR CONDITIONING (17.2%) - LOGIT MODEL
OTHERS	UPME (1995) PROJECTIONS
TOTAL DEMAND	Σ (DEMANDING SECTORS)

Table 5.4 Important decision rules or functional forms used in platform components

COMPONENT	FUNCTIONAL FORMS
ELECTRICITY	RURAL EXPANSION PLAN INDICATIVE EXPANSION PLAN NEW CAPACITY = f(CAPACITY, SYSTEM'S MARGIN)
GAS	GAS PLAN
WOOD	NO SUPPLY RESTRICTIONS
OTHERS	NO SUPPLY RESTRICTIONS
POOL PRICE	f (CAPACITY, DEMAND)

Table 5.5 Important functional forms used in platform components

COMPONENT	DECISION RULE (POLICY)
POLICY	VARIATIONS ON GAS PLAN VARIATIONS ON RURAL EXPANSION PLAN VARIATIONS ON INDICATIVE EXPANSION PLAN VARIATIONS ON LIGHTING PROJECTS VARIATIONS ON FINANCIAL INCENTIVES VARIATIONS ON PRICING

Table 5.6 Important policy alternatives designed for the platform

The specification of the detail and functionality of the modules should be driven by: a) the research needs for validation and testing of the platform under different specifications, and b) the need to provide the most appropriate model for the Colombian case. Appendix II contains a full version of the Colombian platform.

5.4.6 Supply and demand variables incorporated in the model

Table 5.7 display comprehensively all the appliances and equipment initially considered, as well as the fuels and energy sources included in the platform.

SOCIO-ECONOMIC SECTORS (DEMAND)	ENERGY SOURCES (SUPPLY)
HOUSEHOLDS:	**ELECTRICITY:**
COOKERS:	
* ELECTRICITY	HYDROELECTRICITY
* ELECTRICITY EFFICIENT	GAS
* NATURAL GAS	COAL & OIL
* LPG	OTHERS
* WOOD	
WATER HEATING:	**GAS:**
* ELECTRICITY	
* NATURAL GAS	NATURAL
* LPG	LPG
* SOLAR	
LIGHTING:	**WOOD**
* EFFICIENT	
* NOT EFFICIENT	**SOLAR**
REFRIGERATION:	
* EFFICIENT	**OTHERS**
* NOT EFFICIENT	
OTHERS	
INDUSTRY:	
LIGHTING:	
* EFFICIENT	
* NOT EFFICIENT	
OTHERS	
COMMERCE AND GOVERNMENT:	
LIGHTING:	
* EFFICIENT	
* NOT-EFFICIENT	
REFRIGERATION:	
* EFFICIENT	
* NOT EFFICIENT	
AIR-CONDITIONING:	
* EFFICIENT	
* NOT EFFICIENT	
OTHERS	
OTHERS	

Table 5.7 Demand-side and supply-side variables included in the platform

5.5 PLATFORM DEVELOPMENT STRATEGY

This section poses the platform development strategy as a research enquiry in its own right. It examines the viability of the proposed approach and tests practical issues related to the implementation stages. The key elements of concern when trying to apply this novel approach include: a) that it has never been attempted before in this context (with a client such as the Colombian Ministry of Mines and Energy), b) that it implies development of components in places distant from the customer's base (limited contact and discussion), and c) that there are validity and credibility questions with respect to the proposed methodology. In this context there are specific queries related to application feasibility, theoretical relevance and alternatives available.

Against this background a work plan was set, taking into account the key elements of concern just explained above. Note that the client's base was Bogota; the tasks of research direction and supervision, methodology development, architecture design of the analysis platform, development of initial prototypes, development of specific components and initial policy analysis were based in London; and the project administration and development groups were based in Medellin. Travel was an unavoidable issue and research stages need to be defined according to the meeting agenda. The overall plan was set as follows:

Preliminary stage (six months)
Methodology definition
Initial platform design
Initial platform prototype
Preparation of work plan: objectives, means, strategy and agenda

First stage (three months)
Presentation, discussion and agreement on methodology, ends and means
Presentation and discussion of platform prototype (capabilities and general content)
Conformation of groups: steering group and development group
Initial data base

Second Stage (three months)
Construction of database
Further developments of platform
Preliminary results analysis

Third stage (two months)
Evaluation and validation
Scenario building
Preliminary policy analysis

Fourth stage (six months)
Training
Joint development
Discussion on policy analysis
Research conclusion and further work.

Therefore, as a number of troublesome issues emerged from the very beginning, a careful strategy had to be designed to ensure credibility, group cohesion and work efficiency. In the first place, theoretical issues had to be addressed for the Colombian case and methodological specifics had to be developed, according to the ideas manifested in Chapters 1-3 of this thesis and the experience gained from the British case. Secondly a detailed agenda had to be outlined to guarantee that every member of the development team shared the same vision, adequately learned the proposed methodology, clearly appreciated its role and delivered its product to schedule. And thirdly, a careful follow up and review agenda was required during the platform implementation and transference stages.

5.5.1 Platform structure

With this agenda in mind, preliminary tasks needed cautious consideration, including the development of a prototype which could clearly exhibit the final platform characteristics and functionality. Although simple to understand, this version had to expose the complex multiple-component structure contained in the platform.

The first visit to Colombia, for a fortnight, included the following time-table:

a) Definition of specific goals with client.
b) Conformation of platform development and steering groups.
c) Explanation of methodology, definition of general platform structure and further development of the model prototype.
d) Explanation of methodology to the Ministry's planning support group, sharing knowledge gained, and showing initial results (taking note of reactions).

In the first meeting with the Ministry a formal presentation included: description of problematic policy issues, discussion of methodological requirements, and explanation of intended solutions. During this presentation, Figure 5.6 and a subset of variables contained in Table 5.7 were exhibited. A summary of the main DSM and SSM policy issues intended to be addressed with the platform support were also shown. The meeting ran surprisingly smoothly. The Ministry staff showed interest and were ready to help in defining platform aims, variables requirements, and DSM and SSM issues to be addressed. They seem receptive because of their evident need of tools to assess policy matters.

The model-building group, composed of engineers from the clients group and Master's students in planning engineering, speedily grasped the methodological basis, their role in the project, and shared a vision on deliverables. The general platform structure was built and a second prototype version was released. This took into consideration the original features plus all those additions proposed by the client.

Just before finishing the first visit to Colombia, a second presentation of the project in the Ministry followed - this time with the planning support group (which includes representatives of major electric utilities and energy industries). The presentation was well taken, except for a single sceptical voice on the model softness and validity. Yet the general mood could be described as one of apprehensiveness and challenge. Their concern was not so much with respect to the softness of some variables as in relation to major assumptions and structural integrity of the platform.

A three months agenda was then set (including INTERNET communication). As there had been agreement on the platform structure, it was required to build a database, make relevant functional and parameter estimations, and construct complementary model pieces and modules. In this first stage the model developed during two weeks passed from Prototype 1 to Prototype 2, according to the summary presented in Table 5.8.

	PROTOTYPE 1	PROTOTYPE 2
VARIABLES	52	69
ARRAY ELEMENTS AND SCALARS	179	174
LEVELS	7	8
AUXILIARIES + CONSTANTS	45	61
PAGES	6	9

Table 5.8 Platform development progress

5.5.2 Data base and model estimation

During the following three months the main tasks included: a) construction of a data base to support the platform, b) definition of appropriate functional and parameter structures, and c) building additional components.

The time-table was followed along the lines previously defined, in spite of a slight drop in enthusiasm at the Ministry. This posed an important credibility question which needed to be addressed. The methodology and prototype were presented in an important biannual conference on energy modelling held in Colombia (Dyner et al., 1995). At this point, the platform development group suffered minor adjustments. It is interesting to note that during this period the electricity supply pool was created, following ideas from the British experience. The prototype progress is summarised in Table 5.9.

	PROTOTYPE 3
VARIABLES	145
ARRAY ELEMENTS AND SCALARS	714
LEVELS	15
AUXILIARIES + CONSTANTS	130
PAGES	20

Table 5.9 Platform development progress

5.5.3 Validation and policy analysis

The prototype was maturing rapidly at this stage as the ministry group started to get much more involved in the project. However, before becoming Version 1.0 of the platform, it needed to pass major tests. For this reason, the agenda for the third visit to Colombia included:

a) Validation and consistency of general behaviour.
b) Discussion of major policy issues to be analysed.
c) Policy analysis with support from the platform.
d) Platform appearance.

As validation and consistency tests took place, adjustments were made to the platform with the assistance of staff from the Ministry of Mines and Energy. As the country was revising domestic tariffs and was involved in the design of major DSM programmes, some policy issues were proposed for examination with the platform support. The combination of DSM programmes and pricing policies yielded interesting results in the initial stages of analysis.

The Platform was presented for the second time to the planning support group, Ministry of Mines and Energy. It was overwhelmingly accepted with only one observation this time - the need to guarantee proper training and transferability. The prototype progressed into platform version 1.0 as summarised in Table 5.10. Appearance was also improved at this stage.

	PLATFORM v1.0
VARIABLES	263
ARRAY ELEMENTS AND SCALARS	1339
LEVELS	21
AUXILIARIES + CONSTANTS	242
PAGES	30

Table 5.10 Platform development progress

5.5.4 Platform transference

At this stage, the development group was showing the necessary cohesiveness. As everyone was active and participating with regularity, learning was taken place at an accelerated rate. This was happening approaching the official Ministry's launching of DSM policies and programmes.

Important transference was naturally materialising. The Ministry started making use of the platform results to evaluate DSM policies and programs in a casual fashion. Also, as the gas plan required monitoring, the Ministry decided to developed on its own a module to follow it up. Yet the re-usability of the platform to support new policy analysis remains an open question.

5.6 CONCLUSIONS

This chapter has described the basis of the Colombian platform, the issues it seeks to address, its structure and experimental implementation. The contribution can be summarised in two broad categories: methodology and modelling technicalities.

Methodology

The platform development strategy that has been followed is very much imbedded as part of the methodology itself. This proved to be successful for two main reasons: a) it dissipates the black-box syndrome effect, and b) it overcomes the ownership issue.

The platform architecture has been based upon the need to implement generic, modular, adaptable and transportable structures, capable of supporting the process of system analysis for intervention. It is evident that with Colombia seeking to balance market liberalisation and demand-side planning, the platform has to provide the basis for examining various policies which might be difficult to reconcile, making use of analogies from elsewhere upon how various sub-modules may operate (e.g. power pool, consumer choice).

The platform developed here therefore provides a context-rich basis for investigating a number of different policy issues. Although a similar framework has been undertaken in the US continuously since 1976 (Naill, 1992), the open literature gives limited information with respect to the modelling protocol that needs to be followed if such a platform is to provide a sustained level of policy support through changing circumstances.

As has been shown in this chapter, a System Dynamics based platform has the potential to provide such evolutionary policy support under complex policy environments, although it then needs to have a multifaceted perspective on its use. In particular, the application of SD in these circumstances goes beyond the single-focus of providing insight into a pre-selected policy issue. Yet, if the traditional approaches are losing some of their relevance in the new era of market liberalisation, and SD is well placed to fill the new modelling requirements, it seems that it must offer governmental energy advisors some of the same features of longevity, modularity, adaptability and detail that the other approaches have provided. The features then constitute requirements for a clearer modelling protocol to be developed upon a systems simulation platform.

To summarise, the platform that has been developed following the methodology proposed in this thesis can be characterised as being capable of coping with:

- Scale and modularity
- Adaptability
- Transferability and transportability.

Also, as will be examined in the next chapter, this instrument for policy evaluation, training and learning also aims to support:

- Incrementalism
- Transparency
- Reduction of complexity.

Modelling Technicalities

The platform constructed here for energy analysis introduces interesting features, not previously applied simultaneously in this field. Apart from the building process features, for the Colombian case there are a number of innovations:

- Breadth and depth has been an issue throughout. The result is a medium-sized modular model.
- Strong interrelationships between DSM and SSM issues.
- General archetypes used for conceptualisation purposes.
- Model transferability from the British case to the Colombian case.
- Dynamic elasticities as reported in the American COAL II model (Naill, 1977).
- Application of consumer choice models as in the European case, Backus (1994).

- Endogenous price dynamics as technology penetrates the market. This is also affected by income distribution and government policies on financial subsidies. Although part of this has been used elsewhere, see for example (Lyneis, 1993), there is no reference to it in the energy field.
- Soft decision variables and hard technical variables interact ubiquitously. Both types of variables have been examined for sensitivity.

Furthermore, the platform also contains the standard System Dynamics features for representation of organisational structures:

- Non-linearities
- Feed-backs and delays
- Group behaviour.

The model thus included both 'new' SD structures as well as known 'old' structures used elsewhere in energy and other applications. The coupling of these forms is a contribution to the field.

6 ENERGY POLICY FORMULATION IN COLOMBIA

The motivation behind building a platform to support energy policy formulation and assessment for the Colombian case was discussed extensively in Chapter 5. Its structure and components were also explained in detail. In this chapter its capability to support important policy issues with respect to demand, supply and transport of energy resources are examined extensively. On the supply side, major concerns include the three following plans: large-scale gas supply, rural electrification and indicative power supply. On the demand side, issues are dominated by government programmes and strategies on rational energy use. And, on the transport side, policies address problems related to customer connections to gas and electricity networks.

In Colombia, planning has failed in the major part as goals have rarely been met. This has meant that in practice prices have been historically lower than indicated in all plans, projects have seldom followed established time-tables, and non-technical losses have only been reduced temporarily and on average have remained as high as 12% of the total energy produced. Consequently, most electricity utilities run large financial deficits and the country has suffered two major blackouts in a period of less than twelve years. Under these circumstances, market forces with the aid of regulation could be of some help in solving these problems as they indirectly incorporate some of the most significant system plan objectives - low prices and supply reliability. Company efficiency and performance should improve, markets should indicate appropriate investments, and competition

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Results of this chapter have been included in papers: a) presented at the international conference of the IAEE held in Budapest in 1996, and b) with D. Bunn to be published in the International Journal of Global Energy (Vol. 8, 1996).

should keep prices low. However, to attain these objectives market failures and oligopolistic power will have to be reduced, and regulation has to operate effectively - nothing trivial.

Market theory and its application to the utilities sector has been discussed extensively in Armstrong, Cowan and Vickers (1994), Beesley (1993), Beesley (1994), Beesley (1995), Beesley (1996), and Jackson and Price (1994). Predominantly, authors conclude that the most relevant policy variables in liberalised utilities are those related to prices, competition, reliability and quality. There is also an overwhelming agreement on partial accomplishments, in the areas of productive and market efficiency, and of some drawbacks with respect to the limited competition taking place in this new environment. Nevertheless very little has been said with respect to the barriers imposed by strenuous initial conditions, or the speed of the transition process. And almost nothing has been written in this context with respect to the role of planning or Demand-Side Management (DSM).

In actual practice, especially in developing countries, the deregulation process starts from difficult initial conditions and social, economic and political obstacles. Hence light-handed supply planning and policies on rational energy use, along with cautious competition and price regulation, may contribute to soften the impact on both customers and companies during the transitional stages. In this chapter we will address this subject extensively.

6.1 POLICY ISSUES IN THE NEW ENVIRONMENT

In Colombia the utility and electricity laws of 1994 have created new structures for the energy sector. Nonetheless the transition towards a more liberalised environment turns out to be a delicate affair as low prices, low reserve margin and high subsidies are not the most favourable initial conditions. Thus a number of open questions emerge with respect to:

- Evolution of prices
- Subsidy regimes
- Supply reliability
- Supply alternatives
- Demand side management
- Competition in the market of large consumers
- Competition in the retail market.

In consequence, for the Colombian case, organisational design of the energy system becomes as important as transitional measures, taking into account the disadvantageous initial conditions, the development stage of the nation and the overall political climate.

In the end, a more liberalised set-up in the energy sector may stimulate a more balanced situation, producing a more "reasonable" evolution of resource consumption (from the economic and technically efficient point of view), with less political intervention. This transition in the Colombian electricity sector should be more harmonious and produce a system structure less vulnerable to blackouts, stimulating competition and the entry of private investors in the power generation industry. It should also promote productive efficiency, improving the financial situation of the electricity utilities and reducing non-technical losses.

Under these circumstances, it may be possible and desirable to maintain some cross subsidies. However, these have to be explicit (Vickers, 1996) and could also be part of a strategy to reduce drastically non-technical system losses.

It has been noted in previous chapters that the Colombian energy sector had been driven historically by supply-side management criteria, which have had a tendency in specifying a limited number of alternative resources. Although demand-side management had been almost not-existent in the past, the design of rational energy use programmes started to emerge during 1995, at the time when the electricity market for large consumers was created. The strategy for DSM programmes appears to be a long term one and ought to take into account the new market arrangements. This presents challenges, some of which will be investigated for policy purposes in this chapter.

Further developments of the 1994 electricity and utilities laws might consider possible stable designs for the Colombian energy sector. To be consistent, these structures must be capable of working in two directions: On the one hand, formulating policies on a small number of variables (prices, quality, subsidies, losses) while, on the other hand, generating light-handed plans for DSM and Supply-Side Management (SSM). The theoretical idea is to create a reliable competitive environment and to regulate prices - experimentation using simulation frameworks maybe be desirable to assess results before actual policy implementation.

At the company level, as long as an open competitive market is not fully established, it will be necessary to follow companies using efficiency instruments capable of measuring reductions in non-technical losses, and improvements in billing and marketing effectiveness. These issues, however, will not be investigated in this thesis.

As has been appreciated, the complexities manifested in the Colombian energy sector are immense and require major intervention from different perspectives. Although economic growth has been an encouraging factor, energy policy has shown weaknesses in supporting the overall developing climate with respect to supply alternatives, coverage, security of supply and efficiency. These weaknesses have created a number of distortions within this sector in relation to resource exploitation, public company management and demand side management. Thus, for example, in most Colombian regions gas is still not available (in spite of abundance); electricity is the only alternative in some Departments; power generation is largely hydroelectric, with a small portion of very inefficient thermoelectricity plants; non-technical electricity losses exceed 12%; and, electricity subsidies are applied extensively.

In the future, both public policy co-ordination and private initiatives might be more widespread, according to the new legislation, the governance set-up and the observed initial investment plans. For this purpose, all involved in the Colombian energy sector would probably consider learning from experiences taking place in the UK and other developed and developing economies around the world.

In the new energy system, a number of crucial interlinked problems have become visible: Selection of DSM and SSM programmes, scheduling and prioritisation of projects (seeking possible synergies), incentives for private investors and market regulation, among many others. The incrementalist approach may serve this policy purpose, in line with some co-ordinated action, in the search for positive feed-back elements for development, as discussed in Arthur (1990).

The methodology proposed in this thesis enhances an incrementalist approach to support policy. In this sense, it is relevant to establish:

a) What to do first, and
b) What comes next.

Also, as the platform building process itself reduces some of the major complexities involved in the system, this process, as much as the final tool created, provides an appropriate environment for:

- Learning,
- Training, and
- System analysis.

A number of problems are then candidates for investigation: price policies, DSM issues, consumer benefits, delays to the large-scale gas plan, speed of technology penetration, threats of blackouts, unbalanced power generation composition, performance of regional companies, and incentives for investment. Some of these will be addressed here and others will be left open for further research.

Policy issues selected for investigation in this thesis are grounded on real concerns. These are tested at times when the overall panorama appears dominated by threats of yet another blackout in Colombia. Thus as new government ministers take office, desperate announcements of severe price increases appear to be the solution. These hikes, well above 35% in real terms (CREG, 1995), intend to improve the supply companies' finances, reduce demand (to avoid immediate rationing) and encourage capacity investment (specially from multinationals).

An integrated approach to system assessment may be an alternative to apparently obvious isolated policy proposals, as dangerous counterintuitive effects are not readily evaluated. In this sense it is not clear what undesirable outcomes may result as a consequence of abrupt large price raises. For example: What would be the effect on final consumers? What can final users do to protect income? What pricing alternatives may be considered? What will be the effect on DSM policies? What consequences will this have on conservation or substitution programmes? What will happen to non-technical losses? What will be the effect on inflation? Thus, the platform developed here may be used to address some of these questions and to examine other possibilities.

This chapter will assess the platform's value and will establish its specific capability to:

- Support policy
- Evaluate alternative plans and programmes
- Support policy by building minor model extensions
- Support policy by constructing some module additions.

Specifically, policy issues will investigated with respect to:

- DSM programmes
- Fuel price increases
- Subsidies and household billing
- Supply plans
- Marketing requirements of the gas plan
- Teaching and marketing requirements of DSM programmes
- Speed of technology penetration

- Policy robustness.

These and other issues that have been raised in the previous chapter render unknown outcomes to the Colombian energy system, specially during the transitional stages. Economic theory only speculates on equilibrium conditions and econometric methods assume stable historical parameters. Yet the new organisational set-up requires analysis under a much more dynamic environment. Hence, simulations with the aid of the platform built here are required to evaluate the speed of transition, as well as policy effectiveness and the corresponding barriers to be overcome.

The following sections will prove how the multiple features integrated into the platform constructed for the Colombian case support both policy making and the evaluation of programmes and projects.

6.2 SCENARIOS

In the previous section and in Chapter 5, policies, programmes and actions that may be considered within the framework established in this research have been examined in some detail. In this section the capabilities of the construct proposed in this thesis to aid in analysing some of these issues will be demonstrated, leaving room for further research in the Colombian case, especially in the areas where the platform has proven to be successful in the British case.

In particular, the performance of DSM programmes and some source supply plans will be examined under unfavourable conditions; in addition, the effect of pricing and financial policies on energy demand will also be investigated in the following subsections.

6.2.1 Case 1 - Moderately pessimistic scenario

In the first case examined here, some policies, programmes and actions, on DSM as well as on SSM are explored. The intention is to establish synergy effects of several concurrent programmes on the overall energy system.

On the supply side, the electricity grid expansion plan is supposed to go ahead according to government expectations, but the gas plan is assumed to register some delays as shown below. On the demand side, DSM programmes are applied in the areas of lighting, cooking, space cooling and refrigeration.

The following specific assumptions are made in this case:

- Only 80% of the gas plan is achieved.
- 60% of planned electricity grid expansion is accomplished.
- On average one light bulb is intended to be replaced per household.
- Financial arrangements to help customers pay for appliance acquisition are not available.

Yet, simulations show promising results even under these adverse conditions:

- Figure 6.1 shows how cooking with traditional technologies declines steadily in urban areas, because of the high penetration rates of cooking with natural gas, LPG and electricity efficient technologies. As expected, demand for natural gas grows more rapidly than for any other energy source.
- Figure 6.2 shows how traditional lighting falls under the impact of efficient lighting in the domestic sector. Note that although the fall is only temporary the market-share is permanently eroded.
- In total, electricity savings by the year 2010, across all sectors, reach nearly 75% of the electricity generated in 1995 (which was about 40000 GWh/year). This is equivalent to slightly less than the additional supply requirements to satisfy demand until about the year 2005. These important savings are attained mainly in the domestic

sector (where most effort is placed) since most of the new customers acquire 'non-traditional technologies', apart from some substitution of electricity-based appliances into gas-based or efficient electricity appliances.

- Figure 6.3 exhibits an almost constant number of households using electric cookers in rural areas. LPG and electricity efficient cooking have a higher penetration rate than that based on traditional electricity. This penetration is attained at the expense of wood.
- Figure 6.4 contrasts the total energy demand projected by UPME (line 1) (UPME, 1995), with the simulated energy consumption under the conditions established in this moderately pessimistic scenario (line 4). Also, it is possible to observe the difference between the indicative expansion generation plan (line 2), and the simulated capacity required to satisfy demand (line 3).

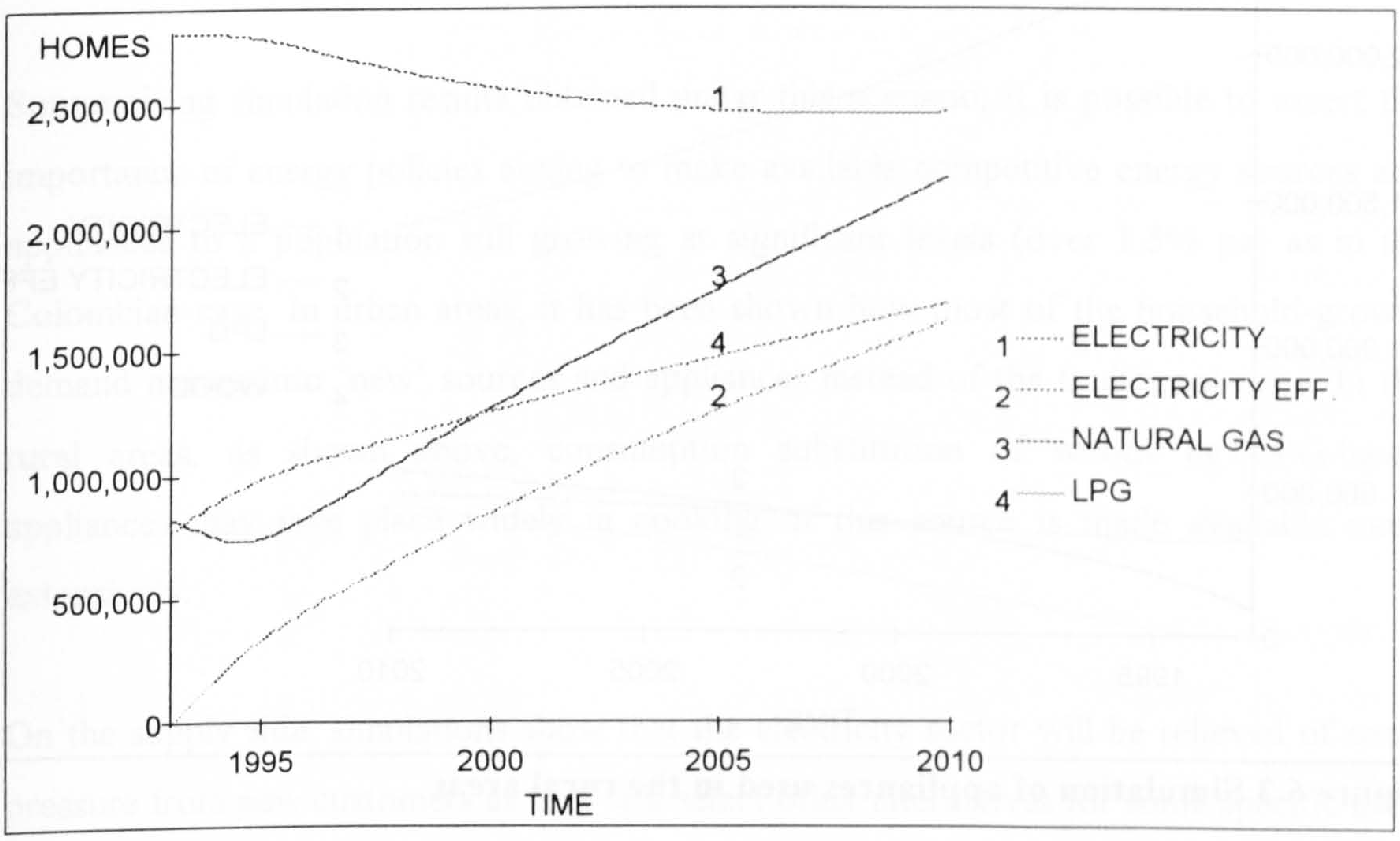


Figure 6.1 Simulation of DSM for cooking under a moderately pessimistic scenario

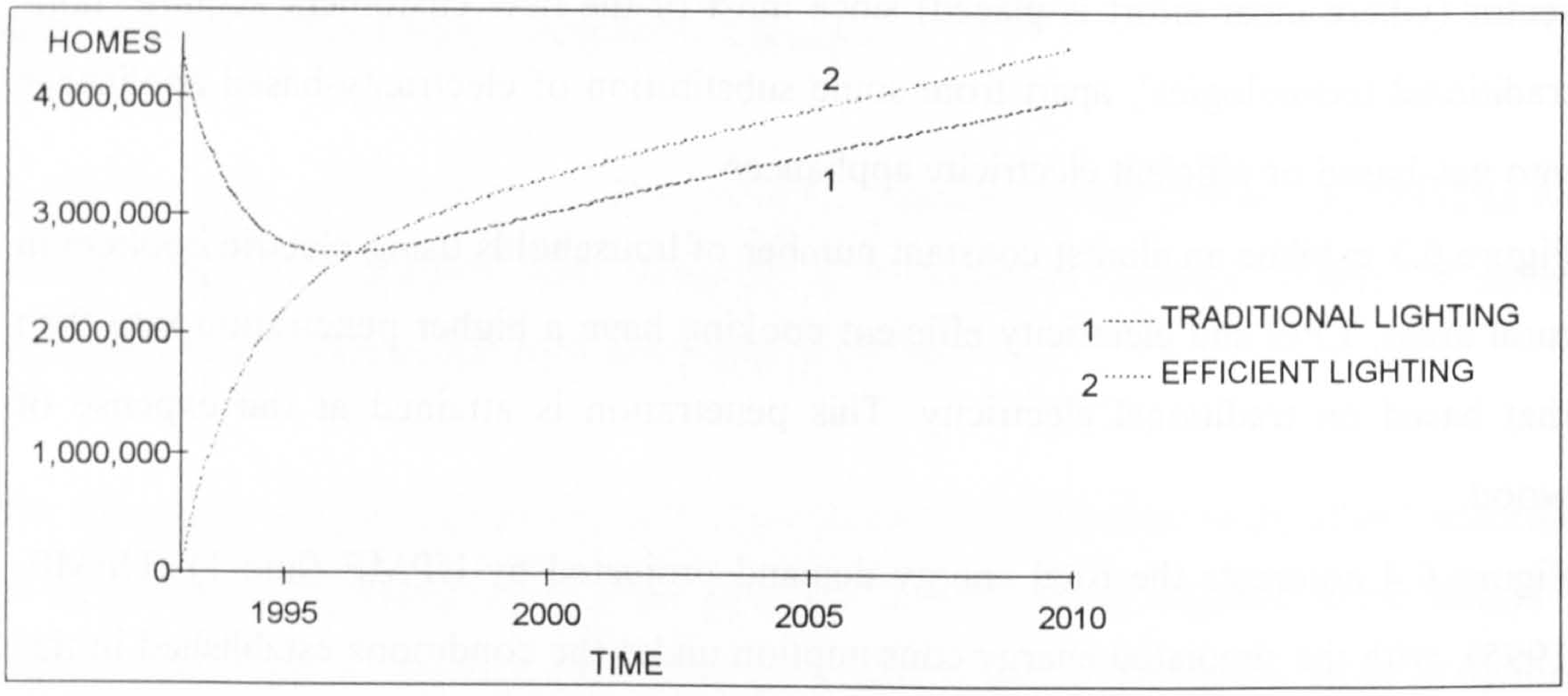


Figure 6.2 Simulation of DSM for lighting

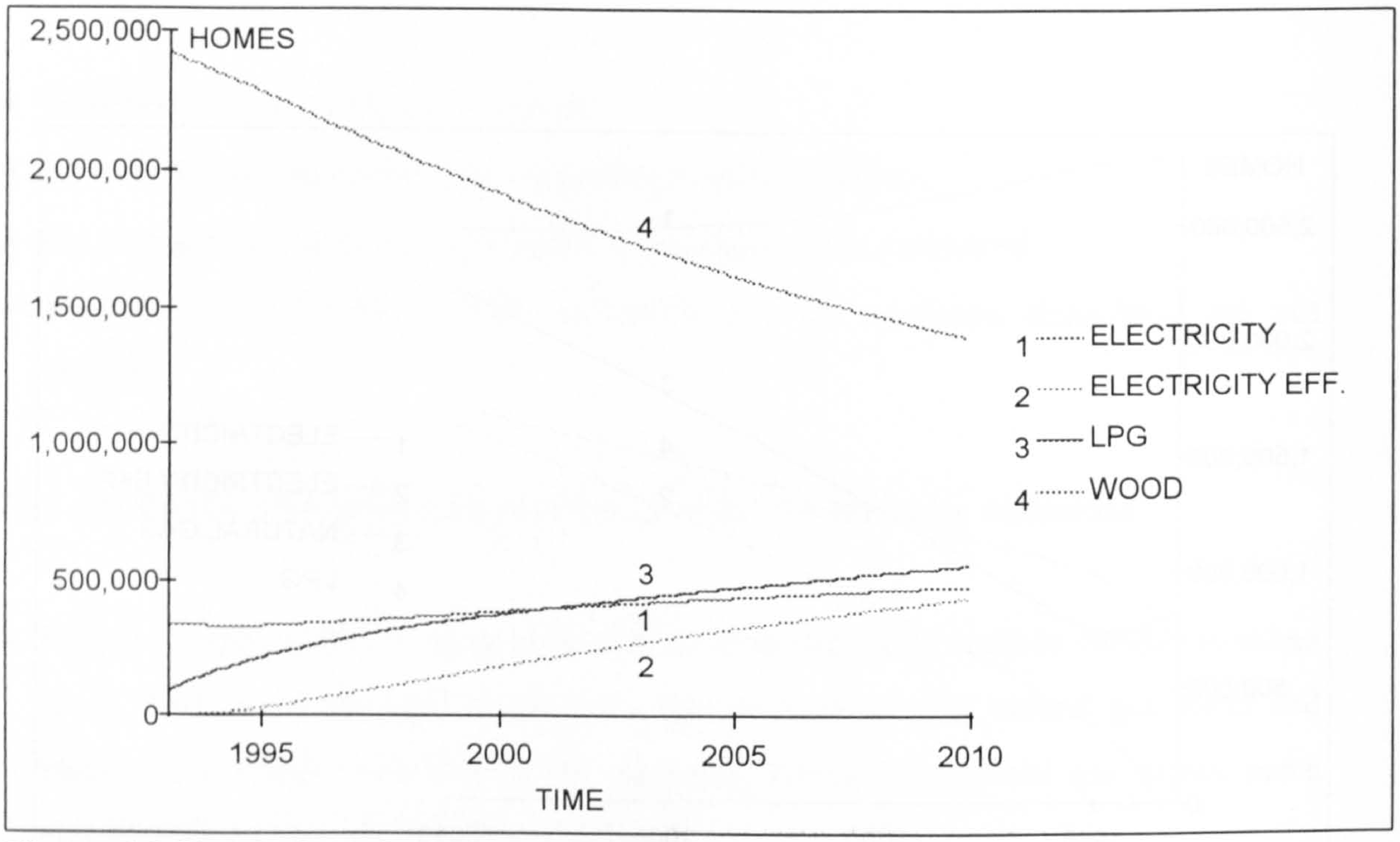


Figure 6.3 Simulation of appliances used in the rural areas

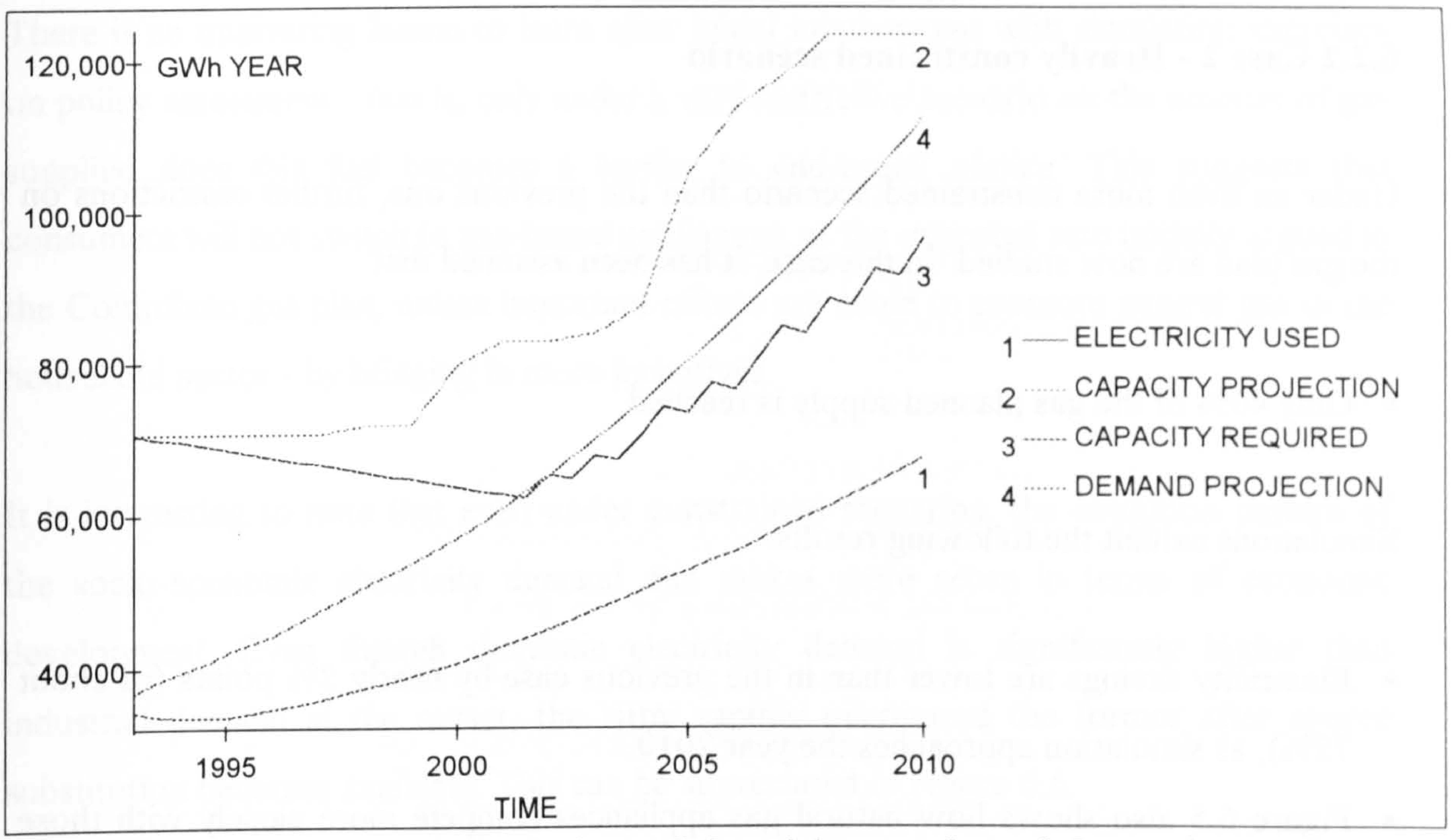


Figure 6.4 Projections and simulations of electricity supply and demand

Summarising simulation results obtained under this scenario, it is possible to assert the importance of energy policies aiming to make available competitive energy sources and appliances to a population still growing at significant levels (over 1.5% pa) as in the Colombian case. In urban areas, it has been shown how most of the household-growth demand moves into 'new' sources and appliances instead of the traditional ones. In the rural areas, as shown above, consumption substitution of wood- by LPG-based appliances may take place widely in cooking, if this source is made available more extensively.

On the supply side, simulations show that the electricity sector will be relieved of some pressure from new customers as they will select other alternatives for some specific uses; that the large-scale natural gas plan will have to meet strong demand; and that efficient appliances will be acquired by a significant number of customers. The extent of these demands will be examined in the following scenarios.

6.2.2 Case 2 - Heavily constrained scenario

Under an even more constrained scenario than the previous one, further restrictions on the gas plan are now studied. In this case, it has been assumed that:

- Only 40% of the gas planned supply is reached.

Simulations exhibit the following results:

- Electricity savings are lower than in the previous case by nearly 2% points (of about 75%), as simulation approaches the year 2010.
- Figure 6.5 also shows how natural gas appliances compete more closely with those based on LPG and electricity efficient technologies.

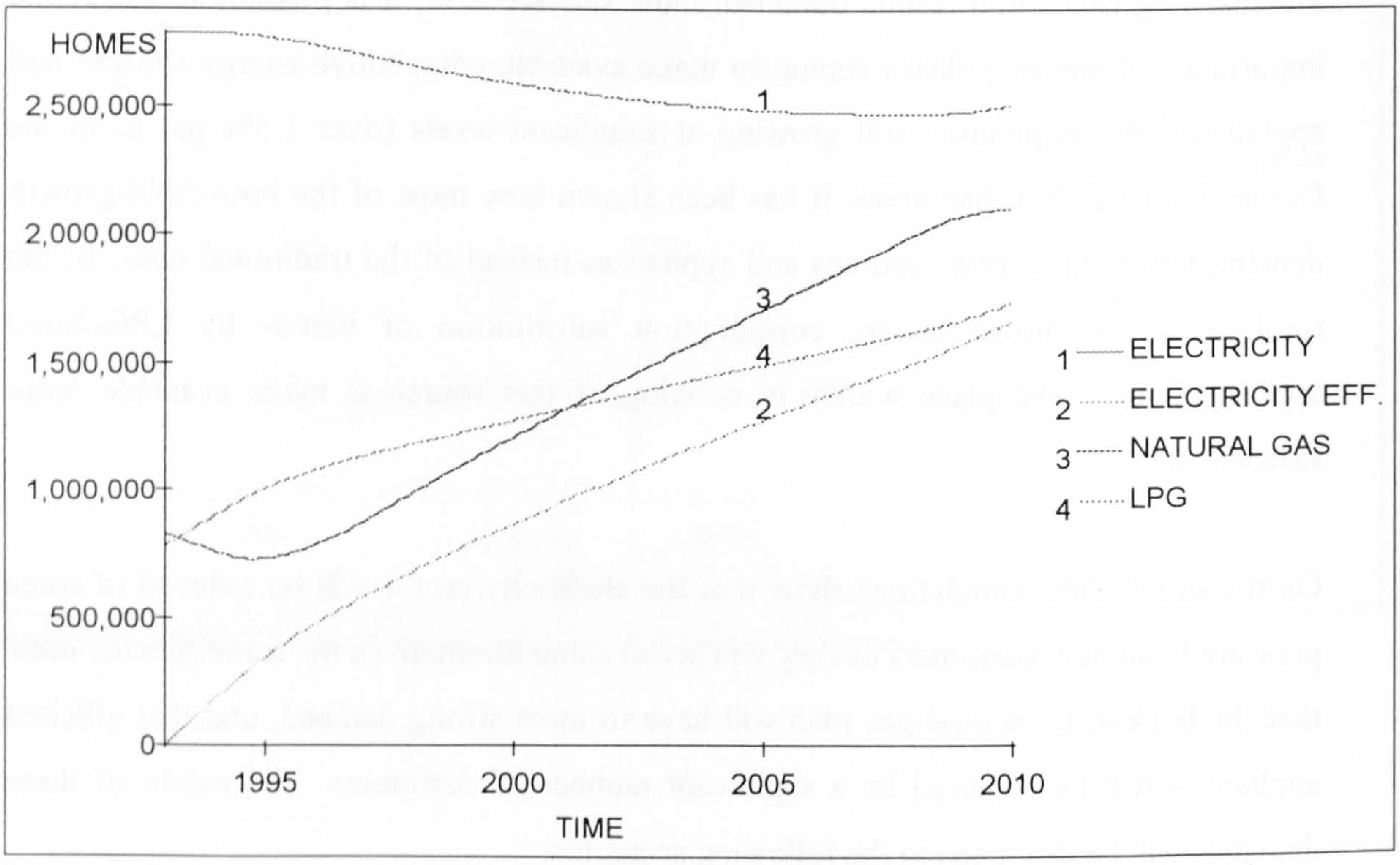


Figure 6.5 Simulation of DSM programmes under a heavily constrained scenario

There is an interesting lesson to learn after initial involvement with simulation exercises on policy assessment - that is, only under a very restrictive scenario on the amount of gas supplied does this fuel becomes a barrier to end-users' choice. This suggests that consumers will not switch to gas-based appliances, at the expected rate initially argued in the Colombian gas plan, unless important efforts are made to promote natural gas in the household sector - by bringing in more incentives.

It is interesting to note that even under constrained scenarios, the evolution pattern of the socio-economic electricity demand mix makes more sense in terms of economic development. Even though domestic electricity demand is significantly higher than industrial demand at the outset, the latter rapidly overcomes the former after source substitution becomes available. This can be appreciated in Figure 6.6.

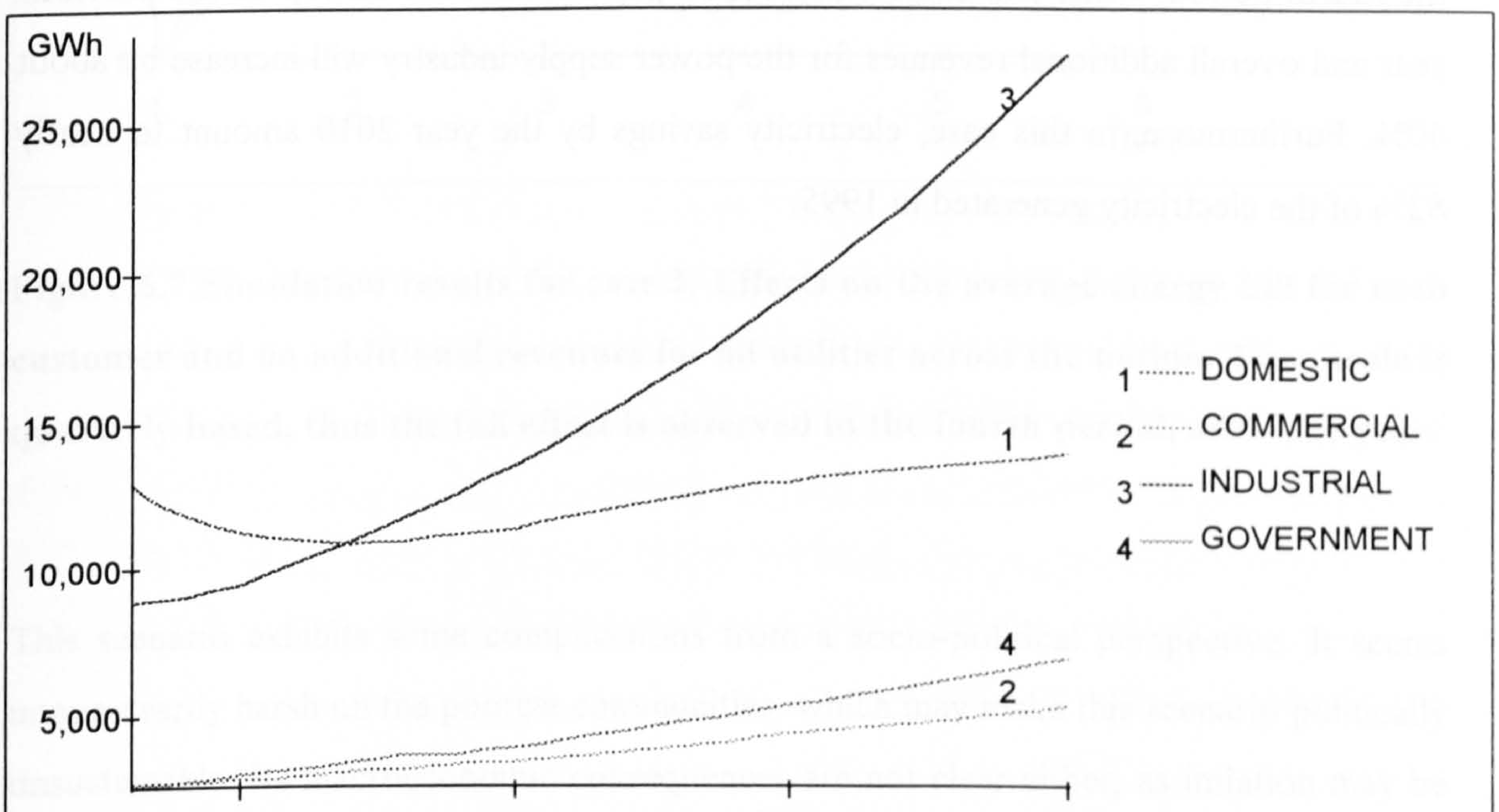


Figure 6.6 Simulation of electricity consumption by different sectors

6.2.3 Cases 3 and 3' - Sudden large electricity price increase scenario

Colombia has considered sudden electricity price increases in the household sector. These increases may exceed by 35%, in real terms, 1995 domestic tariffs. The specific scenario in this case assumes that:

- The gas plan runs according to schedule.
- There is limited availability for switching suddenly to efficient and other fuel-based technologies (this is done via a substantial price increase of 15% in real terms).

Figure 6.7 shows the effect of a sudden electricity price increase on the average household energy bill and on total sales across the country. Here, price rises have been assumed to spread quarterly during one year. The most serious effect is observed during the fourth period, when end-users will have to pay almost 20% on top of the previous year and overall additional revenues for the power supply industry will increase by about 40%. Furthermore, in this case, electricity savings by the year 2010 amount to nearly 82% of the electricity generated in 1995.

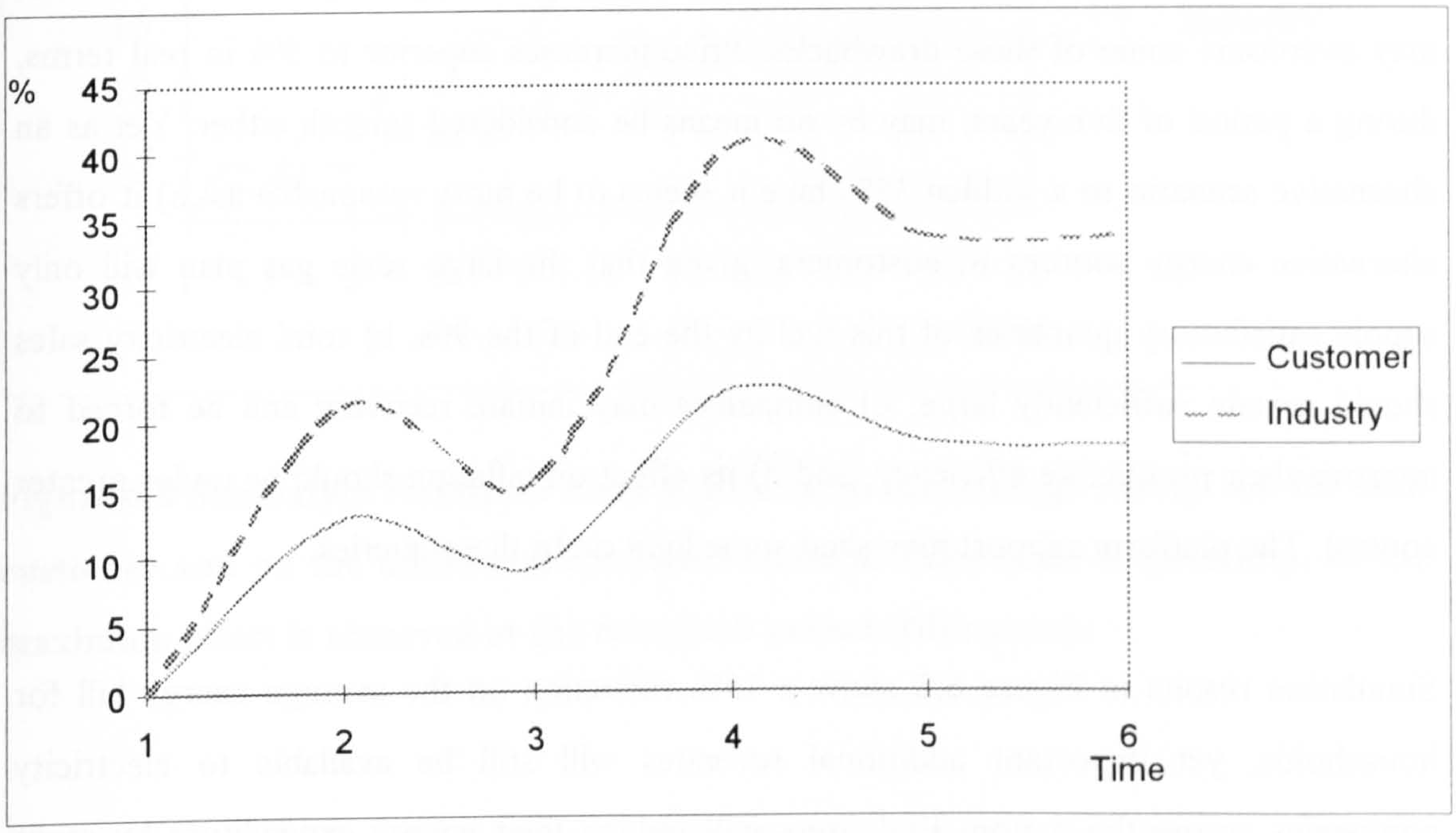


Figure 6.7 Simulation results for case 3. Effects on the average energy bill for each customer and on additional revenues for all utilities across the nation. Time scale is quarterly based, thus the full effect is observed in the fourth period, after one year.

This scenario exhibits some complications from a socio-political perspective. It seems unnecessarily harsh on the poorest communities, which may make this scenario politically unsustainable. Its macroeconomic consequences are not clear either, as inflation may be affected much more than initially estimated. These issues will be investigated in the cases following.

At this point it is important to define scenario 3' as a reference or base-case scenario for further comparisons ahead. This is exactly the same as scenario 3, except for all assumptions related to price increases.

6.2.4 Case 4 - Smooth price increment scenario

As sudden electricity price increases over 35% in real terms may neither be politically viable nor sustainable from the social and political perspective, perhaps other alternatives may overcome some of these drawbacks. Price increases superior to 5% in real terms, during a period of five years, may by no means be considered smooth either. Yet as an alternative scenario to a sudden 35% hike it seems to be more reasonable as: a) it offers alternative energy sources to customers, given that the large scale gas plan will only supply satisfactory quantities of this fuel by the end of the 90s, b) total electricity sales should remain sufficiently large, c) companies may initiate recovery and be forced to improve their productive efficiency, and d) its effect on inflation should be under greater control. The platform support may shed some light on to these queries.

Simulation results in Figure 6.8 show a 15% reduction on the average energy bill for households, yet important additional revenues will still be available to electricity companies across the nation. End users will reduce their energy expenditure by more than 8% during the critical period as a good number of customers will shift to other energy sources and reduce electricity demand (given by the price elasticity effect). In this case there will also be diminished inflationary impacts. For example, inflation due to gradual electricity increments will amount to less than 0.21% (i.e. 0.07 * 0.03) in the first year, instead of that originated by a sudden increment which could reach to about 1.05% (i.e. 0.35 * 0.03). Note that the average weight of electricity in the consumer price index was about 0.03 in the year 1995.

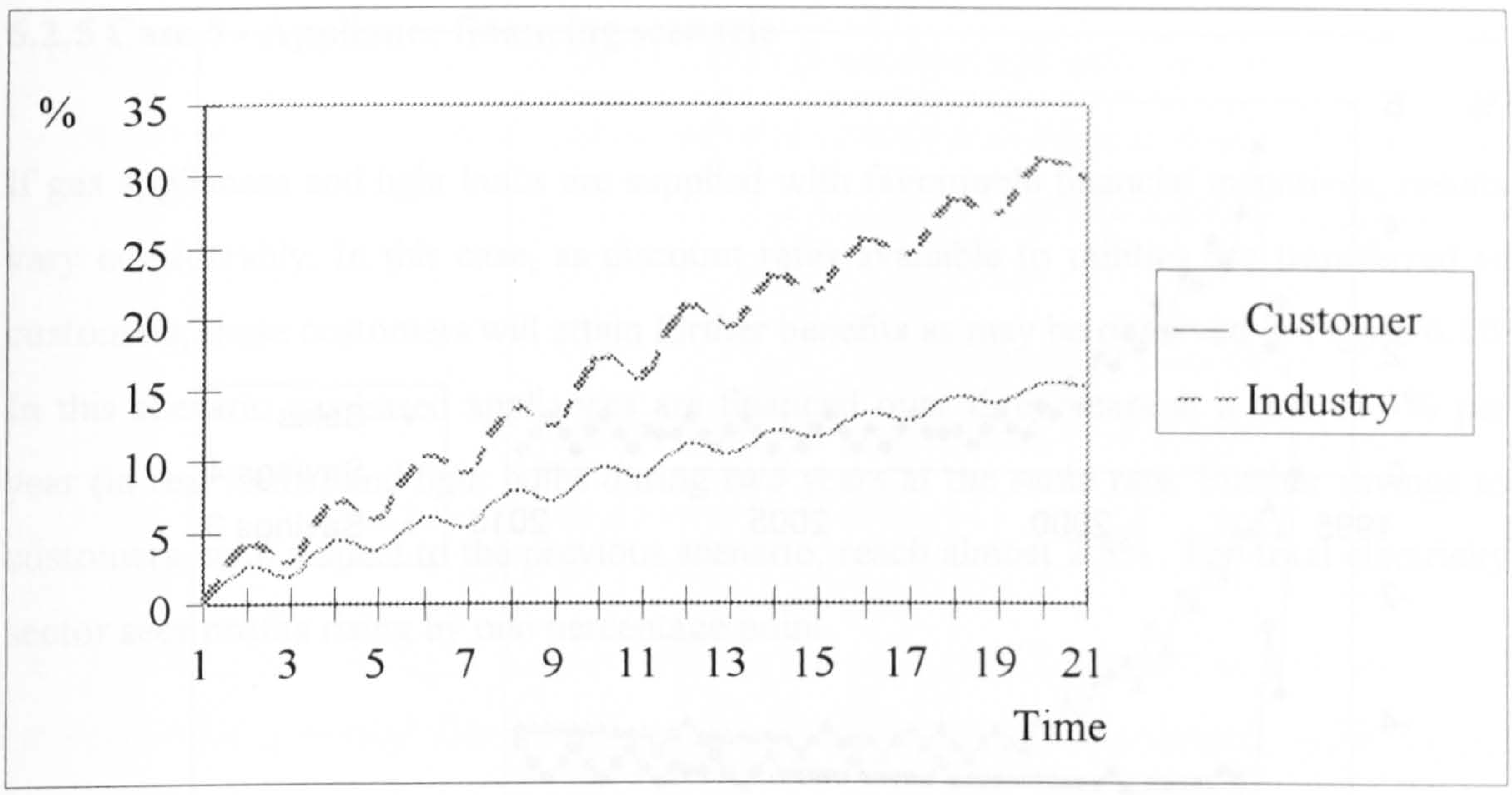


Figure 6.8 Simulation results for Case 4. Effects on the average energy bill for each customer and on the additional national revenues. Time scale is quarterly, so the maximum effect is observed at the twentieth period (fifth year).

Furthermore, Figure 6.9 illustrates the effect of this gradual pricing policy on additional sales and on relative savings. The upper line denotes additional electricity sales across the industry with respect to the Case 3 scenario; the intermediate one indicates the average customer's energy savings in this case with respect to a scenario Case 3' (which has been defined before as being exactly the same as the Case 3 scenario with the exception of all assumptions related to price increases); and, the bottom line signals savings in Case 3 with respect to Case 3'. This means that under the Case 4 scenario the average customer accomplishes significant savings in the long term and the electricity industry needs not sacrifice significant sales in the immediate future. In fact, while this scenario reaches savings near to 1.7% of the total electricity required after one year, the previous scenario brings down demand by over 4.9%.

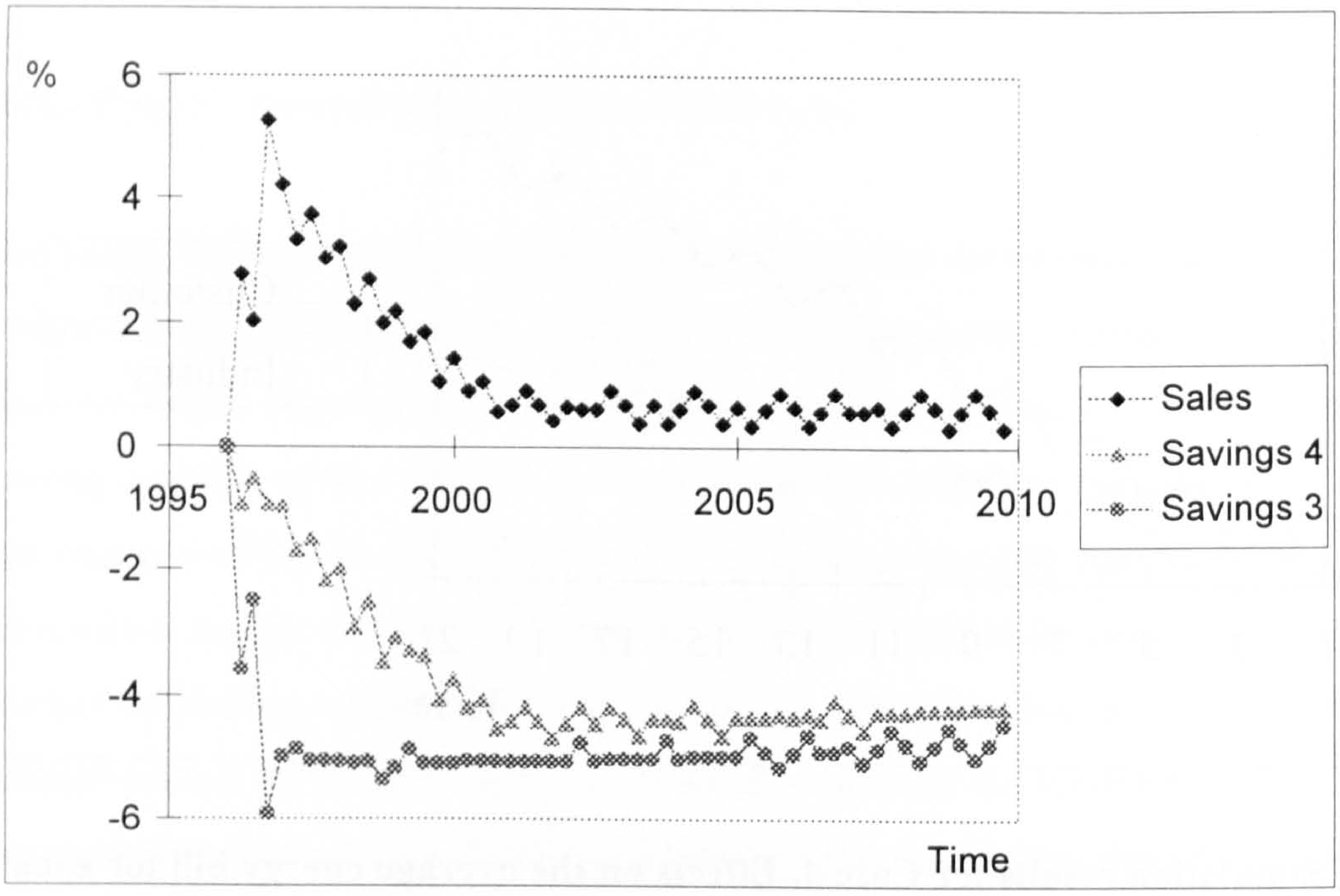


Figure 6.9 Electricity sales and savings accomplished under Case 4 scenario, and savings reached under Case 3 scenario.

This results seem counterintuitive. Arguably, this scenario is better than the sudden price increases scenario, on the grounds of industry sales, customer benefits and inflationary impacts. The electricity industry will be selling greater quantities at slightly lower returns than in Case 3 (but still the returns are significant high - over 30% after 5 years). Customers are better off (approximately 5% in the long run). Additionally, inflation is reduced by 0.84 percentage points.

Elasticity has played a three-fold role in this case: a) price elasticity, reducing the amount of electricity used, b) income elasticity, increasing the household stock (and the amount of electricity demand), and c) cross elasticities, shifting demand to other energy sources like gas.

6.2.5 Case 5 - Appliance financing scenario

If gas appliances and light bulbs are supplied with favourable financial incentives, results vary considerably. In this case, as discount rates available to utilities are transferred to customers, these customers will attain further benefits as may be observed in Figure 6.10. In this scenario gas-based appliances are financed over three years at a rate of 3% per year (in real terms) and light bulbs during two years at the same rate. Further savings to customers, with respect to the previous scenario, reach almost 2.5%. The total electricity sector sees profits rising by one percentage point.

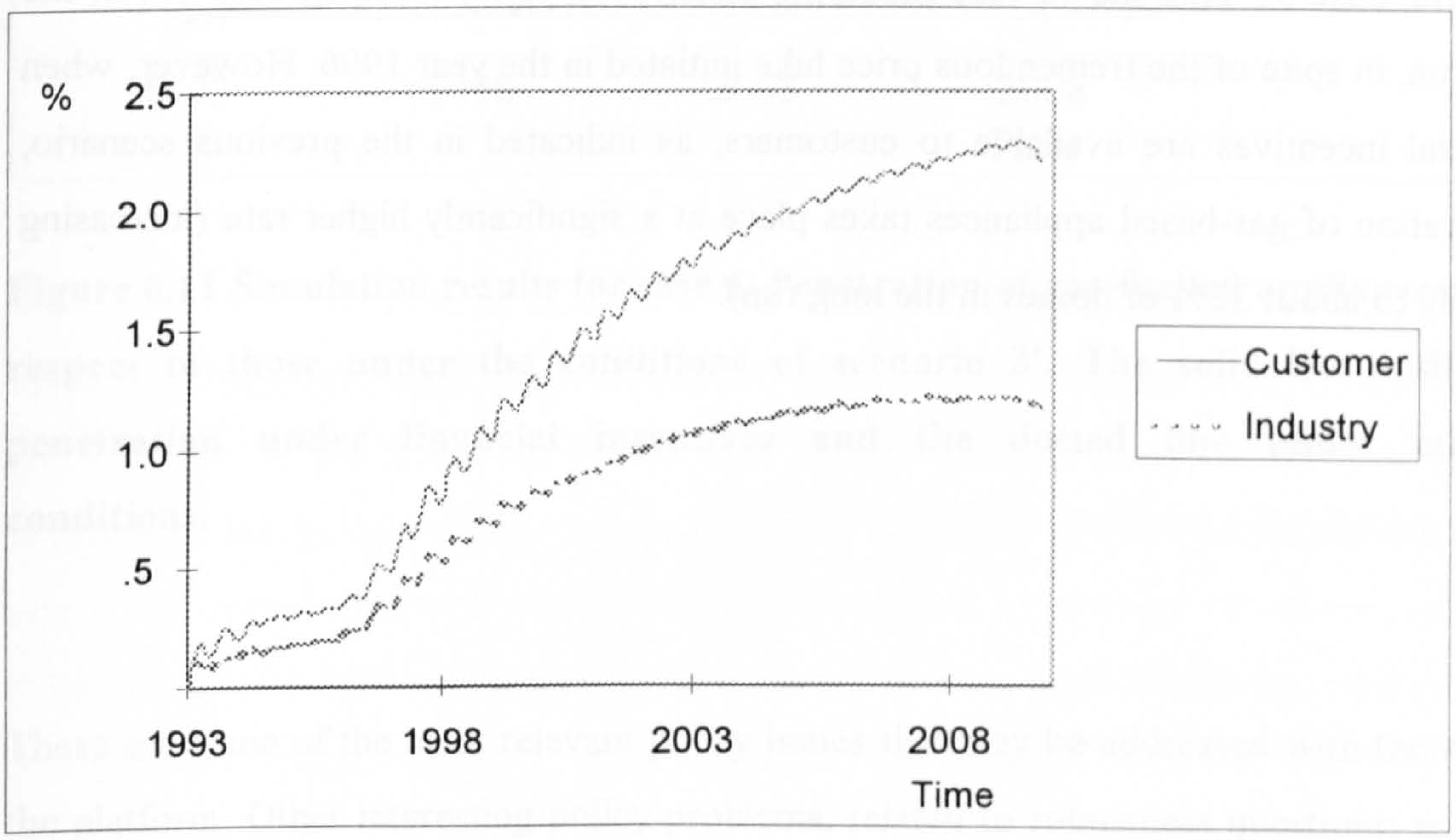


Figure 6.10 Simulation results for Case 5. Customer savings and industry's additional returns with respect to Case 4.

6.2.6 Case 6 - End user income restriction scenario

In this case the effect of income restrictions on technology acquisition is examined. Problems related, not to the average end-user income, but rather to income distribution and to the associated capacity to invest on energy appliances are investigated.

It is important to note that this functionality (to account for income distribution effects) was only built into the model as it became relevant during the latest part of this research. Here it has been assumed that:

- Price increases are as in Scenario 4
- Income distribution is as calculated in Londoño (1990)
- Customers invest less than 1.5% of their income on energy appliances.

The dotted line in Figure 6.11 indicates the penetration ratio of gas fuelled appliances at market prices (customers are subjected to income investment barriers), with respect scenario Case 3'. This shows very moderate penetration rates, reaching only 1% in the long run, in spite of the tremendous price hike initiated in the year 1996. However, when financial incentives are available to customers, as indicated in the previous scenario, penetration of gas-based appliances takes place at a significantly higher rate (increasing steadily to about 32% of homes in the long run).

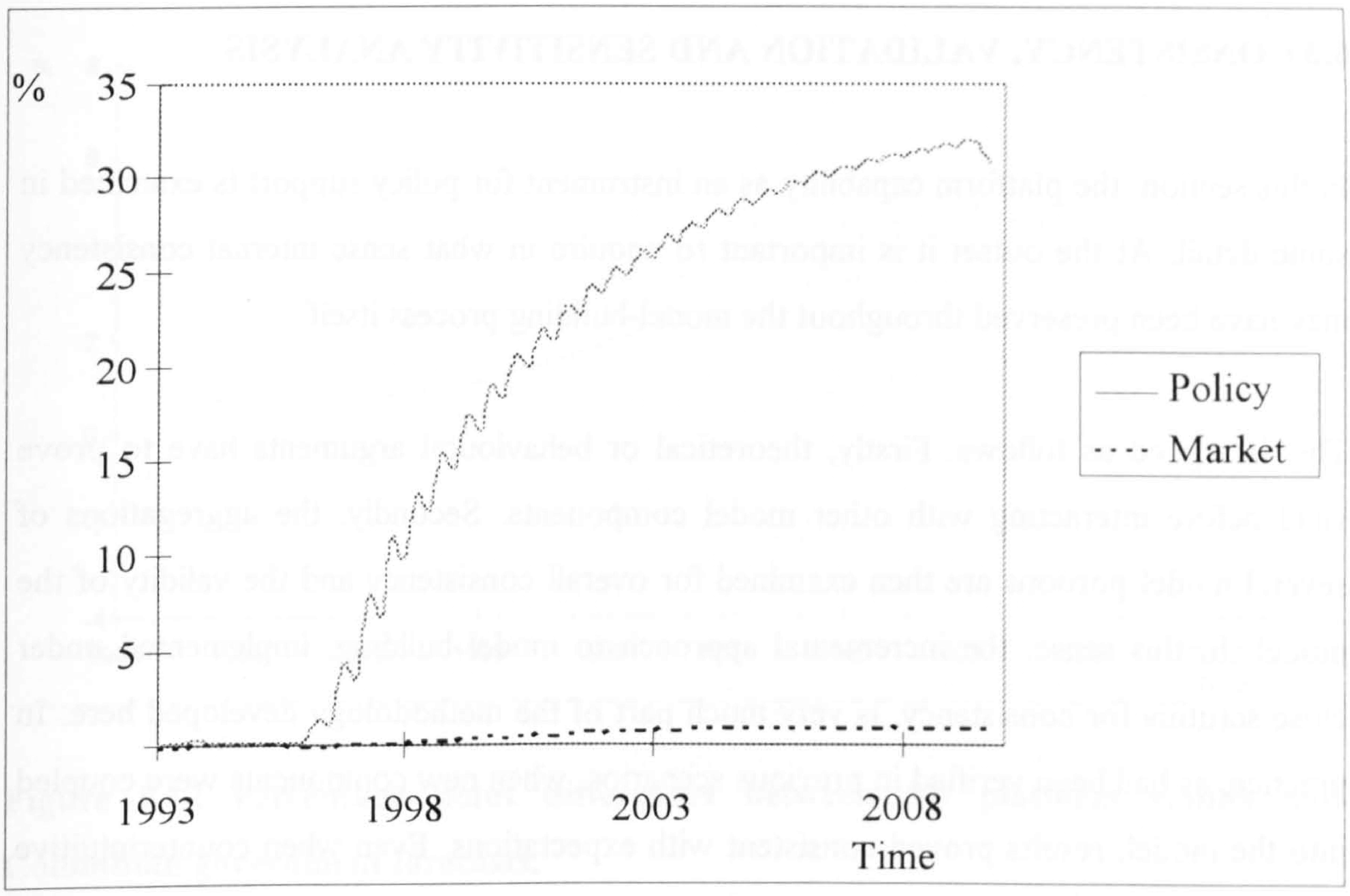


Figure 6.11 Simulation results for case 6. Penetration of gas-fuelled appliances with respect to those under the conditions of scenario 3'. The solid line indicates penetration under financial incentives and the dotted line under market conditions.

These are some of the most relevant policy issues that may be addressed with the aid of the platform. Other interesting policy problems, related to robustness questions, such as system reliability and effect of the Niño phenomenon will be undertaken in the next section, but the platform validity contention will be dealt with first. Cost-effectiveness is not investigated in this thesis as the main aim of the exercise is to provide insights in relation to the likely effects of DSM programmes.

6.3 CONSISTENCY, VALIDATION AND SENSITIVITY ANALYSIS

In this section, the platform capability as an instrument for policy support is examined in some detail. At the outset it is important to enquire in what sense internal consistency may have been preserved throughout the model-building process itself.

This is argued as follows. Firstly, theoretical or behavioural arguments have to prove valid before interacting with other model components. Secondly, the aggregations of several model portions are then examined for overall consistency and the validity of the model. In this sense, the incremental approach to model building, implemented under close scrutiny for consistency, is very much part of the methodology developed here. In practice, as had been verified in previous scenarios, when new components were coupled into the model, results proved consistent with expectations. Even when counterintuitive results emerged, this had to be explained *ex post* under theoretical grounds.

Three different ideas related to the platform analysis issue are also discussed in this section: a) consistency with respect to other approaches, b) policy soundness, and c) policy robustness (including sensitivity analysis).

6.3.1 Consistency with respect to other approaches

Results obtained using the SD platform developed here ought to be consistent with respect to other approaches, otherwise discrepancies have to be explained. Figure 6.12 shows the percentage point differences between government forecasts and results from the SD platform for electricity demand. Both calculations assumed a low rational energy use perspective. Percentage point differences increase exponentially at a rate close to 0.5% per year. This mismatch is almost entirely explained by the rise in the household rate of demand.

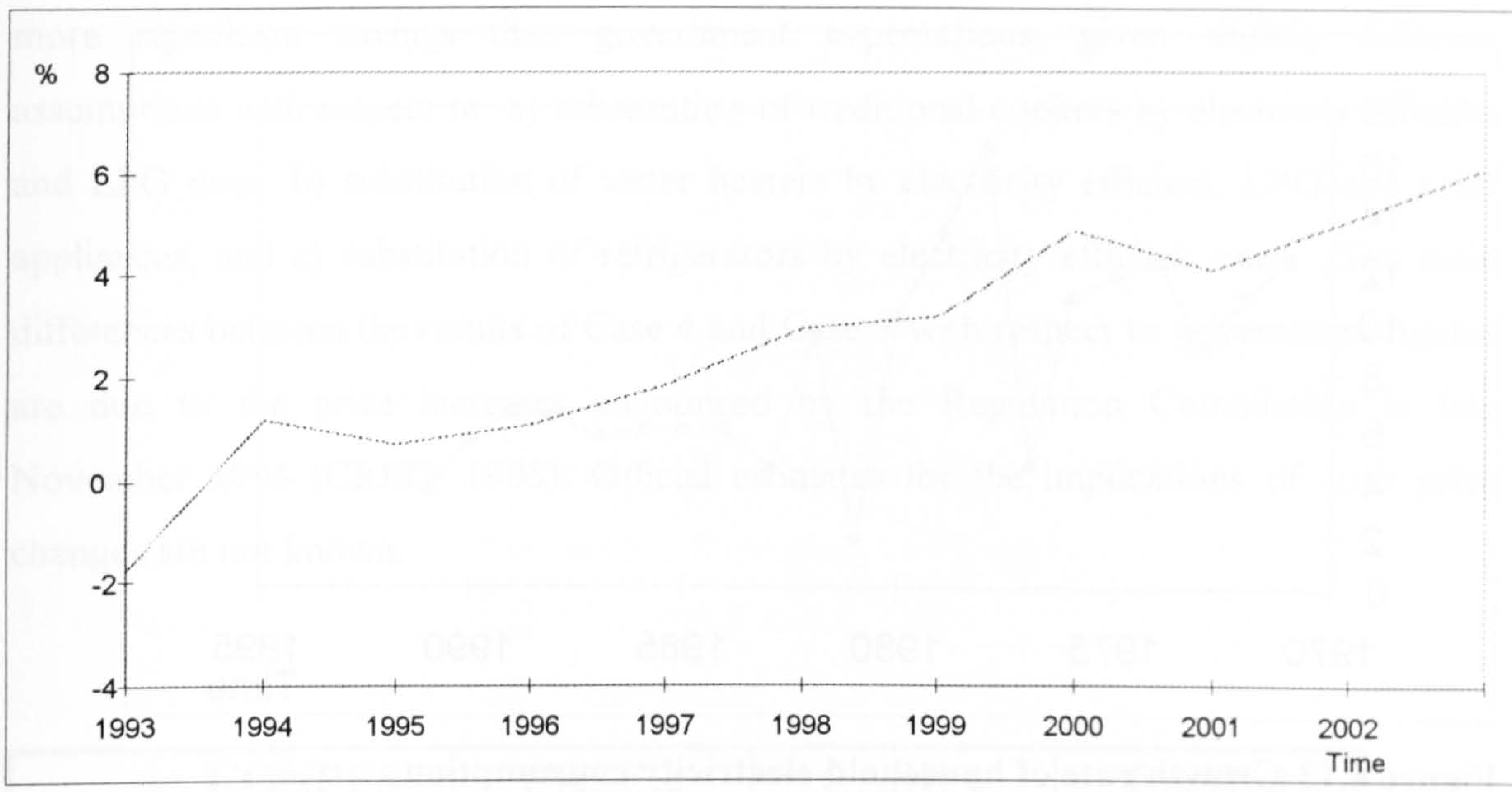


Figure 6.12 Percentage point differences between SD platform results and Colombian government forecasts.

While Government projections are based on historical demand figures, the model developed in this thesis takes into account declining rates in population growth as well as decreasing deficits in housing requirements, as indicated in the previous chapter. In actual fact the government reference scenario assumes an average of recent historical increases in electricity consumption, discounting the blackout effect, and extrapolates this growth to the year 2005. Their high and low scenarios are too extreme to be considered here.

Furthermore, the government approach tends to overestimate demand at a time when generally there is a downwards trend in the growth of both electricity connections (as can be appreciated in Table 5.2 and Figure 5.6) and electricity consumption (see Figure 6.13). Furthermore, government projections for household demand growth of about 5.8% in the base case is not consistent with estimated income elasticity, as GNP per capita is expected to grow at below 5%.

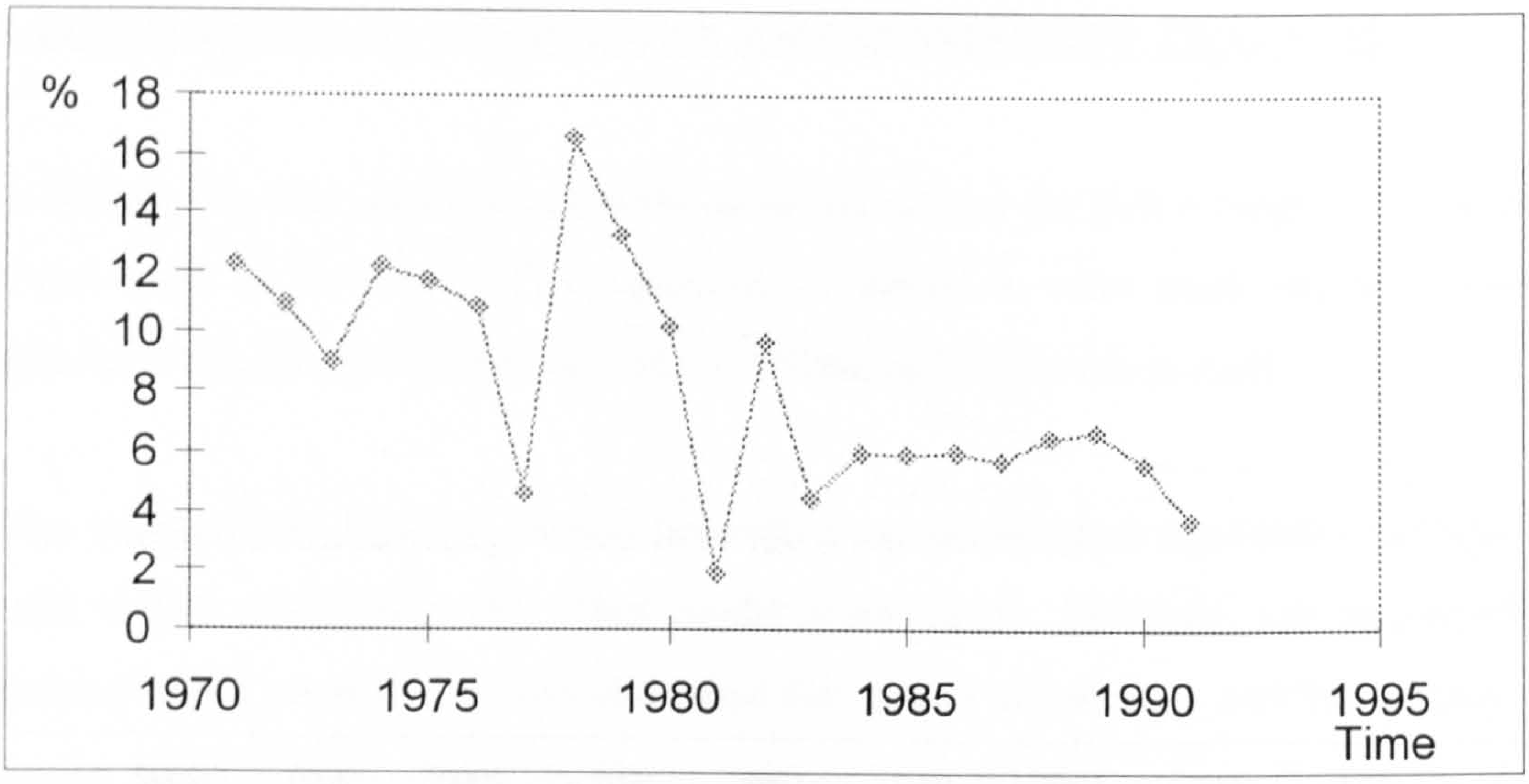


Figure 6.13 Growth rate of household electricity consumption

Although system inertia plays an important role, other factors will perhaps have an even greater impact on the energy sector - namely electricity tariff increases and gas supply to households at competitive prices. Consequently, discrepancies observed should not have a significant effect in the short and medium-term, and this is reflected in Figure 6.12. For example, short term differences between both approaches may be less than 3 percentage points by the year 2000. This is, however, a matter of contention far from being resolved yet. The evolution of energy demand in the household sector requires further research as more information becomes available.

In this sense, a question is open for further enquiry: How dominant is inertia? This can be broken down into two questions: In the medium-term, will the domestic demand for electricity be diminished as the population growth declines? alternatively, independently of the customers satisfaction on household-building needs, will an average increase in GNP superior to 5% guarantee a steady increase in households' electricity demand?

However, in relation to DSM issues, estimates here are consistent with those reported by the government. Table 6.1 shows percentage energy savings calculated by the government (CONPES, 1995), and those provided by simulation runs under Scenarios 2, 4 and 3, respectively. The model, under the conditions of the Case 2 scenario, yields more significant savings than government expectations, given slightly different assumptions with respect to: a) substitution of traditional cookers by electricity efficient and LPG ones, b) substitution of water heaters by electricity efficient, LPG and solar appliances, and c) substitution of refrigerators by electricity efficient ones. The main differences between the results of Case 4 and Case 3 with respect to government figures are due to the price increases announced by the Regulation Commission in late November 1995 (CREG, 1995). Official estimates for the implications of such price changes are not known.

	CONPES	CASE 2	CASE 4	CASE 3
1996	3.10%	4.57%	4.87%	4.87%
1997	4.71%	5.59%	6.93%	10.71%
1998	5.65%	6.62%	8.83%	11.69%

Table 6.1 Energy savings estimated by CONPES (1995) and by the model under Case 2, Case 4 and Case 3 scenarios.

Figure 6.14 shows electricity demand under Case 3 and Case 4 scenarios (previous section), which may be compared with the government's reference scenario. In Case 3, as the price hike occurs suddenly, demand drops much more rapidly than in Case 4.

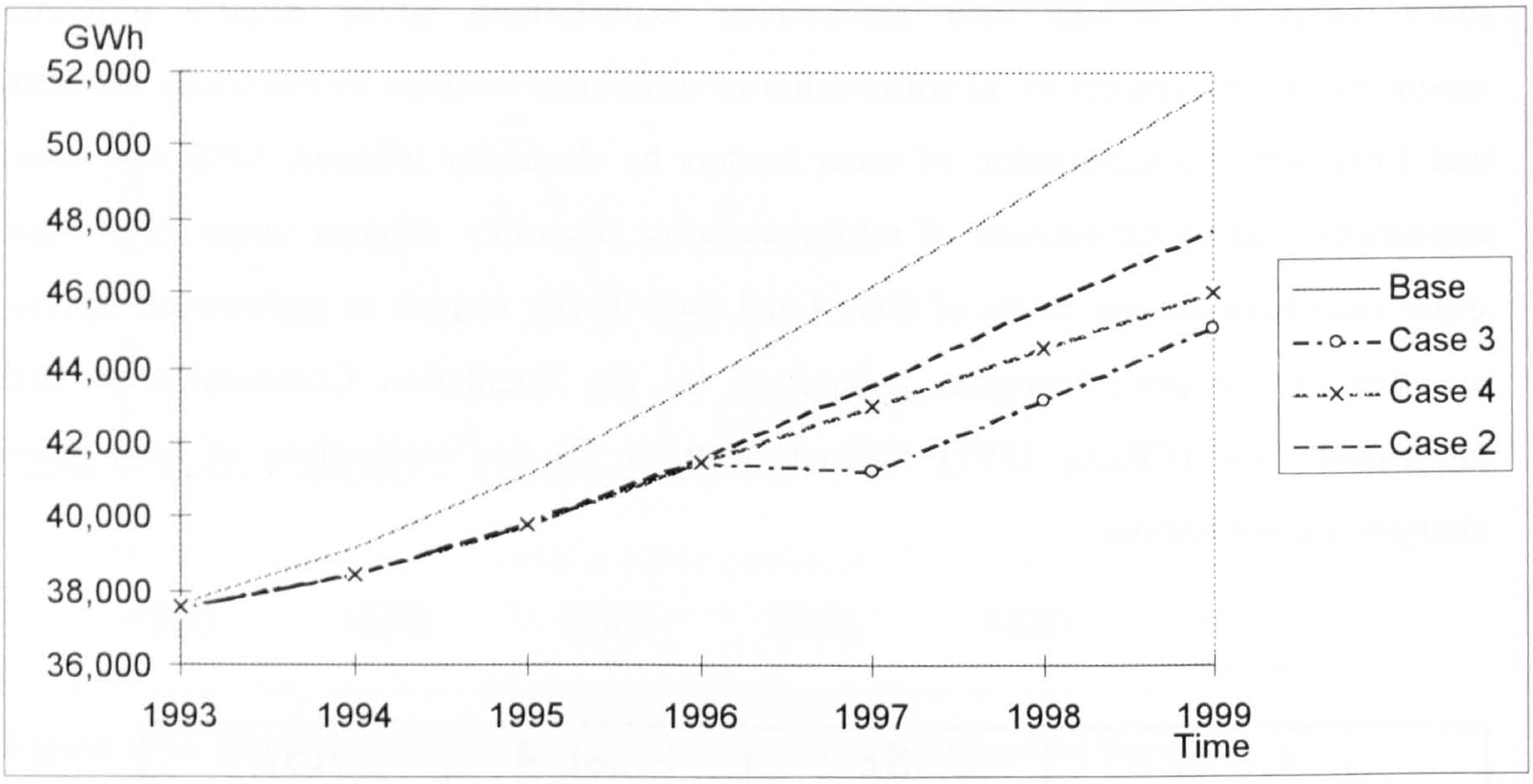


Figure 6.14 Energy demand under a base case scenario, Case 3 scenario, Case 4 scenario and Case 2 scenario.

From discussion above, two major conclusions may be inferred: a) that estimates for electricity demand here are slightly below the government ones, based on lower medium-term expectations of electricity demand in the household sector, b) that in the worst-off scenario, energy savings calculated by the model exceed government figures by about one percentage point of the total electricity demand forecasts, due to some assumption differences, and c) that large increases on the electricity tariff will contribute significantly to energy savings. It is important to note that most programmes are running behind schedule at the time of writing.

6.3.2 Policy soundness

This section pursues enquiries in two directions. First, with respect to the platform's validity for supporting energy policy in Colombia and, second, in relation to policy soundness on rational energy use.

The first question is partly answered by the learning process tried via the model-building approach pursued in this thesis. Model builders, analysts and planners have been involved in the platform construction throughout. Some analysts from the Colombian Ministry of Mines and Energy have been exposed to both general discussions on theoretical foundations and architectural design, as well as to the detailed model building. Also, some had the opportunity to follow, intervene and actively participate in the building process itself. And, most of all, everyone could criticise or contribute positively with general ideas or more concrete aspects with respect to the platform content. In this sense the platform is not only a group effort product but, arguably, it is also one that has been exposed to strict testing in a falsifiable fashion, as in Popper (1994).

It is important to note that this approach makes policy makers aware of the platform capabilities, what the components are and how to improve it. Also, participants have a shared view of what is worth investigating with it, and what its limitations are. Thus policies on DSM may be addressed, with the support of the platform, to learn of possible effects and to evaluate a number of alternative options. All this is part of the validation process which helps confidence-building relating to aspects of model usefulness (Forrester and Senge, 1980; and Barlas and Carpenter, 1990).

With respect to the other line of enquiry proposed above, in relation to policy soundness of rational energy use issues, a viability check of the large-scale natural gas plan and of the efficiency lighting programme will be pursued next.

The gas plan is examined first. Scenarios discussed in section 6.2 show how gas penetrates in the residential sector at a "good rate". Nevertheless, investigating this issue further, some interesting outcomes are found. Figure 6.15 shows the penetration of the natural gas plan in the residential sector with respect to government targets. Note that in all cases government plans fall short. In the early days goals failed to be met by well over 15% and, as time passed, this gap widened to at least 28%, in the most favourable case.

It is also possible to assert from Figure 6.15 that when financial incentives are available (Case 5) significant differences are exhibited, in the positive sense. Additionally, Figure

6.15 reveals that electricity prices have only a minor effect on the penetration of the gas plan in the household sector. Note that Case 3' and Case 3 show very little difference, in spite of being almost identical, with the exception that the former considers no electricity price increases at all.

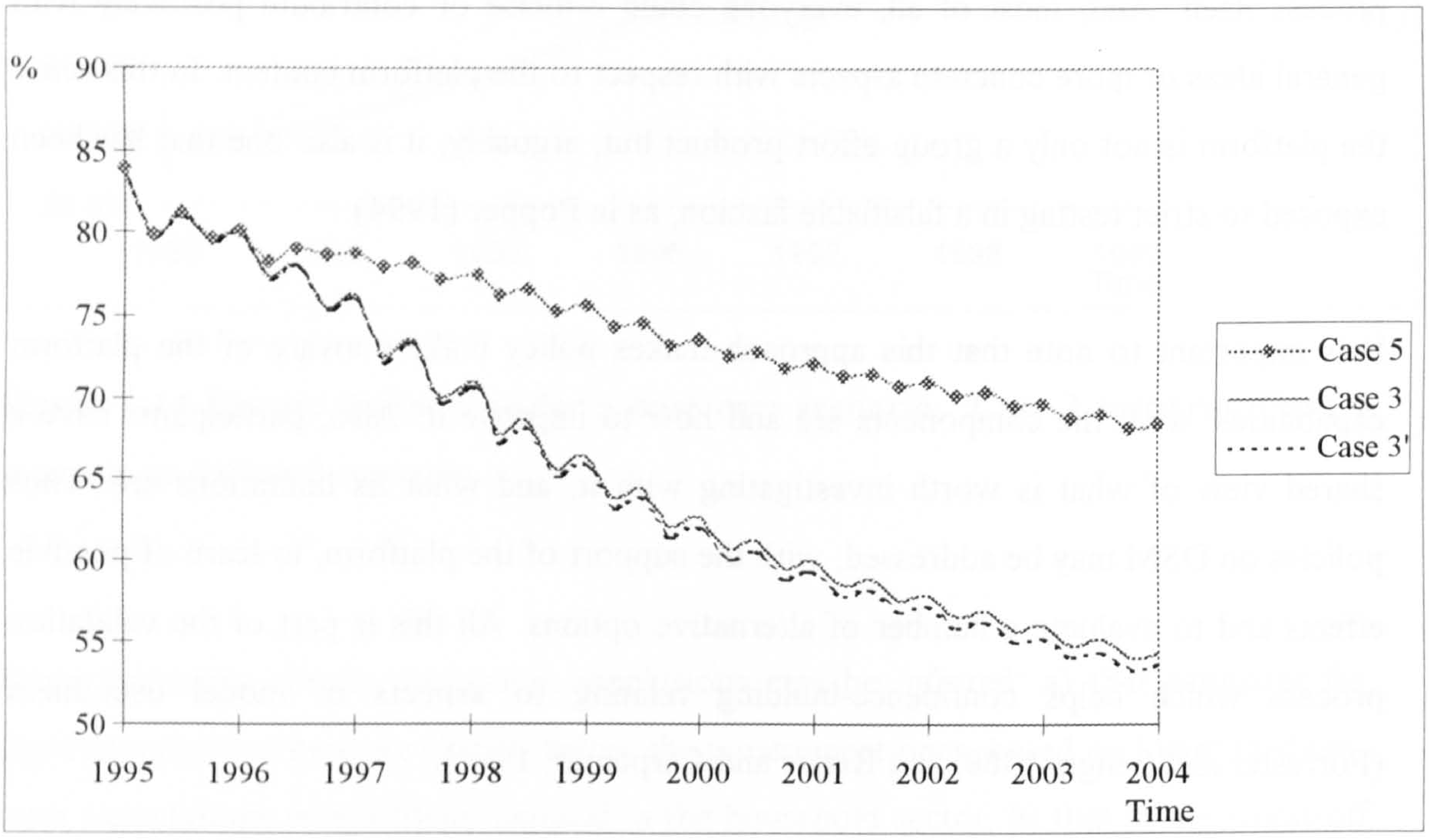


Figure 6.15 Penetration of gas under the large-scale natural gas plan under conditions of Case 5, Case 3 and Case 3' scenarios, respectively.

Figure 6.16 shows the progress of the natural gas plan for Cases 3 and 5 with respect to the base Case (Scenario 3'). This confirms that, under these circumstances, while financial incentives aid penetration at a significant rate, electricity price increases make little difference to this end.

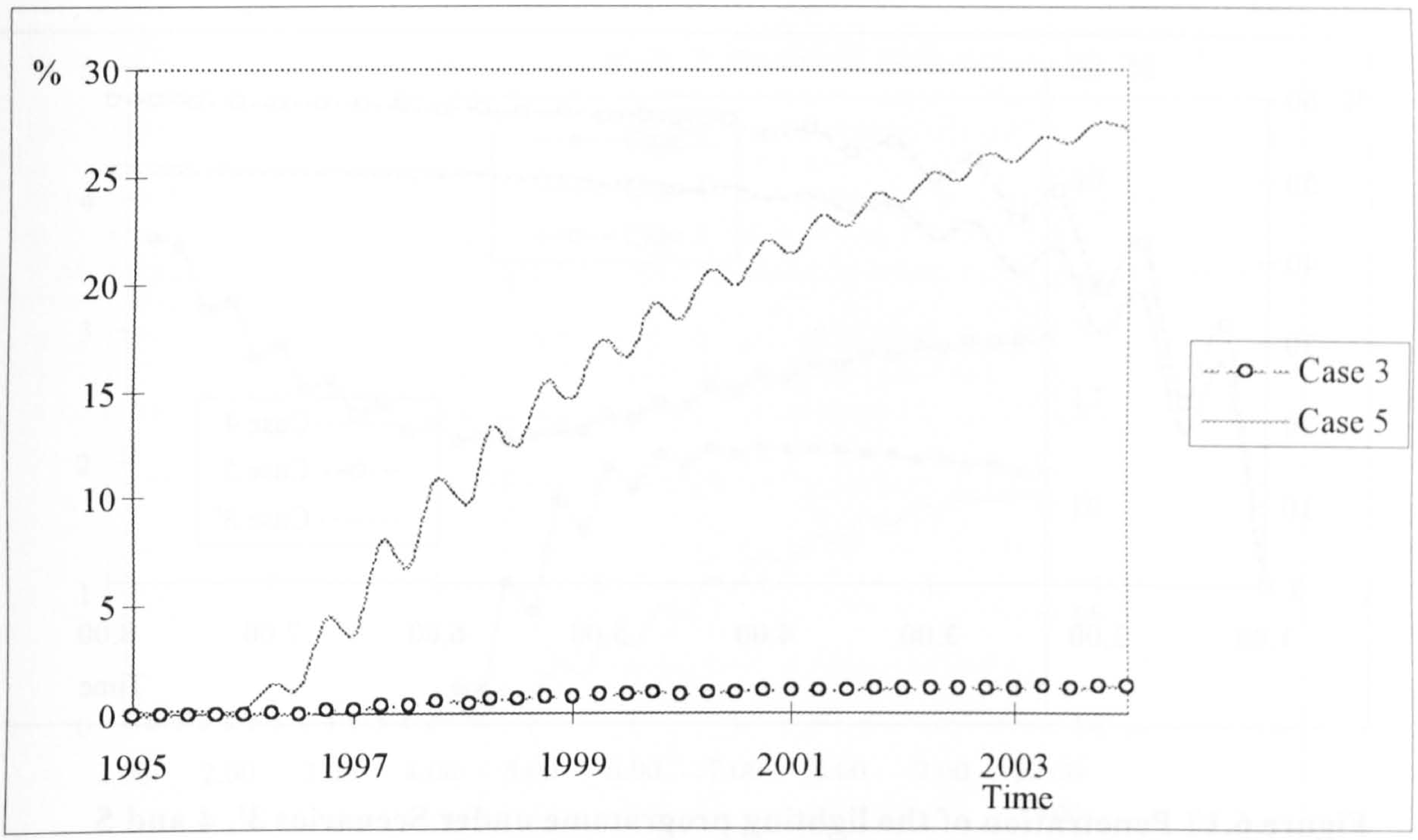


Figure 6.16 Progress of the large scale natural gas plan with respect to Case 3' scenario.

In the second place, the lighting programme is examined. Figure 6.17 shows the penetration of Scenarios 3', 4 and 5. Efficient light bulbs are available from year one but financial incentives and electricity price increases start in the fourth year only. Again, as previously discussed, financial incentives have a much more important impact than large electricity price hikes. Electricity savings calculated here for the Case 5 scenario are just 11.5% below the CONPES (1995) goal, which aims to save about 1300 KWh by the year 1988. These simulation results may be encouraging as they confirm government policies. Nonetheless it is important to note that no samples have been taken to check for actual behavioural responses.

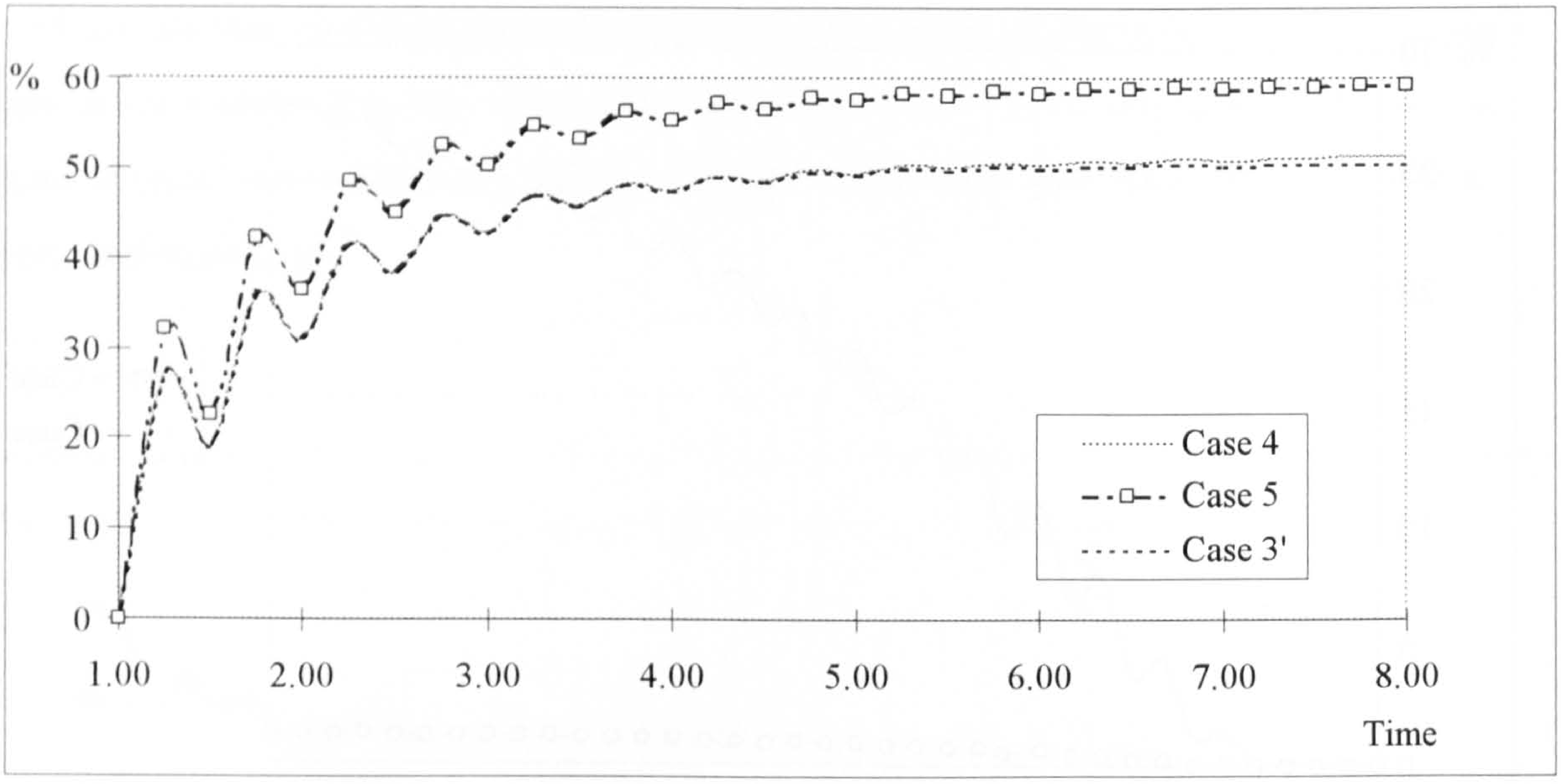


Figure 6.17 Penetration of the lighting programme under Scenarios 3', 4 and 5

Figure 6.18 shows the penetration of the efficient lighting programme with respect to the base case Scenario 3'. It is possible to appreciate how all cases benefit from price increases starting in year 4, specially Case 3 Scenario. The scale on the right corresponds to Case 5, while the scale on the left is for Cases 3 and 4.

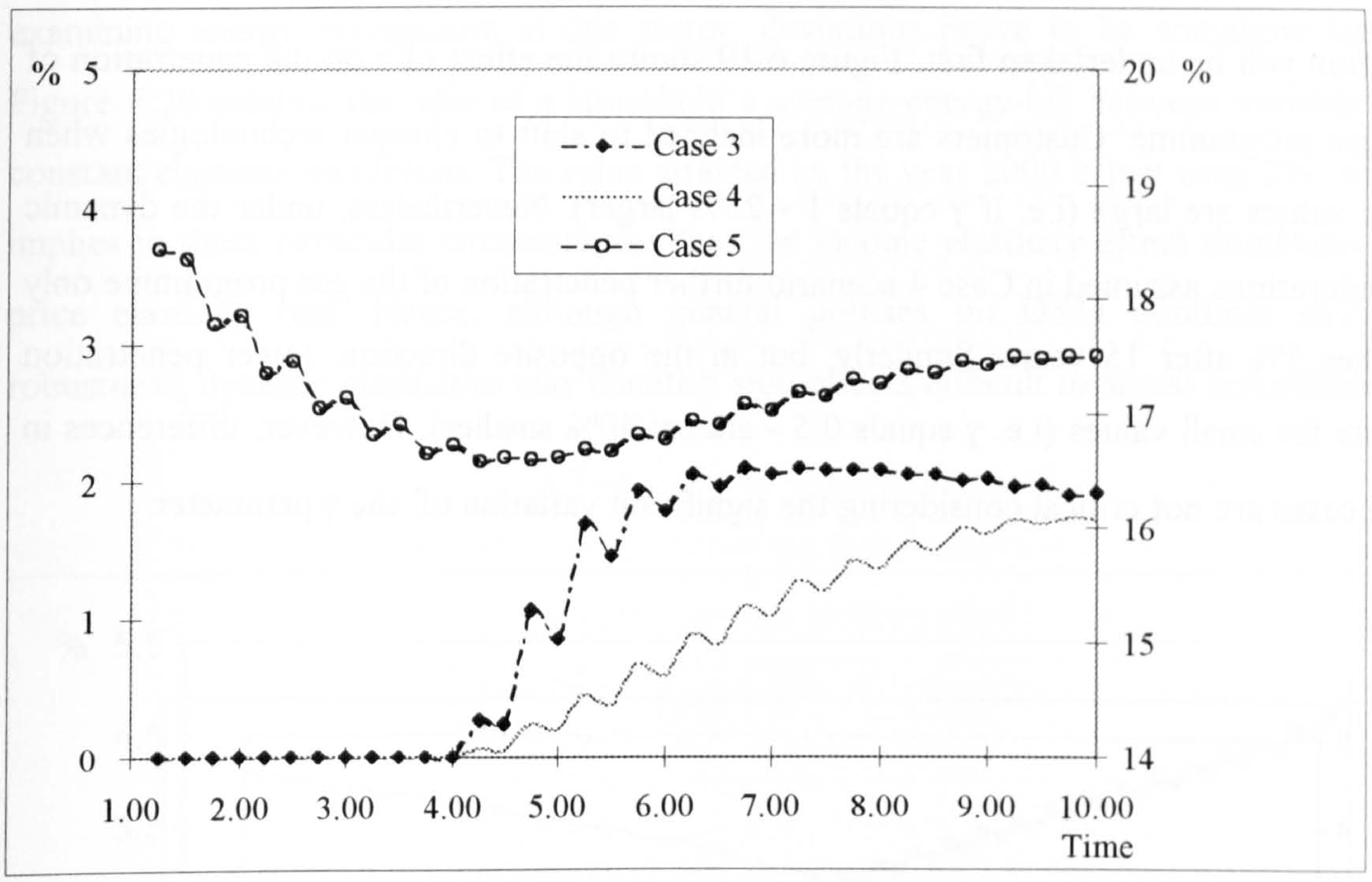


Figure 6.18 Penetration of the lighting programme under Case Scenarios 3, 4 and 5, with respect to Case 3' scenario.

Thus, at this point it is important to highlight the fact that some government plans (i.e. natural gas supply and efficient lighting) while somehow optimistic, nevertheless the corresponding direction is undisputed. The reader may also note that while the CONPES (1995) paper is more conservative when estimating policy effects on energy savings, it does point in the right direction. Even under these circumstances, additional complementary actions will be required to attain the desired goals. In this sense, the overall strategies are sound although, depending on the information source, plans or programmes reflect inconsistencies (sometimes overestimating effects, other times underestimating them).

6.3.3 Robustness analysis

The last policy issues on DSM investigated in this thesis are those related to robustness. In this sense, sensitivity with respect to the γ parameter on the consumer's choice criterion will be undertaken first. Figure 6.19 shows the effect of γ on the penetration of the gas programme. Customers are more inclined to shift to cheaper technologies when these values are large (i.e. if γ equals 1 - 25% larger). Nevertheless, under the dynamic considerations assumed in Case 4 scenario further penetration of the gas programme only reaches 5% after 15 years. Similarly, but in the opposite direction, lower penetration occurs for small values (i.e. γ equals 0.5 - almost 40% smaller). However, differences in both cases are not critical considering the significant variation of the γ parameter.

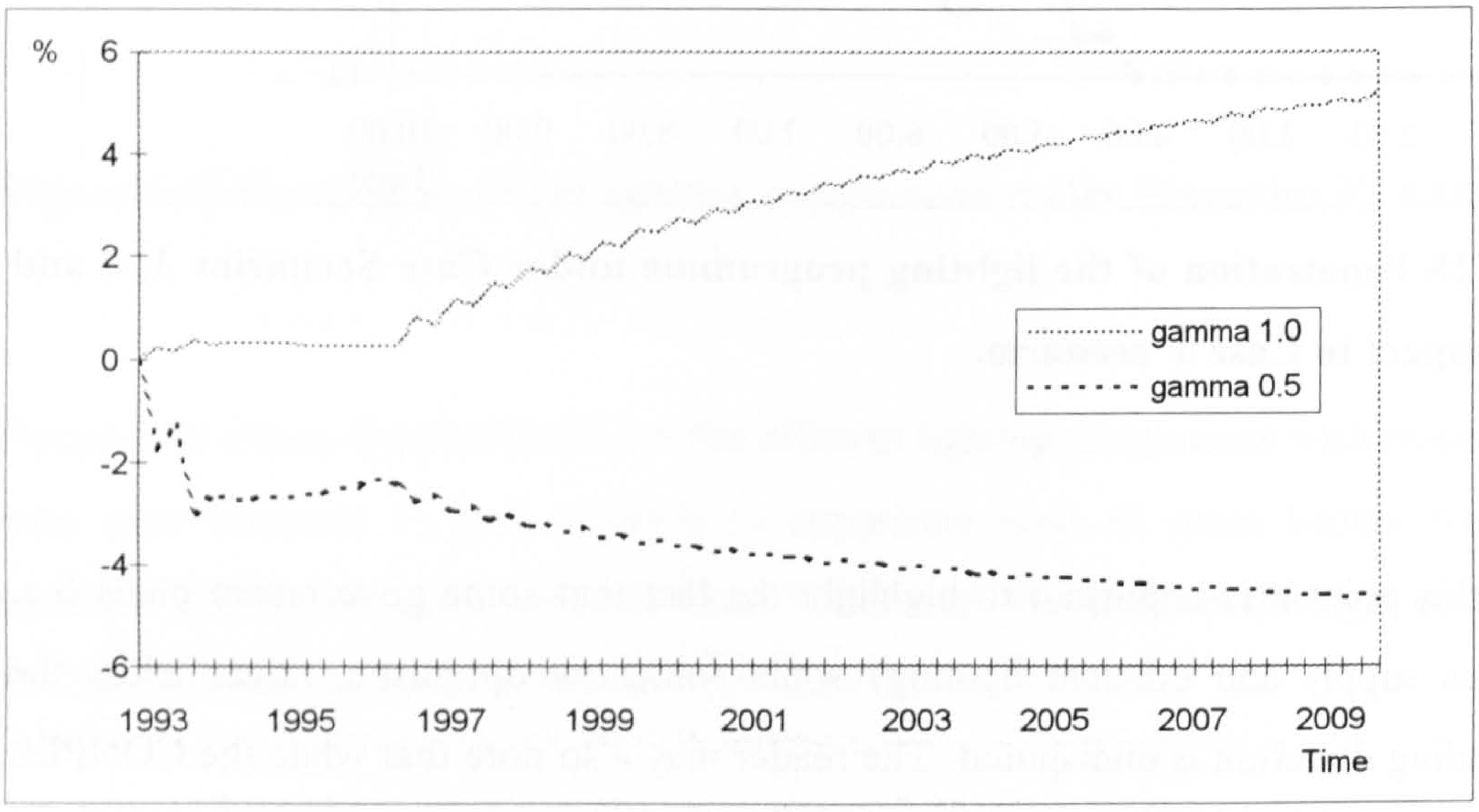


Figure 6.19 Sensitivity analysis with respect to the gamma parameter

Secondly, sensitivity with respect to variable elasticities should be assessed here. This is of utmost importance as suppositions on likely developments of income and price elasticities may be misleading. It can now be assumed that for the best scenario - that under which highest penetration of efficient appliances takes place - both elasticities remain constant.

Simulation results in this case show that the highest discrepancies in gas penetration do not amount to even 0.77 of one percent in the year 2008 - that is, about 23,000 out of 3,021,000 households. On the electric cooking side, the impact will be on nearly 20,000 out of 2,350,000 households in the same year - 0.86 of one per cent. Nonetheless, when examining energy expenditure in this sector, deviations prove to be somehow larger. Figure 6.20 exhibits the ratio of a household's average energy-bill between variable and constant elasticity conditions. The value attained by the year 2000 is just over 2%, which implies in these particular circumstances that the income elasticity effect dominates the price elasticity one. Hence, although general policies on DSM continue showing robustness, dynamic elasticities may manifest side-effects difficult to assess beforehand.

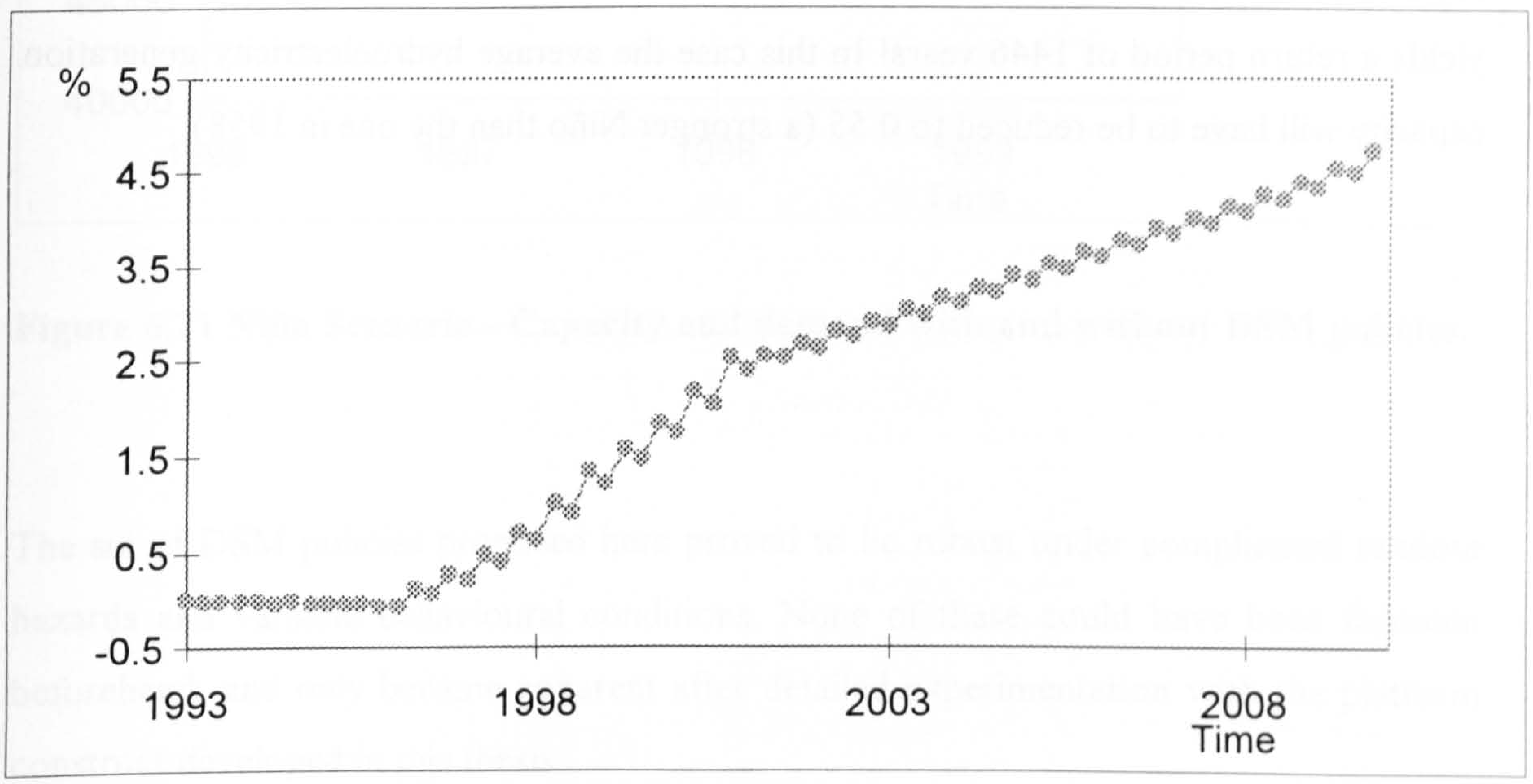


Figure 6.20 Ratio of a household's average energy-bill between variable and constant elasticity.

The third, and last, issue on sensitivity analysis, with respect to robust energy policies on DSM, is that of supply guarantee. Policies on rational energy use seem to be robust to diminished pressure on the supply side. Nevertheless the question is: how much? In the Colombian case, for the year 1997 this may be crucial as the margin between supply and demand will be very narrow.

Up until the time of writing, the strongest Niño registered in Colombia occurred in the year 1958. If the expected Niño in 1997 is as powerful as the one in 1958, the average hydroelectricity generation capacity will be reduced by 0.67 (33%). Under this conditions, and if no DSM policies were implemented, the blackout intensity for the most critical month in 1997 would be approximately 7% of the projected demand. Otherwise, if DSM programmes are undertaken, rationing will be barely missed, as may be appreciated in Figure 6.21. Note that a Niño stronger than this one has a probability of occurrence of about 0.0173. That means, on average, materialising every 57.8 years.

Now, it is also worth noting that under rational energy use criteria the corresponding Niño to produce a 5% blackout has a probability of occurrence of about 0.0007, which yields a return period of 1446 years! In this case the average hydroelectricity generation capacity will have to be reduced to 0.55 (a stronger Niño than the one in 1958).

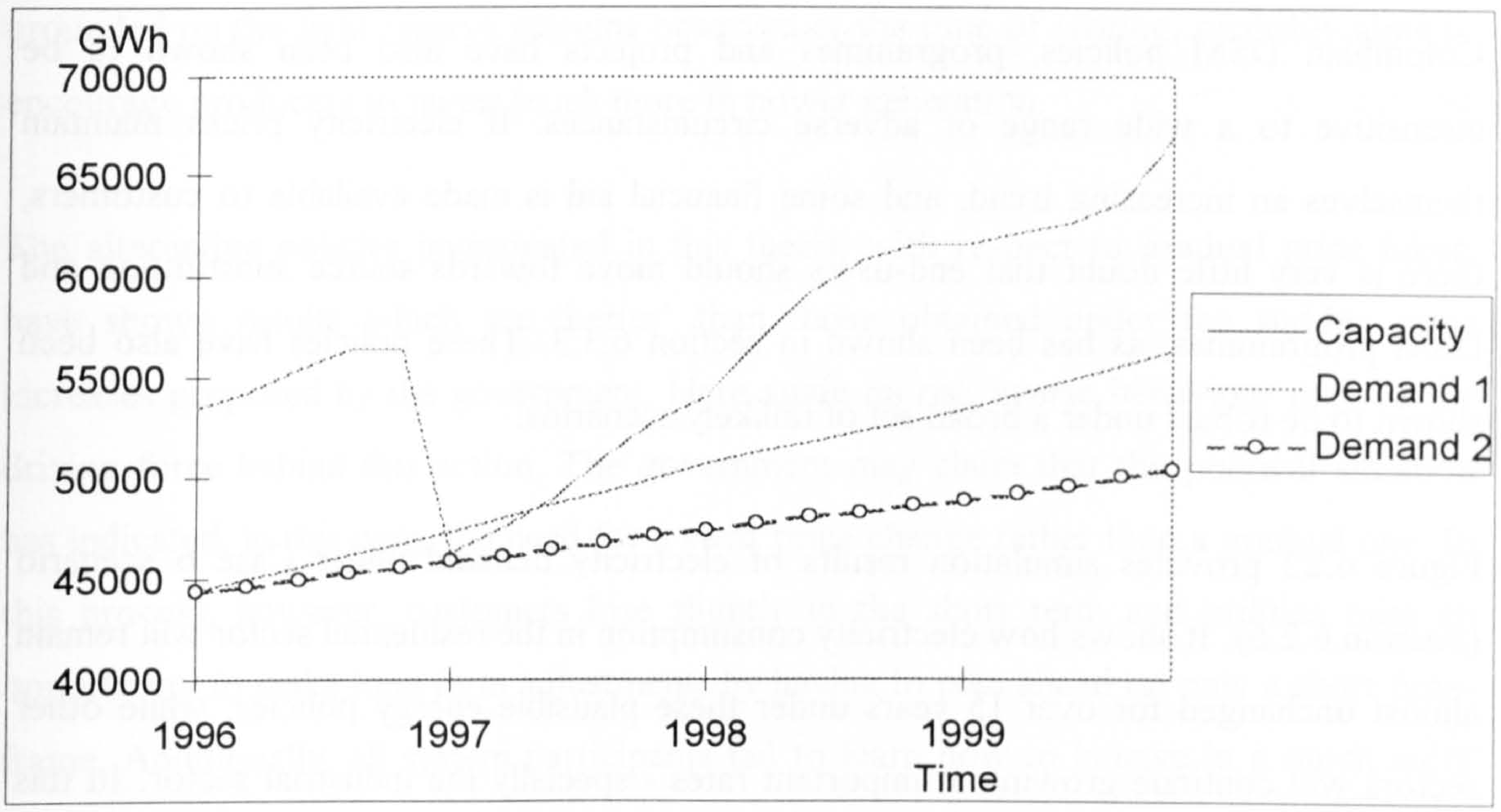


Figure 6.21 Niño Scenario - Capacity and demand with and without DSM policies.

The set of DSM policies proposed here proved to be robust under complicated random hazards and variable behavioural conditions. None of these could have been foreseen beforehand, and only became apparent after detailed experimentation with the platform construct developed in this thesis.

6.4 POLICY CONTEXT-TESTING

The Colombian policy towards energy management has shown itself to be consistent with the economic premises established in the law and, by and large, with most of the Government's objectives and goals. Overall, it has shown to be sound on DSM matters - although sometimes conservative (CONPES, 1995). In few occasions, however, policies seem slightly over-optimistic, especially with respect to source substitution (large-scale gas plan) and the lighting plan (efficient light bulbs). Nonetheless, success or failure will depend very much on implementation matters as will be argued ahead.

Colombian DSM policies, programmes and projects have also been shown to be insensitive to a wide range of adverse circumstances. If electricity prices maintain themselves an increasing trend, and some financial aid is made available to customers, there is very little doubt that end-users should move towards source substitution and DSM programmes, as has been shown in section 6.3.3. These policies have also been shown to be robust under a broad set of unlikely scenarios.

Figure 6.22 provides simulation results of electricity demand under Case 6 scenario (Section 6.2.6). It shows how electricity consumption in the residential sector will remain almost unchanged for over 15 years under these plausible energy policies, while other sectors will continue growing at important rates - specially the industrial sector. In this sense DSM policies are encouraging.

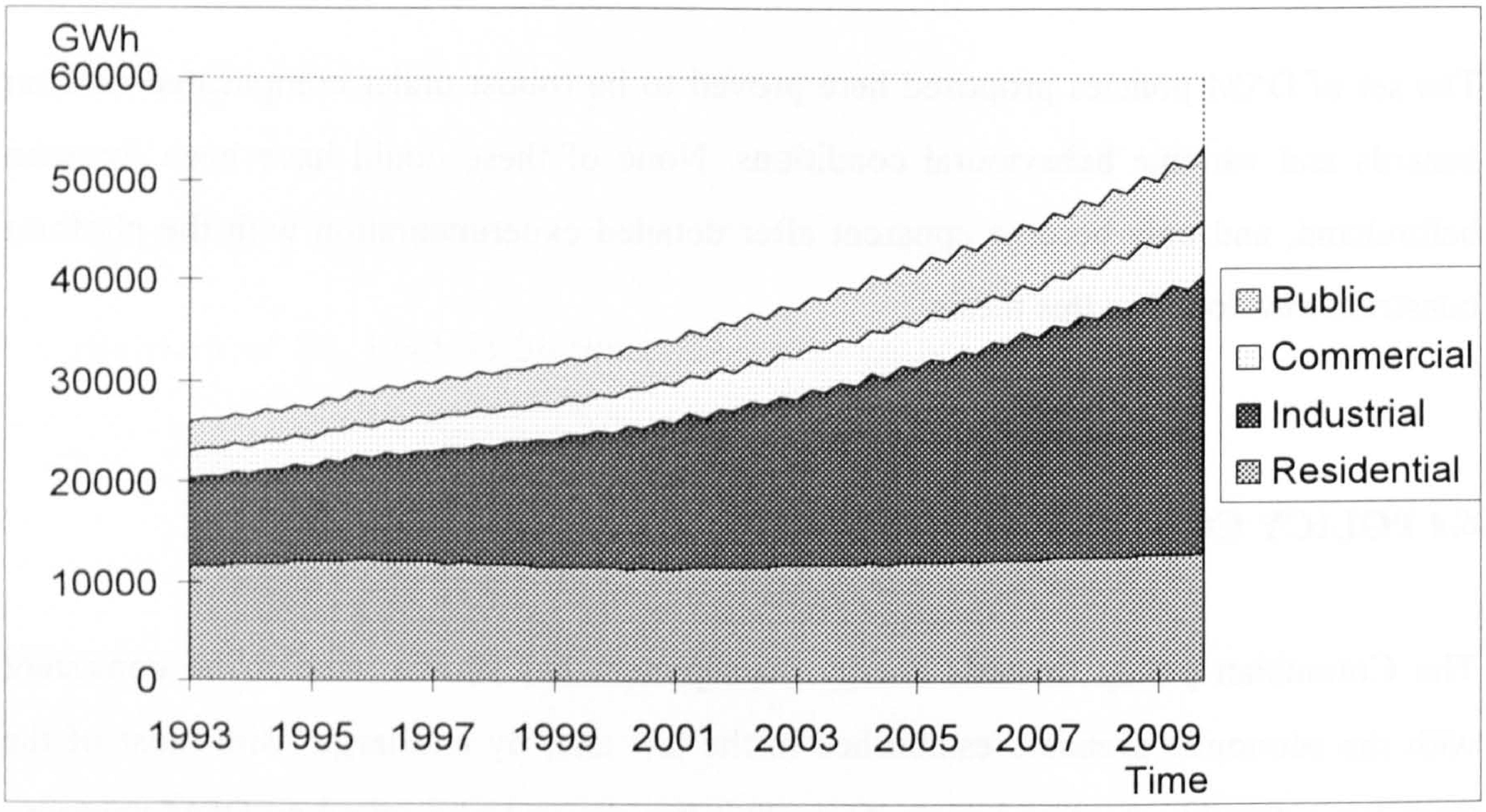


Figure 6.22 Evolution of electricity demand by socio-economic sector under DSM scenario (no losses included).

The government projections of electricity demand seem to reflect its risk averse view in the aftermath of the 1992-94 blackout. This very conservative approach which maybe grounded on the tight reserve margins observed at the time of writing, probably aims to encourage producers to invest much more in power generation.

The alternative policies investigated in this thesis, with respect to gradual price hikes, have shown results which are 'better' than those obtained under the sudden price increases proposed by the government. Here again its risk averse behaviour may be the driving force behind this action. The government may claim that the political situation has indicated, in this case, the need for a swift price change rather than a gradual one. In this process, however, customers lose slightly in the short term and utilities miss an opportunity to make long term adjustments by having to plan ahead on only a short time-frame. Additionally, all system participants fail to learn how to behave in a much more disciplined environment. This is important as further adjustments may be required as illustrated in Figure 6.23, which shows the average bill increase that customers may have to be prepared to pay if tariffs are to follow market prices.

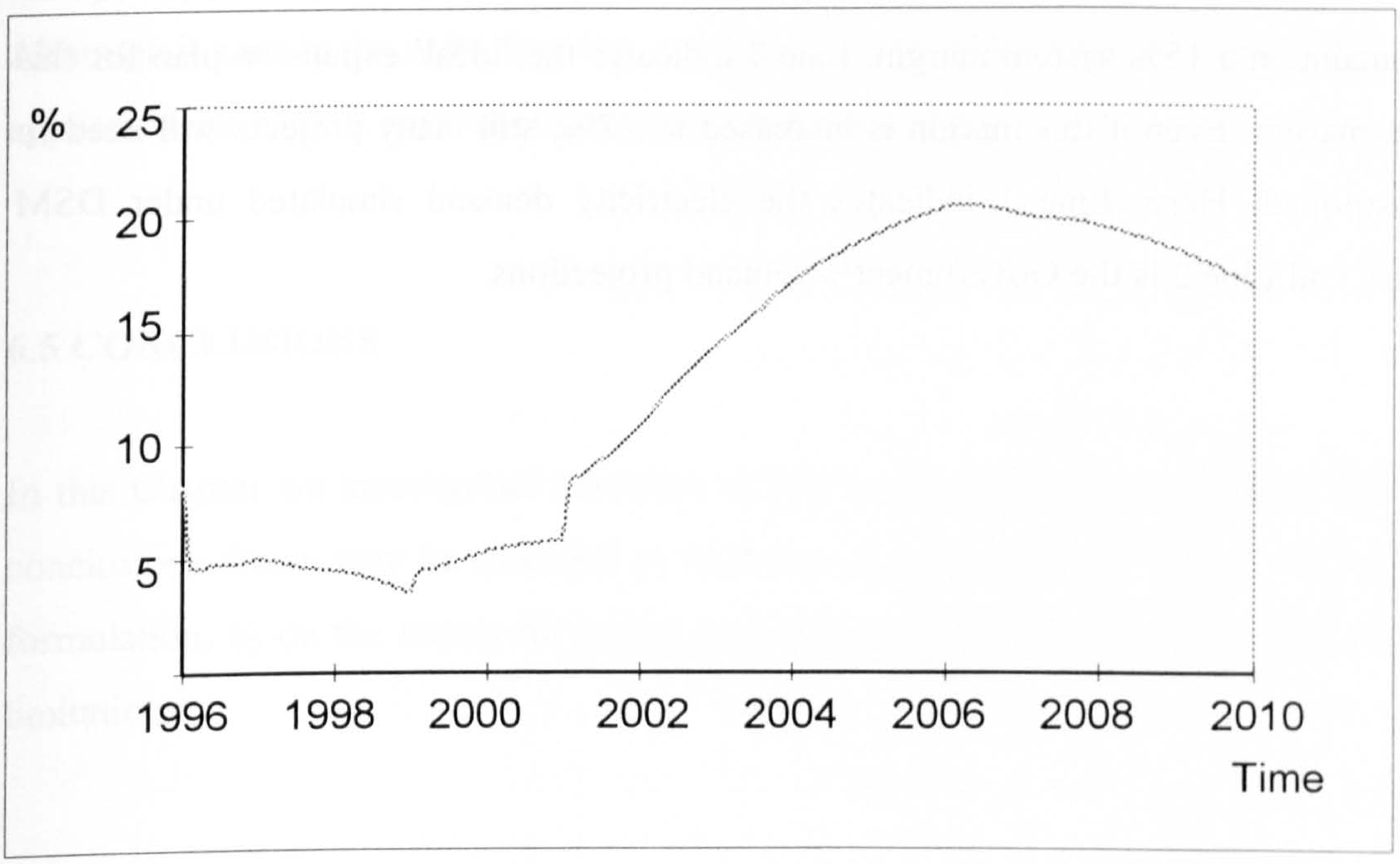


Figure 6.23 Average energy bill increase to end-users

Furthermore, energy policy still needs to prove capable of overcoming some of the major system weaknesses in the area of pricing and supply reliability. Firstly, the transition to real- cost pricing, maintaining cross subsidies to the poorest groups in the community, is by no means a trivial exercise, when the system as a whole is moving towards a more liberalised set-up. Secondly, the pool-pricing mechanism needs to prove capable of delivering the appropriate signals for capacity building in the power sector.

Additionally, plan, programme and project implementation are still at a rudimentary stage of development. The execution question leaves some serious doubts. No precise actions are known and financial aspects are unclear. No matter how well the design stages have been worked through, policies will fail if implementation is not carefully conducted - commitment to policy.

One of the objectives of the Colombian platform is to support supply-side policy evaluation, by way of testing the indicative expansion plan under DSM policies. Figure 6.24 shows what adjustments will be required (Line 4) to the Government's plan (Line 5), to maintain a 15% system margin. Line 3 indicates the 'ideal' expansion plan for this system margin. Even if this margin is increased to 22%, still many projects will need to be postponed. Here, Line 1 indicates the electricity demand simulated under DSM policies, and Line 2 is the Government's demand projections.

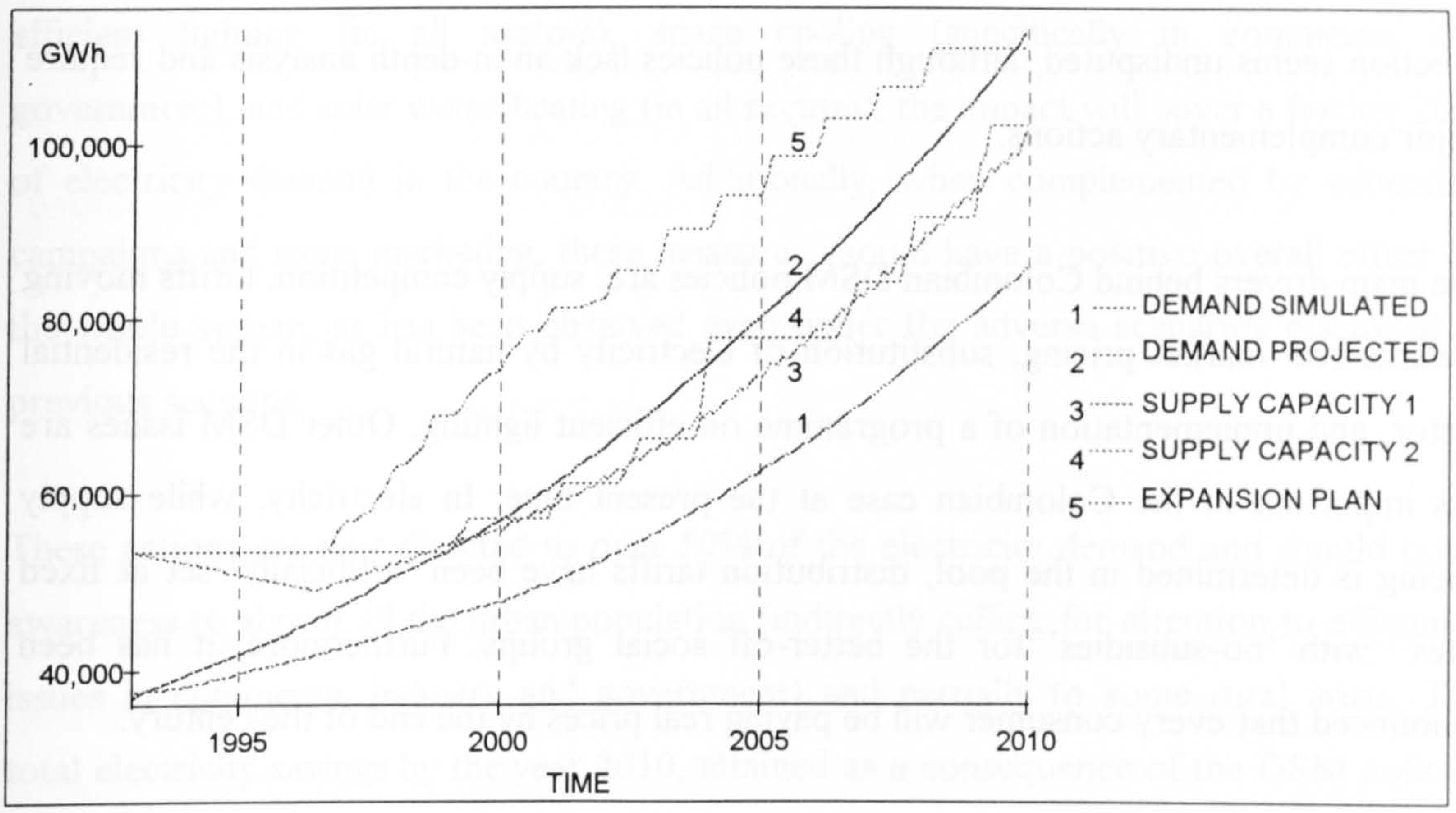


Figure 6.24 Testing supply alternatives

Finally, it has been shown in this section that the Colombian energy policy exhibits strong, less strong and some weak features. This can be summarised as follows. Although it aims in the right direction and has some room for improvements in design, it appears weak when it approaches the implementation stages.

6.5 CONCLUSIONS

In this Chapter we investigated a number of DSM policy issues in Colombia. The main conclusions drawn may be classified in three broad categories, as follows: a) on policy formulation, b) on the means for policy formulation (the platform), and c) on platform limitations.

Policy Formulation

An important conclusion with respect to Colombian energy DSM policies, being elaborated at the time of writing and as the day of implementation approaches, is that the direction seems undisputed, although these policies lack an in-depth analysis and require major complementary actions.

The main drivers behind Colombian DSM policies are: supply competition, tariffs moving towards real market pricing, substitution of electricity by natural gas in the residential sector, and implementation of a programme on efficient lighting. Other DSM issues are less important in the Colombian case at the present time. In electricity, while supply pricing is determined in the pool, distribution tariffs have been 'artificially' set at fixed rates with 'no-subsidies' for the better-off social groups. Furthermore, it has been announced that every consumer will be paying real prices by the end of the century.

This announcement was made at the time when a large scale gas plan was going through its first stages and before a major programme on rational energy use was being launched. Regulators went ahead first, independently, and decided on tariff matters. Hence, planners following behind had to catch up with DSM policies seeking to attain more favourable effects for the system as whole and, specifically, to help end-users alleviate the energy bill burden. Note that the population had neither been informed then as to how to cut down on energy spending nor had they been made aware of energy conservation technologies.

Thus events have been precipitating actions and no adequate anticipatory analysis and planning has been undertaken. While electricity prices are increasing dramatically, the large scale gas plan (which is an alternative to electricity use) is running behind schedule and DSM strategies are rarely known outside the ministry's quarters. Thus no clear signal on conservation or substitution will be perceived by customers. This shows co-ordination failures in government - with the consequent losses of potential synergy benefits.

The methodology developed in this thesis yields some lessons for Colombia. In this case, DSM programmes are focused on households and some commercial sectors, promoting the use of gas and efficient appliances for cooking and water heating. These will have an effect on almost 30% of the total electricity demand. Also, when addressing problems on efficient lighting (in all sectors), space cooling (specifically in commerce and government), and solar water-heating (in all sectors), the impact will cover a further 20% of electricity demand in the country. Additionally, when complemented by education campaigns and some marketing, these measures should have a positive overall effect on the whole system, as has been observed even under the adverse scenarios discussed in previous sections.

These actions are thus directed to over 50% of the electricity demand and should bring awareness to almost all the urban population (indirectly calling for attention to efficiency issues in commerce, industry and government) and partially to some rural areas. The total electricity savings by the year 2010, attained as a consequence of the DSM policies discussed here, could amount to 70% of the electricity generated in 1995.

On the supply side, policies focus on the effect of the gas plan on the system as a whole, particularly on aspects referring to DSM programmes, on the indicative power generation plan, and on the general pattern of electricity consumption by the different socio-economic groups. It is important to highlight here that, even under a very pessimistic scenario, the electricity consumption split among different socio-economic sectors changes significantly. For example, households make a significant shift, from 47% of the total electricity consumption in the early 90s to less than 25% of it in the year 2010.

Scenario analysis provides an important lesson in this thesis. It is shown that pricing alone is not sufficient to attain the best system behaviour. In fact, Case 6 scenario above explains how gradual pricing, along with DSM and financial policies, aid the achievement of substantial overall benefits to all actors in the system. This, which is not entirely intuitive, was observed as a consequence of coincidental occurrences: income increase, high electricity prices, gas supply to households, and DSM policies and programmes. Hence, this result calls for policy co-ordination between regulators and planners to take advantage of the available market forces to overcome market 'imperfections' synergetically.

To conclude, the single most important lesson learned is that financial policies are required to complement fuel pricing policies for the success of DSM programmes. Gradual price increments, along with financial incentives, facilitate customers' acquisition of efficient technologies and prove to be consistent, sound and robust policies for Colombia.

Platforms to support policy formulation

The platform developed in this thesis has shown to be capable of supporting the evaluation of policy programmes and plans on DSM and rational energy use. It may also be of help in assessing the impact of alternative supply and demand policy issues under a broad set of considerations. Furthermore, it may be useful to concept-test structures, programmes and plans, such as the electricity pool and the indicative generation plan.

An integrated approach, such as the one implemented in this platform, may be an alternative to dangerous counterintuitive solutions, for example abrupt large price increases. Also, this tool supports policy formulation by helping to resolve the following queries: What would be the effect of a policy on final consumers? What can final users do to protect income? What alternatives may be considered for a particular pricing policy? What sort of financial incentives should be made available for end-users? What will be the effect on inflation or on the average energy bill? What would be the effect of delays on the large scale gas plan in Colombia? How much electricity will be saved with the implementation of DSM programmes? What power supply projects may be postponed under DSM programmes? Hence, the platform developed here may be used to address this and other important policy issues.

The platform has also proved useful to evaluate major impacts of the natural gas plan on the electricity expansion plan and on DSM policies. Specific programmes on efficient lighting were closely examined. And, the expansion plan of the electricity grid into rural areas was rapidly explored - further alternatives may be considered and their effects may be assessed.

Summarising, the platform, which operates under an incrementalist philosophy, has proven capable of supporting:

- Policy formulation
- Training and
- Understanding of the system dynamics.

Platform use and limitations

For the platform developed here, the theoretical bases are known and the technical grounds are widely available. However, no one can expect the platform to be good as a prediction tool, but rather one that contributes to finding the appropriate direction. In this sense the platform provides insights and contributes to understanding the barriers that need to be overcome. The critical issues emerge much more clearly and the political, marketing and compromising solutions are greatly clarified.

Many questions have been answered but some are still open to further research, such as:

- Regional policy issues,
- Income stratification to address the problem of subsidies,
- DSM issues related to source substitution and the use of efficient appliances in the household, industry, commerce and government sectors,
- SSM issues related to regulation, including pricing signals, compulsory contracting, and induced volatility in the pool.
- Other issues related to the electricity grid, including losses.

Some of these issues call for major changes in the platform such as those related to regional policy concerns, but others seem simple. From the platform perspective, integration of other DSM issues geared to the industrial sector should not be very complicated to implement. However, they would require some efforts and willingness from the government side.

With regards to SSM, policies on non-technical losses call for immediate further research. Here, it is important to understand a number of problems involved, followed by the conceptualisation and assessment of alternative strategic actions. From the modelling perspective, for example, it is not easy to assess what would be the effect of price increment policies on further pilferage.

This study is concerned with criteria for strict policy prioritisation. Groups of identified policy issues will be pursued in any event, with or without the aid of the platform developed here. In this sense, the interest is not so much in relation to what comes first and then what follows, but rather to identify a collection of factors which, handled simultaneously, will have a significant and synergetic effect on the system as a whole.

7 SUMMARY AND CONCLUSIONS

The previous chapters in this thesis elaborated upon three themes: a) methodology formulation for policy or strategy analysis in the energy field, b) building a tool to support the proposed methodology, and c) demonstrating applications to diverse organisational set-ups. In this chapter, after a general overview of the thesis content, each of the three sections coming next presents a summary of the most significant results found, followed by allusions to specific applications to the British and Colombian cases and the major conclusions that have been drawn. The last section includes possible further lines of research.

7.1 THESIS OVERVIEW

In this thesis, two major paradigms dominating the energy field during recent years - integrated energy planning and market liberalisation - have been investigated. It has been found that the use of classical models and platforms in the energy field has not provided satisfactory analysis support. Lee et al. (1990), for example, argue that energy experts have not developed appropriate methodologies to make adequate links between different events, as the ones they possess depended on stable conditions. Furthermore they claim that analysts have been traditionally overconfident of the results produced by optimisation techniques, that the assumptions have not been verified carefully enough, and that the models have a tendency to be excessively large.

An extensive enquiry into the analysis techniques available for policy and strategy assessment in this new environment has led to the identification of important methodological requirements. As market liberalisation has prompted competitive behaviour in the energy arena, the incorporation of strategic modelling has emerged naturally. The SD choice appeared to partially fulfil these requirements but needed to make some progress beyond its own classical approach, according to Forrester, Saeed and others:

> *"Although there is a growing literature in SD in model conceptualization, the process must still be baffling to those who are new to the subject. Provocative and potentially useful ideas exist in the OR field, but these need to be interpreted for possible contribution to the SD sequence... wherein the conceptualization must be guided toward the equation writing and simulation..." (Forrester, 1994).*
>
> *"...a general model of an open system might be hard to find in SD... I would suggest attempting to build submodels of the various functions of the general system separately and then integrating those submodels if you would like to attempt to build a general model of system functions..." (Saeed, 1995).*

Therefore, the Systems Thinking/Systems Dynamics symbiosis proposed in this thesis (Chapters 2 and 3) appears to offer the scope to fulfil the methodological and technological requirements for energy analysis. The new constructs developed here, however, needed to be tested in practice before proving of application value.

The UK energy system was examined first (Chapter 4) with the system's margin problem as the initial focus. The platform structure was then used to address issues related to the volatility in the electricity pool and the strategic arbitrage possibilities across the gas and electricity markets.

The Colombian application followed next (Chapters 5 and 6). In this case, where DSM under market liberalisation required investigation, the methodology needed to be more widely tested. Here, an actual client with complicated policy questions - The Colombian Ministry of Mines and Energy - called for support, thus allowing an extensive examination of the validity of the proposed methodology. Note that the approach was already tested for supply-side issues using the UK case and also that DSM was more urgent in the Colombian case.

In both situations, the proposed platforms proved to be helpful for an incremental approach to policy and strategy analysis under changing circumstances. Contrary to conventional wisdom in the SD field (with few exceptions) with respect to the development and use of small, fully conceptualised and discardable models, the platforms proposed here have also shown to be modular, adaptable to dynamic systems and transportable to new environments. In the following sections, a more detailed discussion of these issues is presented, concluding this thesis with general indications for further research.

7.2 CONTRIBUTION TO METHODOLOGY FORMULATION

This thesis discusses major methodological and instrumental dilemmas emerging as a consequence of: a) the complexity involved in energy systems, and b) the corresponding ideological/political alternatives for systems management that have been considered by both researchers and governments around the world. The requirements for a suitable planning/analysis methodology have been outlined and the constituent features of the support technology have been described, along with its prescribed functionality.

The simplified Systems Thinking/System Dynamics approach that has been proposed here appears to fulfil the methodological requirements previously discussed. Furthermore, it enhances the required functionality and has the following features and capabilities:

- Seamlessness (transparency)
- Behavioural and participative
- Incrementalism
- Continuous adjustments (to handle uncertainty)
- Simulation capabilities.

Furthermore, as has been illustrated, a System Dynamics-based platform has the potential to provide support for such a methodology although it needs to have a multifaceted perspective on its use.

The methodology proposed in this thesis addresses analysis issues for intervention in the energy field. This is a process supported by individuals, instruments and data. At the outset, it is required to understand the system - its structure, internal and external influences, and consequences. Broad influence diagrams thus appear naturally, leading to causality chains, and the learning process gets under way. The system conceptualisation and problem identification stages then begin to emerge.

Organisational ends and objectives have to be shared among participants throughout the process. Goals and/or the system's mission need to be identified at this point. These have to be either implicit, to avoid unnecessary group dispersion, or explicit, to eliminate some erroneous misconceptions. Also, the decision making process and methods to deal with contingencies may require attention. The literature in this area is vast; see for example Ackoff (1970, 1981), Naylor (1986) and Dyson (1990).

The "hardening" in the different stages, supported by modelling, evaluation and quantification, needs to be accompanied by data and measurement instruments. Modelling, particularly, aids both policy formulation and keeps track of the process. This is one of the reasons why a platform to support analysis has been proposed here, rather than just sparse models. Consequently, the tools utilised should meet the criteria of being comprehensive, modular, adaptable, transportable and transferable. Preferably, the tools should allow for behavioural arguments, group participation, process uncertainty and simulation of likely outcomes.

It is important to state the differences between this approach and the SODA analysis, which is based on cognitive maps that contain hundreds, or even thousands, of complex relationships (Eden and Simpson, 1989; and Eden 1994). Here a rather more schematic approach is pursued, in the initial stages. With the aid of perhaps a few dozen causal links, the system is represented in very broad terms (see, for example, Figure 3.3). This representation is supported by theory or by behavioural observations. At this point, however, there is no claim for a faithful representation of the particular system; instead, the idea is to provide initial insights with respect to the context in which some crucial problems arise and where some policies or strategies may be of interest for consideration.

Against this background, an issue, or group of issues, is selected on the basis of the impact to the system as a whole. Prioritisation is not the most important problem to be confronted when starting from scratch, as the process is one of continuous learning, and in the end all initial problems should be approached, one by one. Sometimes, they may even be revisited, if they continue to be relevant as the system evolves. This raises the issue of commitment and patience by client.

Then, in the next phase, further identification of causes and effects is explored, not necessarily with the aid of cognitive maps, but rather using System Dynamics environments such as i'think, POWERSIM or Vensim, for the purpose of building stock and flow diagrams. Using these environments, system simulation and validation may be carried out in a rather friendly fashion. Examination of policy and/or strategy analysis can then follow.

Policy or strategy formulation and evaluation comes next. The intervention phase, if it is supposed to take place, follows next, preceded only by the definition of specific programmes and activities. Assessment of results and revisiting the process will close the cycle, yielding an accumulation of additional learning.

A new loop in the inquiry process can then be initiated, by returning to the general causal diagram, where it may be possible to introduce new broad perceptions from accumulated knowledge and experiences. It is then feasible to proceed as in previous cycles. In the end, the 'final' product is not necessarily a large model, but rather a set of components linked to a common platform, that may be coupled if convenient. This coupling does not always take place to avoid likely confusing effects that may arise in the simulations. Instead, it is sometimes not used with the intention of avoiding large models that may jeopardise customer's confidence, which may in turn distract analysts from their main concern.

This system environment facilitates progressive analysis - progressive learning. Diffuse ideas are represented initially in general cognitive maps as illustrated in Kosko (1993) and then estimation may follow the fuzzy approach (Milling, 1988; Pankaj et al., 1994).

The British case

The British case fulfils a subset of these capabilities only, as this is a theoretical piece intended to analyse and explore possible strategies for a major player in the electricity generation industry. Although grounded on real strategic options, a proper client was not involved in this case. Hence the conceptualisation stages did not include clients as such, nor was there an implementation phase. However, it did reveal the power of system simulation to analyse new market situations for which there is no empirical history.

The Colombian case

The Colombian situation follows closely the methodology construct proposed in this thesis. From the initial stages, when seeking to identify major problematic issues or when trying to understand significant difficulties within an energy system, the general causal structures exhibited in Chapters 1, 2 and 3 support systems conceptualisation. In the Colombian situation policy issues started to become evident, as the discussion followed closely the approach presented in those chapters. Also, detailed problematic policy matters emerged much more clearly when supported by data analysis on the actual system evolution, just as described in earlier sections of this chapter.

The methodology examined in Chapter 2 of this thesis establishes a framework for discussion and policy evaluation. That is, it supports the conceptualisation stages in the investigation process: first at the macro level, portraying a general picture, bringing breadth into the analysis, and then followed by an approach in search of detail, to explain issues in depth. Also, it provides a basis for the incrementalist method: resolving the most important issues at the outset, and then, in a second round of enquiries, considering the next set of important issues, and so on. It cannot be argued that this approach slows down the process. On the contrary, once a number of issues have been evaluated and selected for implementation, several others may have already emerged as the next candidates to consider, and hence the process is continued.

In this way, the methodology embodies continuous feedback and learning. The functional capabilities and technology features thus emerge more naturally. Other methodological attributes follow suit. Adaptability, transferability and transportability, for example, become a more technical matter and, therefore, less relevant for examination at this point. It is important to note, however, that these attributes do reinforce the methodology.

The initial platform content is considered over several rounds of discussions until converging to an agreed selection. Such discussions also take place as the general structure is developed and typical results are exhibited. When improved sets of data are used for experimentation, and results validate the platform, the initial prototype emerges as a useful model. The development process itself, already described, has a two-fold purpose for personnel training: In the first place for specific use in policy assessment and, secondly, to identify further policy issues, and the corresponding technical support requirements, which in this case have been stipulated in terms of new software components.

The platforms constructed here are not finished products, in the sense of contributing to the solution of unique unambiguous problems in both cases. Rather they are dynamic tools that require continuous development to support the assessment of sets of evolving problematic situations. In this sense they are not discardable items, made only for a specific application.

Remarks with respect to the methodology

In this thesis, broad theoretical analysis guidelines have been followed in both the British and Colombian cases. For the Colombian case, the methodology was also adopted all the way up to the implementation stages, as has been extensively discussed in previous chapters, especially in section 5.6. In this sense, the methodology was largely validated.

Major research issues are still open with respect to the implementation, follow-up and continuation stages of the process. These will probably require further platform capabilities, which are beyond the scope of this thesis.

Alternative methodological arrangements to the ones proposed here have also been investigated. Indeed, they have been discussed extensively in the first chapters of this thesis. They lack, however, some important features, including: modularity, adaptability, flexibility, seamlessness, transferability and transportability.

Summarising with respect to the methodology, a number of questions have been considered, including:

- How was the methodology proposed addressed?
- What questions were answered?
- Was it possible to resolve these questions with the aid of other methodologies? How?
- How was the methodological process validated?
- What questions are still open?
- What capabilities were required by the methodology proposed?

All of these have been examined in detailed and final remarks have been drawn in this section. Let us now turn to the support-side of the methodology.

7.3 CONTRIBUTION TO PLATFORM DEVELOPMENT

A platform for analysis was attached to the methodology construct to support it. In fact, this is what makes it operational - it is its heart. After making progress in the conceptualisation and system analysis stages, problematic energy issues are discussed and policies likely to amend these anomalies are considered. Hence the need for tools to assess various possible scenarios and strategic options.

Note that, as explained in Chapters 2 and 3, the platform architecture needed to fulfil some explicit characteristics, given the very dynamic environmental conditions existing in the energy field. In spite of the amount of research invested in this area for a number of years, which helped identify exogenous socio-economic driving forces affecting energy systems, when demand and supply sectors interact between themselves, complex behaviour arises, with no clear foreseeable outcomes.

The generic platform structure then acquires a specific shape when applied to each case in this research. Each one of these structures only includes major components and the corresponding information flows between them. While some of the broad platform constituent schemes (archetypes) developed in Chapter 3 share common ideas, the detailed platform structures attain quite different forms as illustrated in Chapters 4 and 5. This is largely because different problems are being addressed, except for electricity pricing and some interrelationships between the electricity and gas industries.

The transition from conceptualisation, goal definition and policy-formulation phases into the policy evaluation stage needs to be smooth - transparent to the policy maker. This has been addressed in this thesis as the seamlessness methodology characteristic. Modelling becomes very much an intrinsic part of the analysis process. Although platform building is supported by specialists, policy analysts intervene throughout the process. In this sense, policy matters are 'fully' incorporated into the platform and problems are visited and revisited on several occasions.

As has been shown in this thesis, System Dynamics based platforms have the potential to provide evolutionary policy and strategy support under complex policy environments. It seems that they also offer energy analysts some of the same features of longevity, modularity, adaptability and detail that the other approaches have provided.

Furthermore, the platforms have provided the basis for examining various policies and strategies which might be difficult to reconcile, making use of analogies from elsewhere regarding how various sub-modules may operate (e.g. power pool, consumer choice). The platforms developed here therefore provide a context rich basis for investigating a number of different policy and strategy issues. Hence, in this thesis the use of the most important platform characteristics have been illustrated, which are, in essence:

- Seamlessness (see page 55)
- Modularity (see pages 56, 105, 132, 154-156 and 184-185)
- Adaptability (see pages 56, 105 and 132)
- Transportability and transferability (see pages 57 and 105).

The British case

The British case in this thesis illustrates how a model is redesigned into a platform structure to handle a set of interrelated problems. Originally discardable, the model focused on very specific questions related to the reserve margin issue and needed redeveloping. This had the purpose of making it capable of dealing with a wide variety of issues ranging from the evaluation of economic signals for capacity expansion in the electricity industry to the exploration of strategic options open to a major generator.

It is evident, from examining the modelling needs, that a platform for integrated analysis must facilitate dynamic and systematic investigation of strategy, and not just perform a co-ordination function in managing the inputs and outputs of separate, conventional, modules. The SD platform developed for the British case has the strategic focus and breadth to do this.

The Colombian case

The Colombian case in this thesis represents a completely different situation. Here the platform is developed with the purpose of supporting both DSM and SSM policy issues. The platform construct reaches an advanced state of development, readily used by policy makers. In this instance, experimentation has also achieved interesting results, validating a) the methodology, b) the process, and c) the platform. The benefits brought about by the special platform features have been extensively demonstrated in previous chapters.

It is evident in the Colombian case that the platform developed here has provided the basis for examining various policies which might be difficult to reconcile, making use of analogies from elsewhere upon how various sub-modules may operate (e.g. power pool, consumer choice). This platform has also provided a context-rich basis for investigating a number of different policy issues. Although a similar framework has been undertaken in the US, the open literature gives limited information with respect to the modelling protocol that needs to be followed.

The modelling approach made use of experiences from elsewhere. For example, by incorporating as "archetypes" re-customised versions of the SD-type models that have been developed to understand the UK system (Bunn et al; 1993, 1995), it has thereby been possible to investigate whether similar behavioural properties were exhibited in Colombia. Similarly, insights from consumer choice models (Buehring et al., 1991) were assimilated and assessed in this context.

Thus, as a context-testing framework, the platform construction process has evolved through adaptation to changing circumstances, including new components to address a variety of complementary and dynamic issues. Furthermore, transferability of the platform between different groups of modellers, which requires a modular and transparent structure, capable of operating successfully. End users were also trained to use their "own" platform in order to develop it further as new policy issues emerge.

The methodology "free riders"

SD itself provides the platform construct automatically with some features required to yield the desirable methodological outcomes for energy analysis, including:

- Non-linearities
- Non-mechanistic (behaviouralist features)
- Non-stationarity
- Systemic (feed-back)
- Simulation.

Methodological alternatives and the future

Other methodologies considered have shown capabilities inferior to the platform developed here. This has been discussed in an earlier chapter and has been extensively demonstrated throughout this research. A number of features have been implemented in the platform, but much more is still open for investigation, especially with respect to the implementation and follow-up stages of the policy process.

With respect to the platform, many questions have been answered, including.:

- Why use a platform to support the methodology?
- What are the requirements of the platform?
- How was the process validated?
- Why did the English case need redesign?
- Why did the Colombian case need its own specific construction?
- How did the platform-building process evolve?
- What were the alternatives?
- What problems were addressed?
- Which capabilities were implemented overall?
- Which ones still need to be addressed?

7.4 CONTRIBUTION TO POLICY AND STRATEGY EVALUATION

The methodology design in this research has the specific aim of supporting energy analysis for policy or strategy implementation. This has provided insights into the issues in contention and assistance to the evaluation of alternative courses of action.

With respect to the strategy question, diverse schemes available to large players were examined to assess the possibility of further profits. The potential for manoeuvring was created by the separation of regulation for the electricity and gas industries in Britain.

The benefits arising from vertical integration have also been established here. Indeed, it has been shown that IPPs may counteract such possible strategic actions of major players by sharing profits with regional distributors. This, however, is not exclusive to IPPs as major producers may also take advantage of this possibility through the acquisition of RECs or by way of strategic alliances.

However, a number of questions are still open. Firstly, issues related to sustainable or evolutionary strategies leave immense scope for research. Secondly, regulatory matters to counteract a specific set of possible manoeuvring actions are far from being resolved. And thirdly, the enquiry into structural industry modifications, to assess likely outcomes, is very much unresolved.

With respect to policy and planning matters, this thesis examines a number of DSM and SSM issues for a system moving towards a competitive set-up. The approach here included the following steps: a) an assessment of the match between energy use patterns and the related government policy blue papers, b) a taxonomy of policy intent for the near future, c) an evaluation of the corresponding goals and direction, d) a proposal for policy modifications, and e) an appraisal of policy impact.

In both cases much insight was gained and, arguably, counterintuitive results were encountered. In these cases the aid provided by the platform has been proven. In both situations it is shown how to improve policy or strategy via simulations.

Furthermore, evolutionary policies and strategies have been examined by way of applications. Here, however, the term evolutionary includes aspects of the dynamics, but it does not incorporate features related to mutations, as in the case of Genetic Algorithms. Modelling and analysing dynamic strategies and policies has provided additional insights into specific issues being analysed in both the British and Colombian contexts.

For the British case

The particular platform, developed in this thesis for the British case, shows that it facilitates strategy formulation in a rather different way from other tools utilised by main stream strategy analysts, which typically make use of well-known statistical methods (namely, regression analysis), or game theoretical approaches. Here the construct is modular, dynamic and flexible. Modularity for strategy formulation is a feature very much imbedded within the methodology explained here. Hence, strategy effects can be either isolated or examined within the system context. This helped with clarifying synergies and non-linearities.

The dynamic characteristic contains a variety of attributes. It tends to reflect the activity that takes place within the system, as captured by delay and feedback mechanisms. Strategies operate as they would do when implemented in the real system, by way of making adjustments to what is originally proposed, according to the system reaction. Furthermore, dynamic strategy rules as discussed in Section 4.4.3 may be examined within this analysis framework. Here, strategies are a set of possible actions prepared to accomplish certain ends but adaptable to particular environmental circumstances in a learning-like mode. Therefore, they are implemented as a learning process activity, as they should be. Indeed, the whole process is geared towards learning.

The flexibility feature provides the opportunity to experiment with a whole range of diverse strategies, not only by changing parameters within an established range but, more importantly, by examining possible classes of alternatives.

Specific theoretical concerns had motivated the investigation in the British case. These were related to whether a major actor in both electricity and gas markets may benefit from strategic behaviour at the expense of consumers; to whether major players benefit from manipulating markets by way of inducing price volatility in order to force large customers (i.e. RECs) to make agreements at higher premium values; and to whether IPPs could attain benefits from close relationships between independent energy producers and RECs (increasing market shares). In all these situations, the platform supported the analysis and queries were largely resolved.

For the Colombian case

The platform has also proved useful for evaluating major impacts of the natural gas plan on the electricity expansion plan and on DSM policies, and also for assessing the impact of the expansion plan of the electricity grid into rural areas. It was also possible to examine specific programmes on efficient lighting and cooking.

DSM programmes proved plausible in the medium-term for energy sustainability in the Colombian residential sector. Specifically, simulations of the large scale gas plan, along with gradual electricity price increments and some financial incentives for energy efficient appliances, showed important benefits. Further research will encourage the exploration of "sensible" policies, especially in the industrial and public sectors.

Specifically, investigation was conducted to establish whether the Colombian policy towards energy management is consistent with the economic premises established in the 1994 Colombian Electricity Law (The Colombian Parliament, 1994a) and, by and large, with most of the Government's objectives and goals. Overall, it shows itself to be sound on DSM matters - although sometimes conservative (CONPES, 1995). On a few occasions, however, policies seem slightly over-optimistic, especially with respect to source substitution (large scale gas plan) and the lighting plan (efficient light bulbs). Nonetheless, success or failure will depend on implementation matters as much as on complementary educational programmes.

In this sense pricing policies raised queries related to undesirable outcomes. For example with respect to: What would be the effect on final consumers? What can final users do to protect income? What pricing alternatives may be considered? What will be the effect on DSM policies? What consequences will this have on conservation or substitution programmes? What will happen to non-technical losses? What will be the effect on inflation?

Simulations showed that if electricity prices maintain an increasing trend, and some financial aid is made available to customers, there is very little doubt that end-users should move towards source substitution and DSM programmes. However the intensity of the price-hike formula was questioned in this thesis.

The Colombian DSM policies, programmes and projects have also been shown to be insensitive to a wide range of adverse circumstances, as has been shown in Section 6.3.3. These policies have also been shown to be robust under a broad set of unlikely scenarios.

Figure 6.22 (Case 6 scenario - Section 6.2.6) shows how electricity consumption in the residential sector will remain almost unchanged for over 15 years under these plausible energy policies, while other sectors will continue growing at important rates - especially the industrial sector. In this sense DSM policies are encouraging.

Furthermore, energy policy still needs to prove itself capable of overcoming some of the major system weaknesses in the area of pricing and supply reliability. Firstly, the transition to real cost pricing, maintaining cross subsidies to the poorest groups in the community, is by no means a trivial exercise when the system as a whole is moving towards a more liberalised set-up. Secondly, the pool pricing mechanism needs to prove that it is delivering the appropriate signals to capacity-building in the power sector.

Additionally, plan, programme and project implementation are still found at a rudimentary stage of development. The execution question therefore raises some serious doubts. No precise actions are known and financial aspects are unclear. No matter how well the design stages have been worked through, policies will fail if implementation is not carefully conducted.

Finally, it has been shown in this thesis that the Colombian energy policy exhibits both strong and weak features. Although it aims in the right direction, it has some room for improvements in design, and appears weak as it approaches the implementation stages.

7.5 FURTHER RESEARCH AND CONCLUDING REMARKS

This chapter has summarised some of the contributions to knowledge in the area of policy and strategy support made in this thesis and has indicated some further research avenues. In this section, these and other areas of research are considered.

The evolving circumstances of the energy field, from integrated planning to market liberalisation, initially motivated the platform-based methodology proposed in this thesis. Notwithstanding, as a number of issues remain unresolved and further developments begin to unfold, further requirements are now emerging, i.e.:

- ◊ As regulatory and competitive behaviour requires greater consideration, there is a need for incorporating strategic gaming and machine learning approaches.
- ◊ As endogenous choices with a wide range of alternatives are incorporated, which are subject to multiple constraints, "optimising" or "satisfying" rules need to be implemented.
- ◊ As environmental issues maintain social and media forefront attention, there is a need to enhance policy support capabilities.
- ◊ As uncertainties with respect to prices and climate changes have an effect on technology use, there may be a need to incorporate stochastic features.
- ◊ And, as energy industries become more interrelated, given that fuel substitution has been made possible in many areas and that markets are much more integrated, more components need to be incorporated.

These issues, however, far from being unproblematic, are posing challenging research questions with respect to: a) software capability, b) hardware limitations for speedy responses, c) loss of transparency and modelling seamlessness, and d) failure to provide policy and strategy insight. Hence, research opportunities are still plentiful with respect to methodology, platform and policy/strategy extensions.

Methodology

In the methodology field, the platform construct should be able to support the implementation and follow-up stages. Consequently, new additions will certainly be required to this approach. Furthermore, transportability to a completely novel environment, i.e. to extend this experiment to a third country with a different balance of market and planning aspirations, remains the challenge to produce generalisable evidence.

Platform

With respect to the platform evolution itself, there is scope to conduct research in the areas of:

- Policy and strategic issues intending to target specific regional problems and to address other sectors and industries, yet maintaining seamlessness characteristics.
- Vertical integration or diversification strategies, still within the framework of a modular structure, which should be capable of providing insights to analysts.
- Changes in the electricity pool to explore and concept-test incentive structures and feed-back mechanisms.
- Cross-subsidies between socio-economic groups with focus on specific groups and also intending to examine policy appropriateness.
- Environmental issues along the vertical chain pose questions of relevance, size and practicality.

- Policies targeting the transmission network, i.e. addressing technical and non technical losses along the vertical chain, raises concerns with respect to software and hardware capability.

For these purposes the platform will be required to incorporate:

- The corresponding sectors and industries
- The corresponding modules
- Genetic Algorithms and/or Neural Network modules
- Disaggregation of variables
- Software interfaces or new frameworks.

Also related to the platform, more theoretical work may enable the platform to assist in the areas of:

- Incorporation of techniques (i.e. optimisation, stochastic processes, expert systems and neural networks).
- Theoretical economic enquiries (i.e. barriers of entry, consumer choice, and technology propagation).
- Evolutionary strategies and policies (i.e. including, not only time dependency, but also mutations and learning).
- Learning curve issues for technology penetration (i.e. DSM programmes or companies' strategy).

Strategies and policies

On the policy and strategy side, a large number of DSM and Supply-Side Management issues remain open to further research, not only with respect to enquiries in the specific field of evolutionary policy and strategic issues, as mentioned above, but also in the area of:

- Uncertainty with respect to prices, climate conditions and regulation, and
- Robustness considering uncertainty.

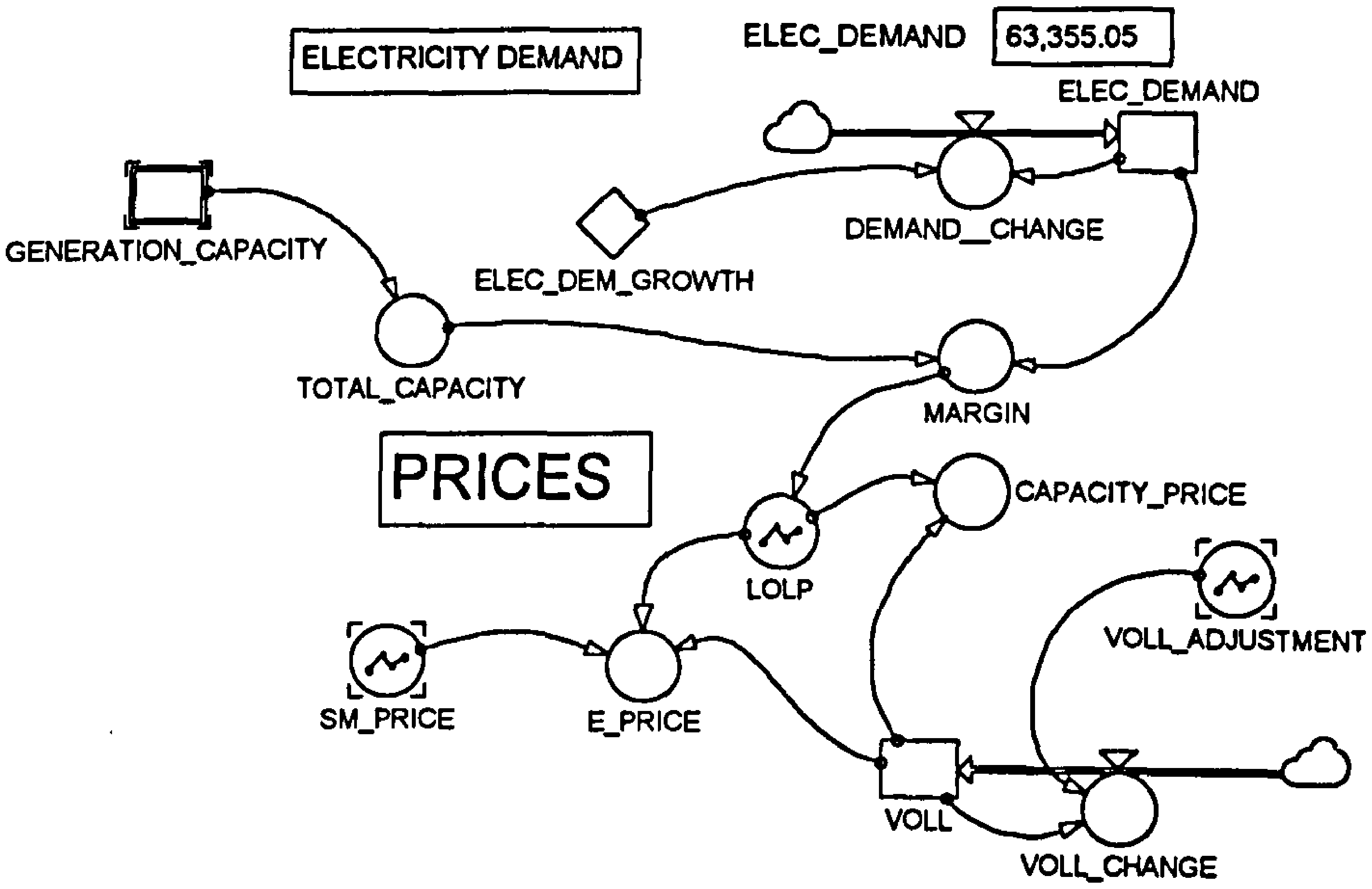
The main contribution of this thesis is to methodology and modelling. Rather than aiming to produce purely theoretical guidelines, this research uses an applied framework to concept- and construct-test policies and strategies for the Colombian and British energy cases. These cases have also helped assessing in practice the proposed methodology and modelling approach. However, despite the applied framework, problems are not anticipated with generalising the findings. With this thesis, the hope is that a substantial start for a new approach has been made.

A1 APPENDIX I
AN SD PLATFORM FOR THE UK

A.1.1 DEFINITION OF VARIABLES

ELECTRICITY DEMAND AND PRICE

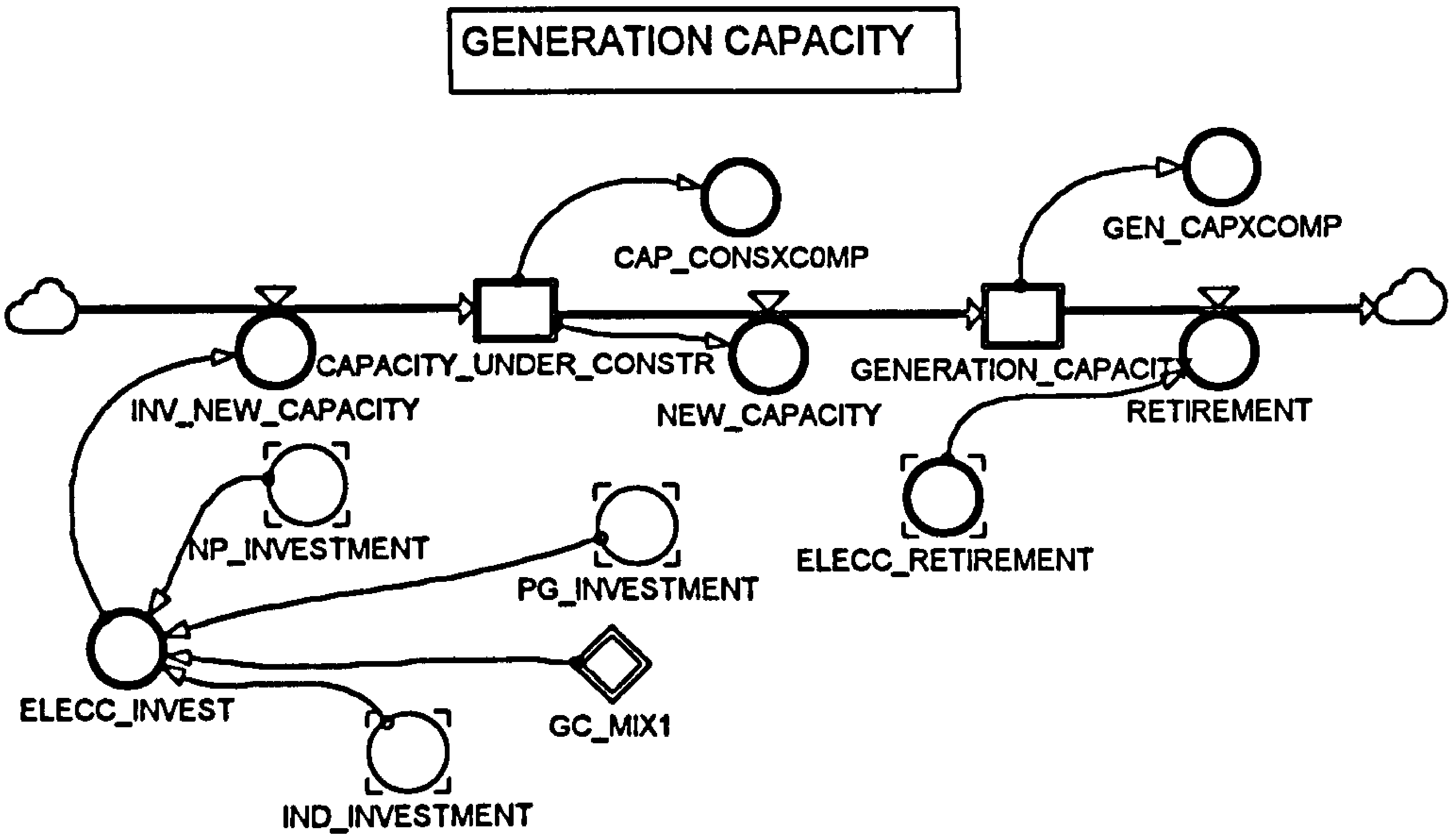
ELEC_DEMAND: Total electricity demand.
DEMAND_CHANGE: Electricity demand increment.
ELEC_DEM_GROWTH: Electricity demand growth rate.
GENERATION_CAPACITY: Generation capacity according to technology (Nuclear, Gas, Coal).
TOTAL CAPACITY: Total generation capacity in GW
MARGIN: System margin (total capacity - demand).
LOLP: Lost of loss probability
VOLL: Volume of loss of load
VOLL_CANGE: Change in VOLL
VOLL _ADJUSTMENT: Adjustment made to VOLL.
CAPACITY_PRICE: Capacity element paid in the electricity pool.
SM_PRICE: System marginal price element paid in the electricity pool.
E_PRICE: Total electricity price.



ELECTRICITY GENERATION CAPACITY

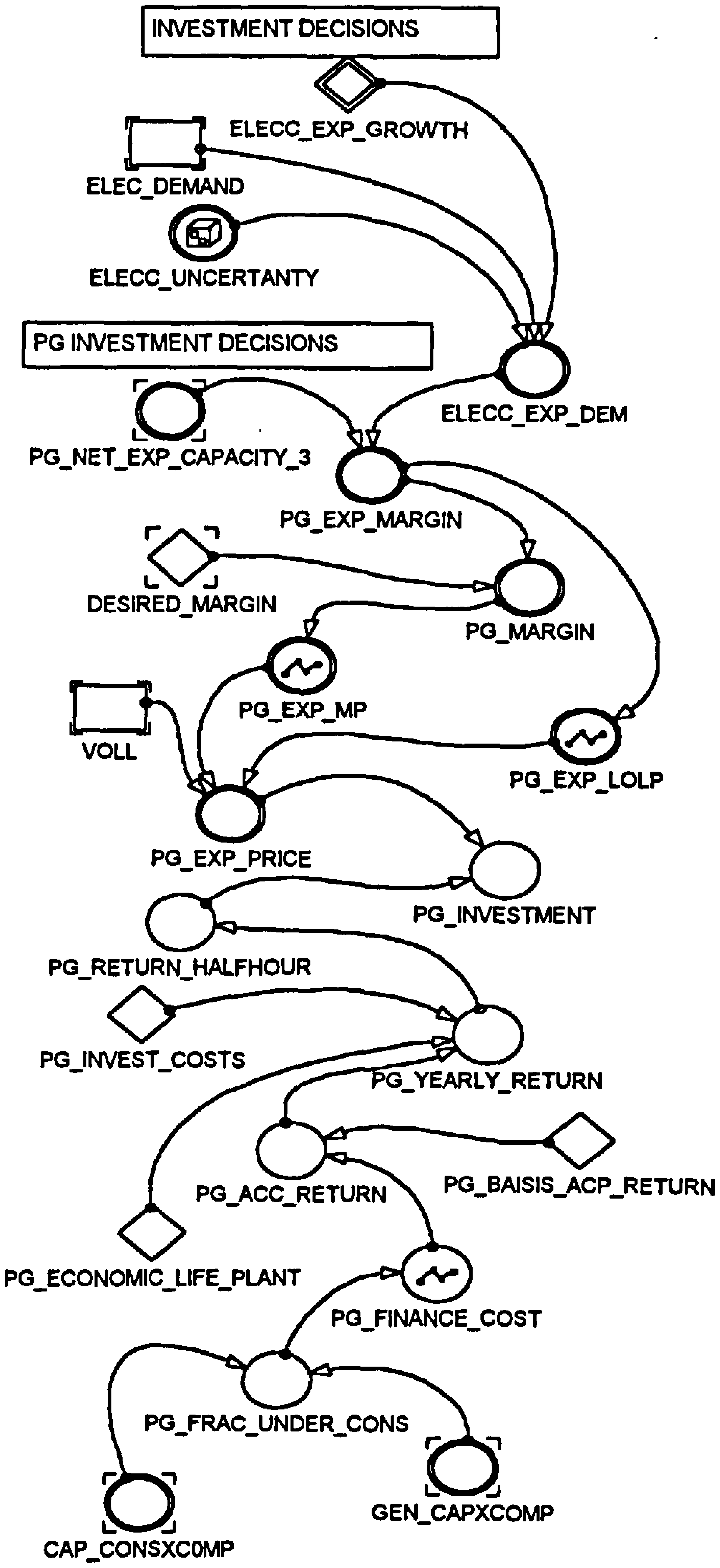
GENERATION_CAPACITY: Generation capacity according to technology (Nuclear, Gas, Coal).
CAPACITY_UNDER_CONSTR: Capacity under construction according to technology (Nuclear, Gas, Coal).
CAP_CONSXCOMP: Total capacity under construction according to ownership.
GEN_CAPXCOMP: Total generation capacity according to ownership.
RETIREMENT: Retirement capacity.
ELECC_RETIREMENT: Retirement capacity plan.
NEW_CAPACITY: New capacity in line for operation.
INV_NEW_CAPACITY: Total investment in new capacity according to technology (Nuclear, Gas, Coal).

NP_INVEST: NP investment in new capacity.
PG_INVEST: PG investment in new capacity.
IND_INVEST: Independents investment in new capacity.
GC_MIX1: Gas-coal mixed in new capacity.



COMPANY INVESTMENT DECISIONS

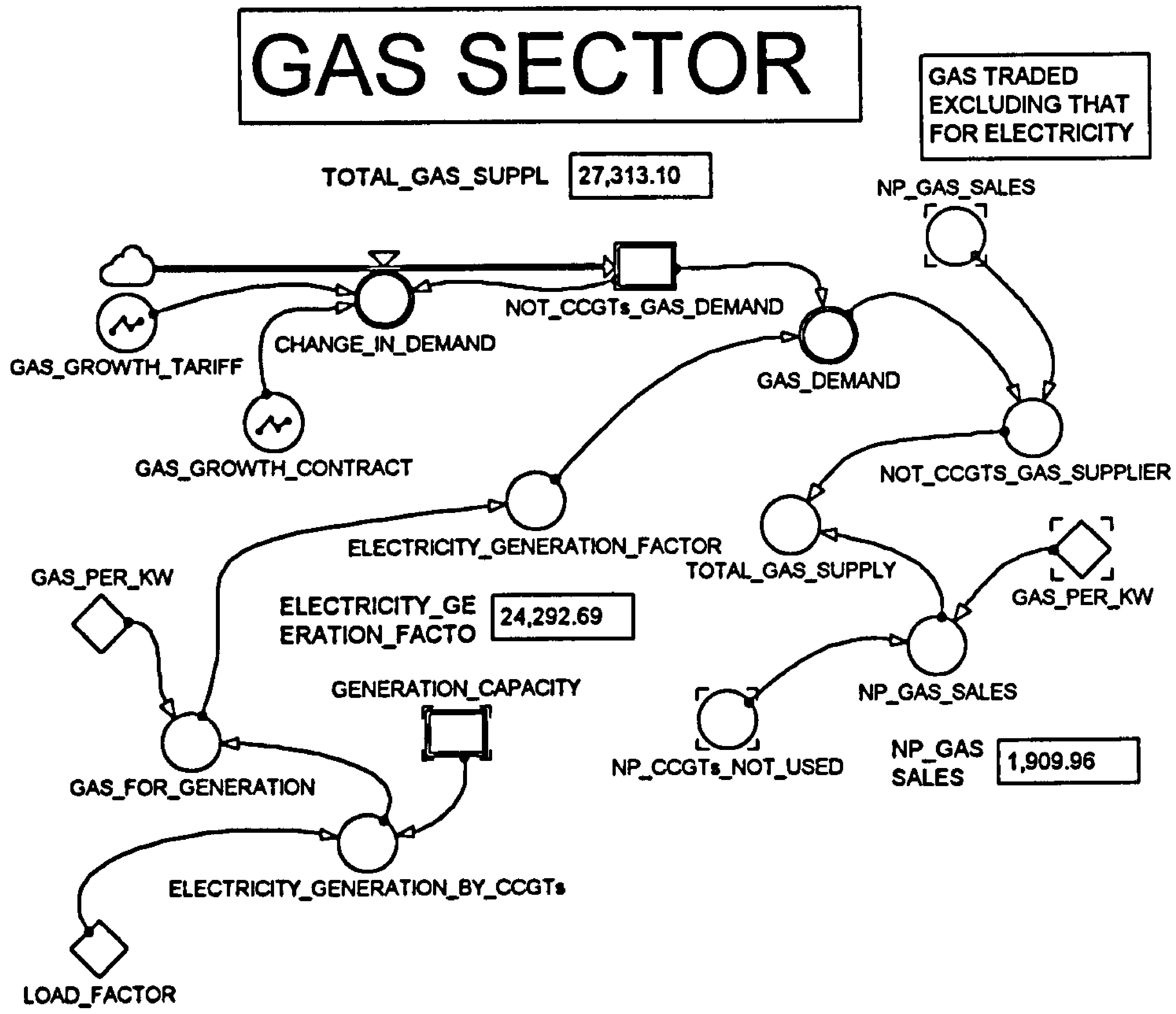
ELECC_EXP_GROWTH: Expected electricity demand growth (NP, PG, IND).
ELECC_UNCERTAINTY: Uncertainties in electricity demand (NP, PG, IND).
ELECC_EXP_DEM: Expected electricity demand (NP, PG, IND).
PG_NET_EXP_CAP_3: PG's expected capacity three years ahead.
PG_EXP_MARGIN: PG's expected system margin.
DESIRED_MARGIN: PG's desired system margin.
PG_MARGIN: PG's system margin.
PG_EXP_MP: PG's expected marginal price.
PG_EXP_LOLP: PG's expected LOLP.
PG_EXP_PRICE: PG's expected price.
PG_RETURN_HALFHOUR: PG's return on investment for average halfhourly prices.
PG_INVEST_COSTS: Investment costs for PG.
PG_ACC_RETURN: PG's acceptable returns on investment.
PG_BASIS_ACP_RETUR: PG's basis for acceptable returns.
PG_ECONOMIC_LIFE_PLANT: PG's economic life plant.
PG_FINANACE_COST: PG's finance costs.
PG_FRAC_UNDER_CONS: PG's capacity under construction.



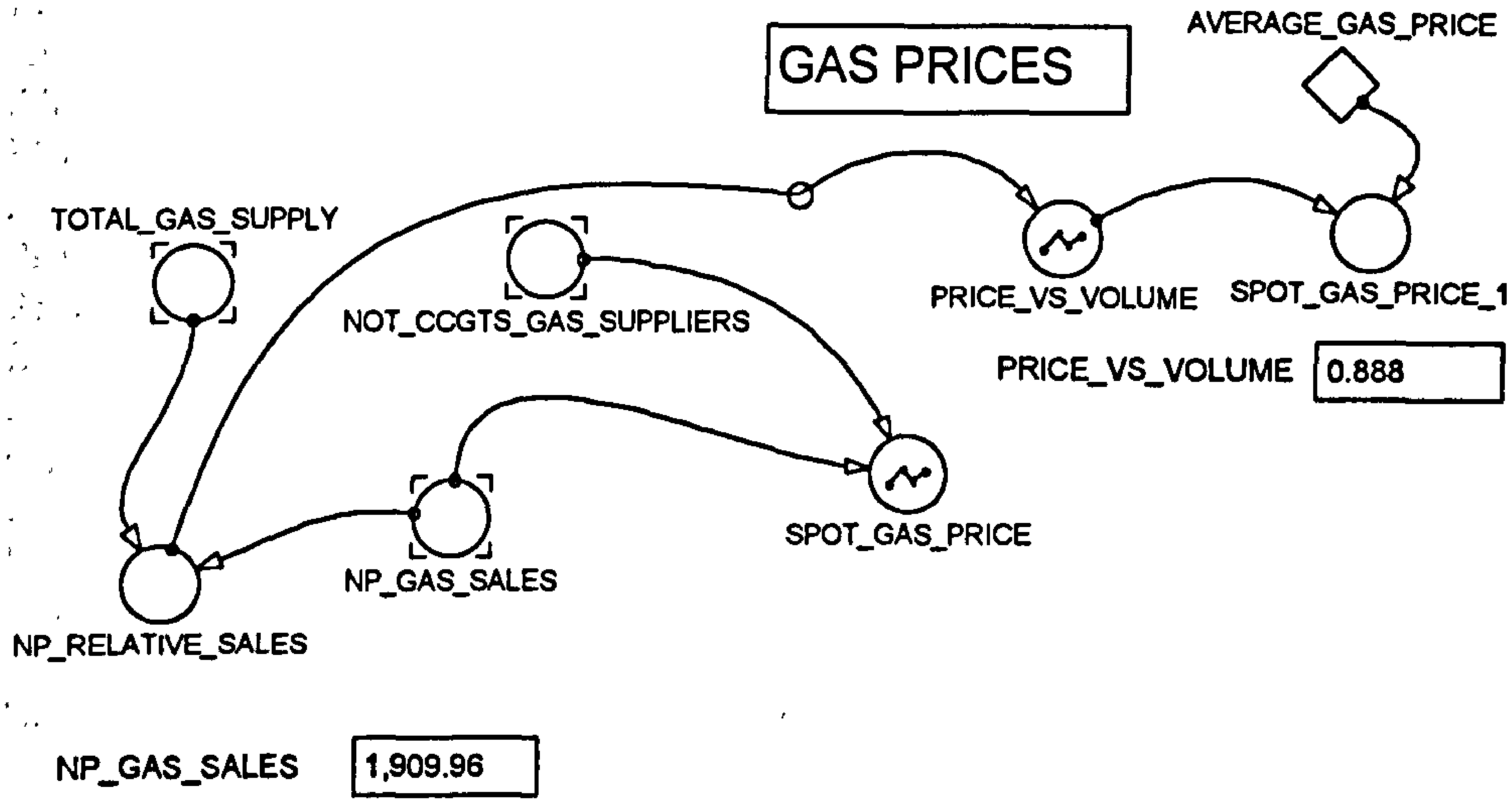
GAS SECTOR

NON_CCGTs _GAS_DEMAND: Gas demand excluding that one for electricity generation using CCGTs.
CHANGE_IN_DEMAND: Change increment in the demand for gas.
GAS_GROWTH_CONTRACT: Gas growth in the contact market.
GAS_GROWTH_TARIFF: Gas growth in the tariff market.
GAS_DEMAND: Total gas demand.
NP_GAS_SALES: NP's gas sales.
ELECTRICITY_GENERATION_FACTOR: Gas used for electricity generation.
NOT-CCGTS_GAS_SUPPLIERS: Total gas supplied except for CCGTs.

TOTAL_GAS_SUPPLY: Total gas supplied.
GAS_PER_KW: Gas required to generate 1 kW of electricity during one year.
NP_GAS_SALES: NP's gas sales.
NP_CCGTs_NOT_USED: Fraction of NP's CCGTs capacity not being used.
GAS_FOR_GENERATION: Total amount of gas used for electricity generation.
ELECTRICITY_GENERATION_BY_CCGTs: Electricity generation using CCGTs' capacity.
LOAD_FACTOR: Average load plant factor.

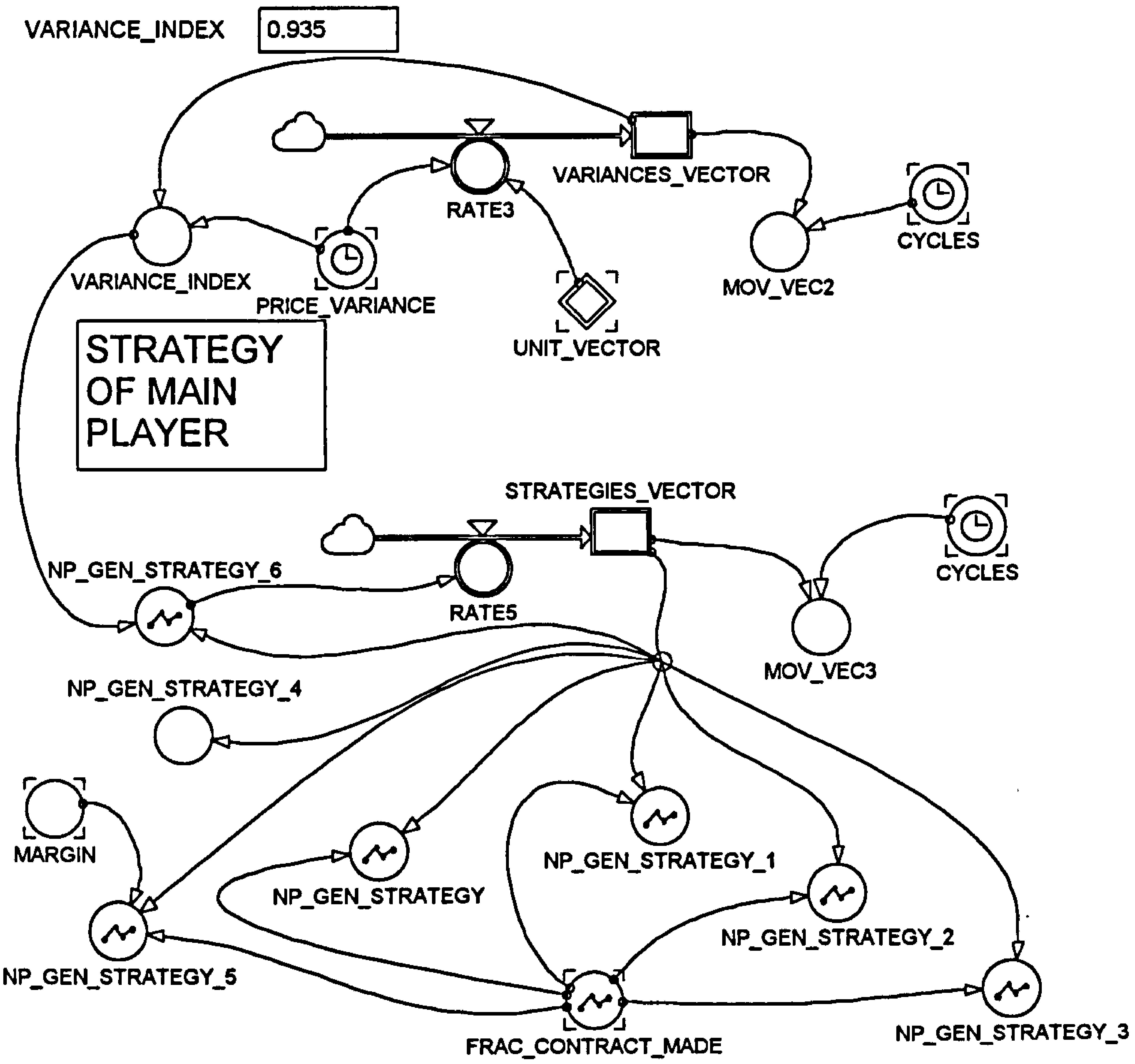


GAS PRICE



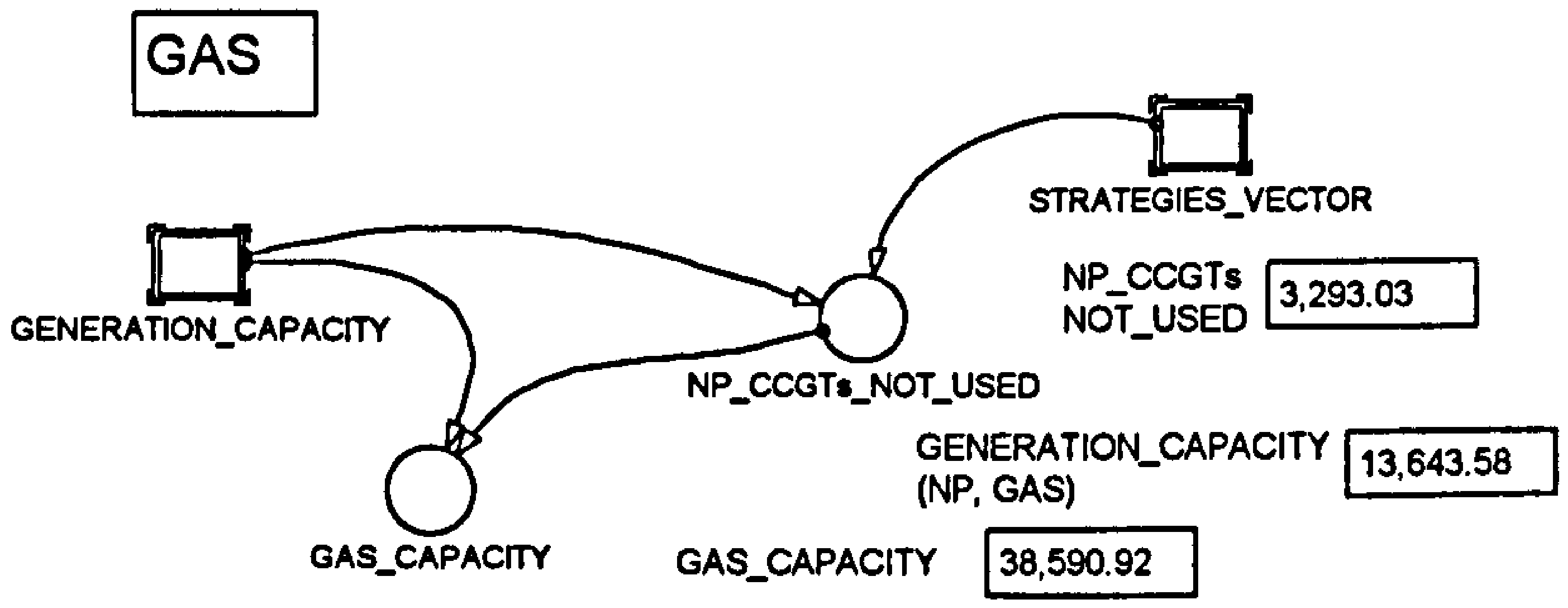
STRATEGY OF MAIN PLAYER

VARIENCES_VECTOR: Vector containing price variances for the last 10 periods.
RATE3: Latest price variance.
PRICE_VARIANCE: Latest price variance.
UNIT_VECTOR: Vector (1,0,0,0,0,0,0,0,0,0)
MOV_VEC2: POWERSIM's way to retain the 10 latest values of a variable in a vector.
CYCLES: Complement of previous variable.
VARIANCE_INDEX: Variance index (latest variance with respect to the average of the previous six months).
NP_GEN_STRAT_1: NP's strategy (making unavailable a percentage of its CCGs generation capacity).
STRATEGIES_VECTOR: Strategy vector containing latest NP's strategies.
RATE_5: Latest NP's strategy.



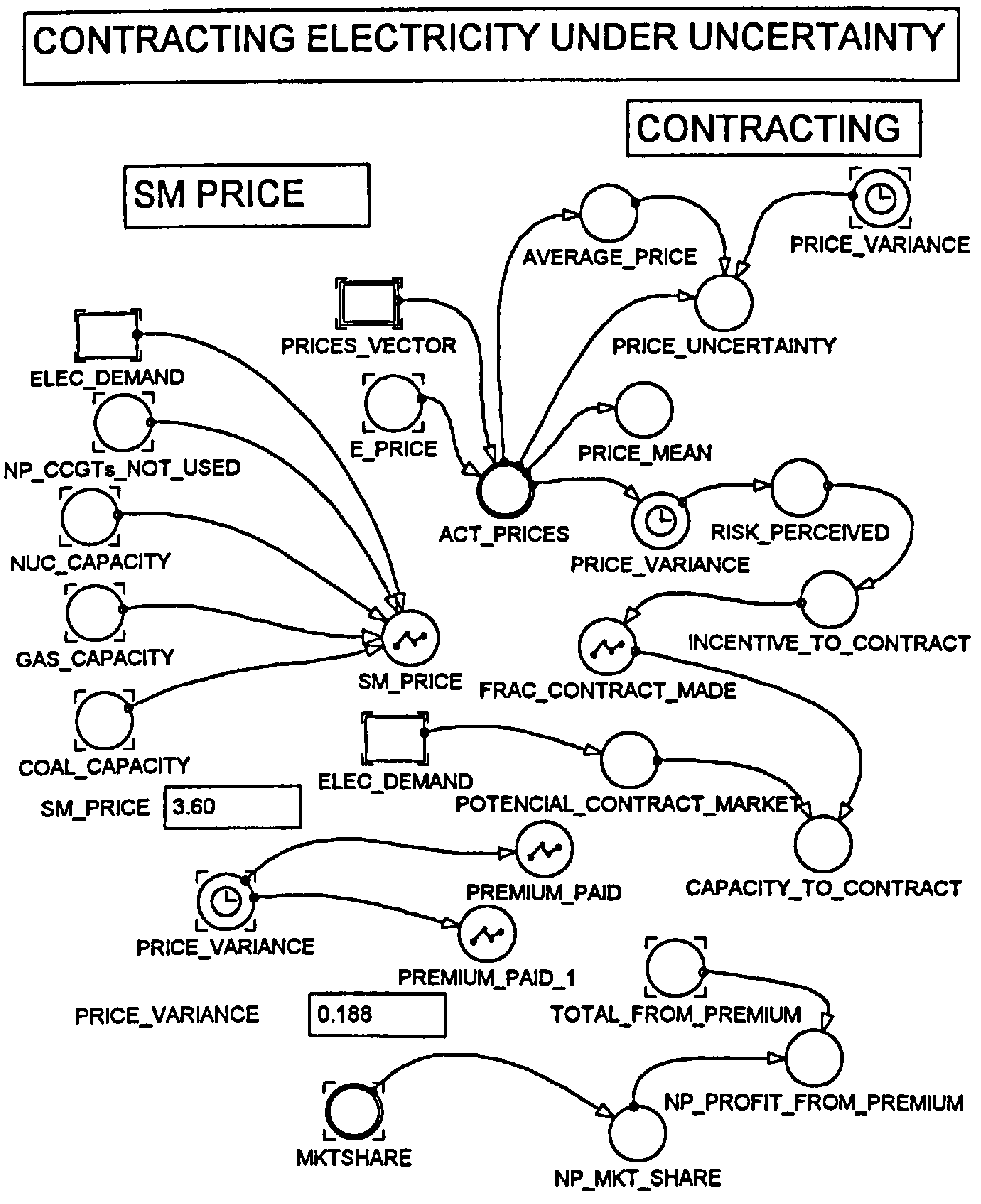
STRATEGY IMPLEMENTATION

NP_CCGTs_NOT_USED: Portion of NP's CCGTs capacity which is not made available for generation.
GAS_CAPACITY: Total system's gas capacity made available for generation.



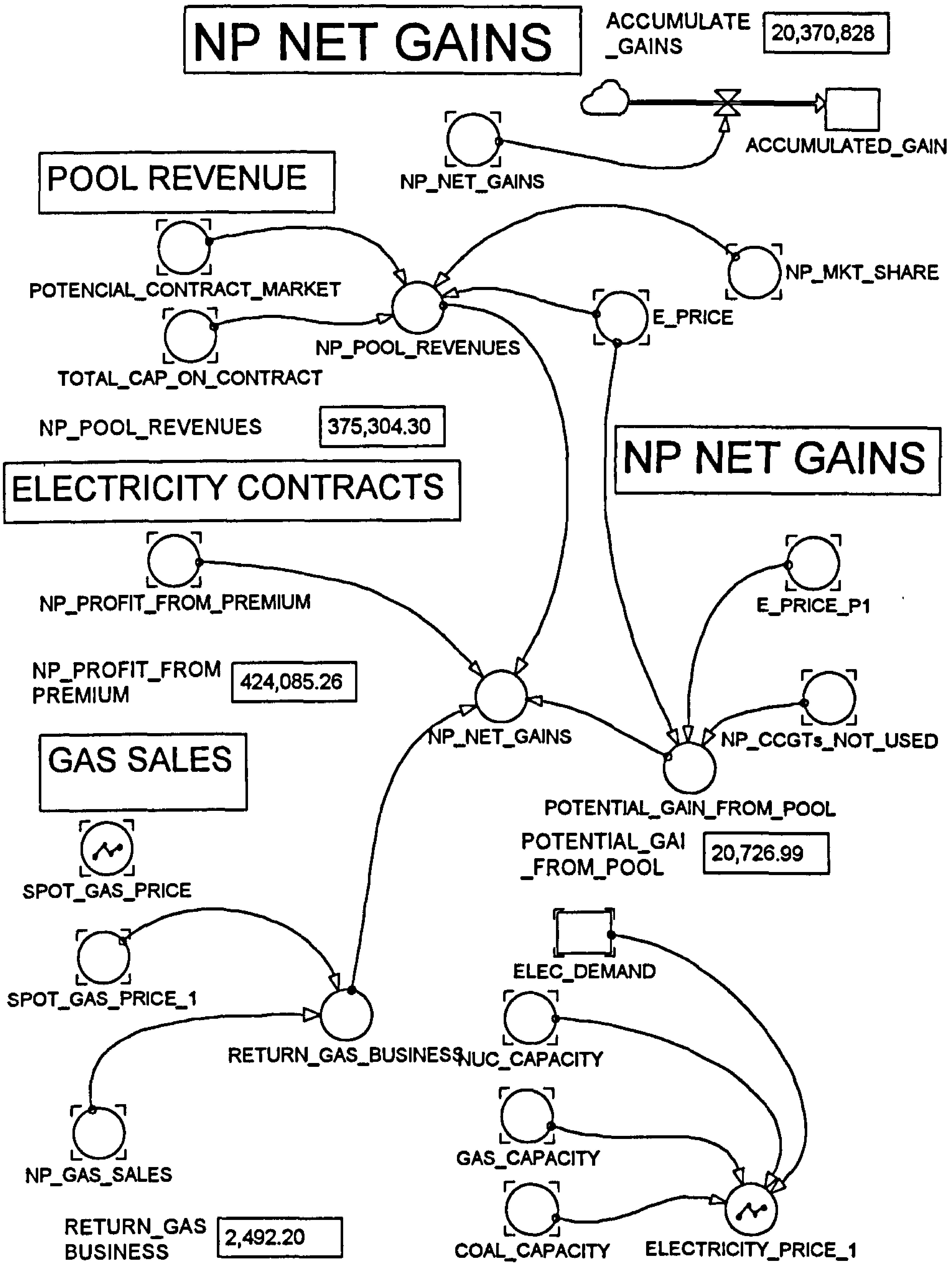
SM PRICING AND CONTRACTING

NUC_CAPACITY: Total nuclear capacity.
GAS_CAPACITY: Total nuclear capacity.
COAL_CAPACITY: Total nuclear capacity.
PRICES VECTOR: Vector containing latest electricity prices
ACT_PRICES: Actualisation of latest electricity prices.
AVERAGE_PRICE: Average electricity price.
PRICE_UNCERTAINTY: Price uncertainty (variance)
PRICE_VARIANCE: Price variance.
PRICE_MEAN: Same as average price.
RISK_PERCEIVED: Same as uncertainty (computed after certain instance)
INCENTIVE_TO_CONTRACT: Incentive to contract.
FRAC_CONTRACT_MADE: Fraction of contracts with respect to the potential contract market.
POTENTIAL_CONTRACT_MARKET: Potential contract market.
CAPACITY_TO_CONTRACT: Total generation capacity to contract.
PREMIUM_PAID: Premium paid on top of contracts.
MKTSHARE: Market-share of different companies.
NP_MKT_SHARE: NP's market-share.
NP_PROFIT_FROM_PREMIUM: NP's profit from premium.
TOTAL_FROM_PREMIUM: Total premium paid.



NP's NET GAINS

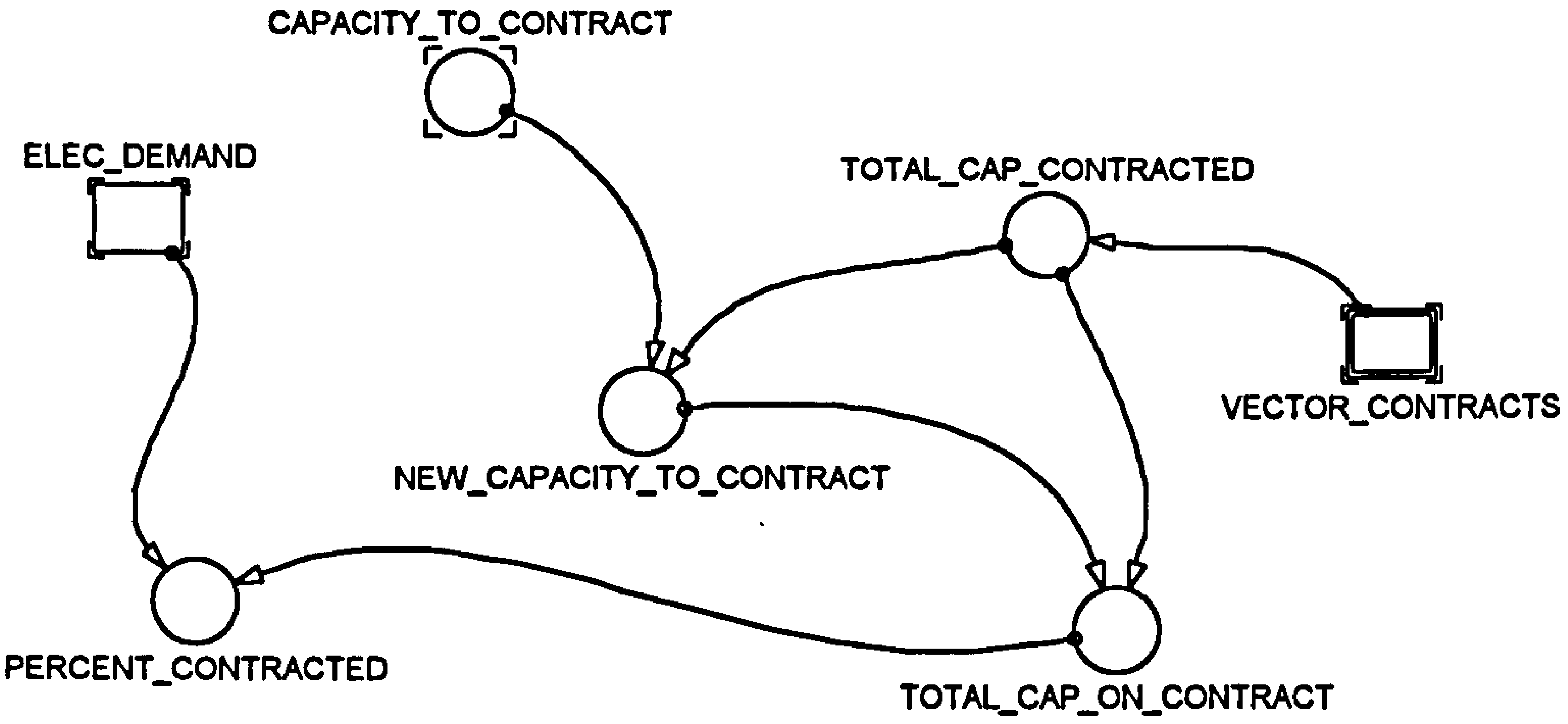
NP_NET_GAINS: NP's net gains
ACCUMULATED_NET_GAINS: NP's accumulated net gains.
NP_MKT_SHARE: NP's market-share.
POTENTIAL_CONTRACT_MKT: Potential contract market.
TOTAL_CAP_ON_CONTRACT: Total capacity being contracted.
NP_POOL_REVENUES: NP's pool revenues.
POTENTIAL_GAIN_FROM_POOL: Potential pool price.
ELECTRICITY_PRICE_1: Electricity pool price when some some CCGTs capacity is not made available.
E_PRICE_P1: Electricity price when some CCGTs capacity is not made available (discounting availability).
NP_NET_GAINS: NP's net gains.
SPOT_GAS_PRICE: Spot gas price.
NP_GAS_SALES: NP's gas sales.
RETURN_GAS_BUSINESS: NP's revenues from the gas business.



MEDIUM-TERM CONTRACTS

VECTOR_CONTRACTS: Vector containing the capacity contracted during the last 10 time periods.
CAPACITY_TO_CONTRACT: Total capacity wanting to contract
TOTAL_CAP_CONTRACTED: Total capacity contracted already contracted.
NEW_CAPACITY_TO_CONTRACT: New capacity to be contracted.
TOTAL_CAP_ON_CONTRACT: Total capacity on contracts.
ELEC_DEMAND: Total electricity demand.
PERCENT_CONTRACTED: Capacity contracted as a percentage of the total demand.

Medium-term contracts in the electricity market



A.1.2 THE UK PLATFORM

```
init    ACCUMULATED_GAINS = 0
flow    ACCUMULATED_GAINS = +dt*NP_NET_GAINS
dim     CAPACITY_UNDER_CONSTR = (GEN_COMPANY,SOURCE)
init    CAPACITY_UNDER_CONSTR = [[2342,0,0],[4648,0,0],[9139,0,0],[0,0,1254]]
flow    CAPACITY_UNDER_CONSTR = +dt*INV_NEW_CAPACITY
        -dt*NEW_CAPACITY
doc     CAPACITY_UNDER_CONSTR = [[2342,0,0],[4648,0,0],[9139,0,0],[0,0,1254]]/3
init    ELEC_DEMAND = 49200   {MW Demanded per year}
flow    ELEC_DEMAND = +dt*DEMAND__CHANGE
dim     GENERATION_CAPACITY = (GEN_COMPANY,SOURCE)
init    GENERATION_CAPACITY = [[0,18794,0],[0,26991,0],[2104,0,0],[0,0,9480]]      {MW}
flow    GENERATION_CAPACITY = +dt*NEW_CAPACITY
        -dt*RETIREMENT
dim     NOT_CCGTs_GAS_DEMAND = (i=1..2)
init    NOT_CCGTs_GAS_DEMAND = [13710,6973]     {MILLIONS OF THERMS}
flow    NOT_CCGTs_GAS_DEMAND = +dt*CHANGE_IN_DEMAND
dim     NP_GAINS_VECTOR = (i=1..5)
init    NP_GAINS_VECTOR = [1260000,1260000,1260000,1260000,1260000]
flow    NP_GAINS_VECTOR = +dt*RATE1_1
dim     NP_POTENTIAL_VECT = (i=1..5)
init    NP_POTENTIAL_VECT = [12600000,12600000,12600000,12600000,12600000]
flow    NP_POTENTIAL_VECT = +dt*RATE1_2
dim     PRICES_VECTOR = (i=1..10)
init    PRICES_VECTOR = [0,5.8,5.6,5.8,5.8,5.8,6,6,6.2,6.2]
flow    PRICES_VECTOR = +dt*RATE1
dim     STRATEGIES_VECTOR = (i=1..10)
init    STRATEGIES_VECTOR = [0,0,0,0,0,0,0,0,0,0]
flow    STRATEGIES_VECTOR = +dt*RATE5
init    TOTAL_MARGIN = 0
flow    TOTAL_MARGIN = +dt*ADD_MARGIN
dim     VARIANCES_VECTOR = (i=1..10)
init    VARIANCES_VECTOR = [0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1]
flow    VARIANCES_VECTOR = +dt*RATE3
dim     VECTOR_CONTRACTS = (i=1..10)
init    VECTOR_CONTRACTS = [0,0,0,0,0,0,0,0,0,0]
flow    VECTOR_CONTRACTS = +dt*R_1
dim     VECTOR_PREMIA = (i=1..10)
init    VECTOR_PREMIA = [0,0,0,0,0,0,0,0,0,0]
flow    VECTOR_PREMIA = +dt*R_2
dim     VECTOR_Z_REVENUES = (i=1..10)
```

```
init     VECTOR_Z_REVENUES = [0,0,0,0,0,0,0,0,0,0]
flow     VECTOR_Z_REVENUES = +dt*R_3
init     VOLL = 1
flow     VOLL = +dt*VOLL_CHANGE
aux      ADD_MARGIN = IF(TIME<2000,0,MARGIN)
dim      CHANGE_IN_DEMAND = (i=1..2)
aux      CHANGE_IN_DEMAND =
NOT_CCGTs_GAS_DEMAND(1)*GAS_GROWTH_TARIFF*[1,0]+NOT_CCGTs_GAS_DEMAND(2)*GAS_GROWTH_CONT
RACT*[0,1]
aux      DEMAND__CHANGE = ELEC_DEMAND*ELEC_DEM_GROWTH   {MW/year}
dim      INV_NEW_CAPACITY = (GEN_COMPANY,SOURCE)
aux      INV_NEW_CAPACITY = ELECC_INVEST
dim      NEW_CAPACITY = (GEN_COMPANY,SOURCE)
aux      NEW_CAPACITY = CAPACITY_UNDER_CONSTR/3
aux      NP_NET_GAINS = NP_POOL_REVENUES+NP_PROFIT_FROM_PREMIUM+RETURN_GAS_BUSINESS-
POTENTIAL_GAIN_FROM_POOL
dim      R_1 = (i=1..10)
aux      R_1 = NEW_CAPACITY_TO_CONTRACT*UNIT_VECTOR_1/TIMESTEP
dim      R_2 = (i=1..10)
aux      R_2 = (E_PRICE_P*(1+PREMIUM_PAIED)*UNIT_VECTOR_1)/TIMESTEP
dim      R_3 = (i=1..10)
aux      R_3 = Z_REVENUES*UNIT_VECTOR_2/TIMESTEP
dim      RATE1 = (i=1..10)
aux      RATE1 = E_PRICE_P*UNIT_VECTOR/TIMESTEP
dim      RATE1_1 = (i=1..5)
aux      RATE1_1 = NP_NET_GAINS*UNIT_1_VECTOR/TIMESTEP
dim      RATE1_2 = (i=1..5)
aux      RATE1_2 = POTENTIAL_GAIN_FROM_POOL*UNIT_1_VECTOR_1/TIMESTEP
dim      RATE3 = (i=1..10)
aux      RATE3 = PRICE_VARIANCE*UNIT_VECTOR/TIMESTEP
dim      RATE5 = (i=1..10)
aux      RATE5 = NP_GEN_STRATEGY_6/TIMESTEP
dim      RETIREMENT = (GEN_COMPANY,SOURCE)
aux      RETIREMENT = ELECC_RETIREMENT
aux      VOLL_CHANGE = (VOLL*VOLL_ADJUSTMENT)-VOLL
dim      ACT_PRICES = (i=1..10)
aux      ACT_PRICES = [1,0,0,0,0,0,0,0,0,0]*E_PRICE_P+PRICES_VECTOR
aux      AVERAGE_MARGIN = TOTAL_MARGIN/(IF(TIME <1991,1,TIME-1990))
aux      AVERAGE_PRICE = ARRAVG(ACT_PRICES)
aux      AVG_PRICE =
(E_PRICE_P+PRICES_VECTOR(2)+PRICES_VECTOR(3)+PRICES_VECTOR(4)+PRICES_VECTOR(5))/5
dim      CAP_CONSXC0MP = (GEN_COMPANY)
aux      CAP_CONSXC0MP =
(ARRSUM(CAPACITY_UNDER_CONSTR(PG,*))*[1,0,0,0]+ARRSUM(CAPACITY_UNDER_CONSTR(NP,*))*[0,1,0,0]+ARRS
UM(CAPACITY_UNDER_CONSTR(IND,*))*[0,0,1,0]+ARRSUM(CAPACITY_UNDER_CONSTR(NUC,*))*[0,0,0,1])
aux      CAPACITY_CHANGE = ARRSUM(CAPACITY_UNDER_CONSTR)-TOTAL_RETIREMENT
aux      CAPACITY_TO_CONTRACT = FRAC_CONTRACT_MADE*POTENCIAL_CONTRACT_MARKET
aux      COAL_CAPACITY = ARRSUM(GENERATION_CAPACITY(*,COAL))
aux      CYCLES = TIMECYCLE(STARTTIME-1,TIMESTEP,1)
aux      CYCLES_1 = TIMECYCLE(STARTTIME-1,TIMESTEP,1)
aux      CYCLES_2 = TIMECYCLE(STARTTIME-1,TIMESTEP,1)
aux      CYCLES_3 = TIMECYCLE(STARTTIME-1,TIMESTEP,1)
aux      CYCLES_4 = TIMECYCLE(STARTTIME-1,TIMESTEP,1)
aux      E_PRICE_D = ELECTRICITY_PRICE-E_PRICE_P
aux      E_PRICE_P = ELECTRICITY_PRICE+(VOLL*100-ELECTRICITY_PRICE)*LOLP_1
aux      E_PRICE_P1 = ELECTRICITY_PRICE_1+(VOLL*100-ELECTRICITY_PRICE_1)*LOLP
dim      ELECC_EXP_DEM = (GEN_COMPANY)
aux      ELECC_EXP_DEM = ELEC_DEMAND*(1+ELECC_EXP_GROWTH+ELECC_UNCERTANTY)   {MW}
dim      ELECC_INVEST = (GEN_COMPANY,SOURCE)
aux      ELECC_INVEST =
PG_INVESTMENT*GC_MIX1(1)*[[1,0,0],[0,0,0],[0,0,0],[0,0,0]]+NP_INVESTMENT*GC_MIX1(1)*[[0,0,0],[1,0,0],[0,0,0],[0,0,0
]]+IND_INVESTMENT*GC_MIX1(1)*[[0,0,0],[0,0,0],[1,0,0],[0,0,0]]+PG_INVESTMENT*GC_MIX1(2)*[[0,1,0],[0,0,0],[0,0,0],[
0,0,0]]+NP_INVESTMENT*GC_MIX1(2)*[[0,0,0],[0,1,0],[0,0,0],[0,0,0]]+IND_INVESTMENT*GC_MIX1(2)*[[0,0,0],[0,0,0],[0,1
,0],[0,0,0]]
dim      ELECC_NET_EXP_CAPACITY = (GEN_COMPANY)
aux      ELECC_NET_EXP_CAPACITY =
[1,0,0,0]*(ELECC_INFORMATION_BIAS(PG)*(CAP_CONSXC0MP(NP)+CAP_CONSXC0MP(IND)-
ELECC_RETIREMENT_IN_3YEARS(NP))+CAP_CONSXC0MP(PG)+TOTAL_CAPACITY-
ELECC_RETIREMENT_IN_3YEARS(PG)-
ELECC_RETIREMENT_IN_3YEARS(NUC))+[0,1,0,0]*(ELECC_INFORMATION_BIAS(NP)*(CAP_CONSXC0MP(PG)+CAP_
CONSXC0MP(IND)-ELECC_RETIREMENT_IN_3YEARS(PG))+CAP_CONSXC0MP(NP)+TOTAL_CAPACITY-
ELECC_RETIREMENT_IN_3YEARS(NP)-
ELECC_RETIREMENT_IN_3YEARS(NUC))+[0,0,1,0]*(ELECC_INFORMATION_BIAS(IND)*(CAP_CONSXC0MP(PG)+CAP
_CONSXC0MP(NP)-ELECC_RETIREMENT_IN_3YEARS(NP)-
ELECC_RETIREMENT_IN_3YEARS(PG))+CAP_CONSXC0MP(IND)+TOTAL_CAPACITY-
ELECC_RETIREMENT_IN_3YEARS(NUC))
```

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dim       ELECC_RETIREMENT = (GEN_COMPANY,SOURCE)
aux       ELECC_RETIREMENT =
[[0,1,0],[0,0,0],[0,0,0],[0,0,0]]*RET_PG+[[0,0,0],[0,1,0],[0,0,0],[0,0,0]]*RET_NP+[[0,0,0],[0,0,0],[1,0,0],[0,0,0]]*RET_INDEP+[[0
,0,0],[0,0,0],[0,0,0],[0,0,1]]*RET_NUC
dim       ELECC_RETIREMENT_IN_3YEARS = (GEN_COMPANY)
aux       ELECC_RETIREMENT_IN_3YEARS =
[1,0,0,0]*ARRSUM(RETIREMENT_YEARS_PG)+[0,1,0,0]*ARRSUM(RETIREMENT_YEARS_NP)+[0,0,1,0]*ARRSUM(RETI
REMENT_YEARS_INDEP)+[0,0,0,1]*ARRSUM(RETIREMENT_YEARS_NUC)
dim       ELECC_UNCERTANTY = (GEN_COMPANY)
aux       ELECC_UNCERTANTY = ((RANDOM(0,1,457217)-0.5)*0.05)*[1,0,0,0]+((RANDOM(0,1,457217)-
0.5)*0.05)*[0,1,0,0]+((RANDOM(0,1,457217)-0.5)*0.05)*[0,0,1,0]
aux       ELECTRICITY_GENERATION_BY_CCGTs = ARRSUM(GENERATION_CAPACITY(*,GAS))*LOAD_FACTOR
aux       ELECTRICITY_GENERATION_FACTOR = GAS_FOR_GENERATION
aux       ELECTRICITY_PRICE =
IF(ELEC_DEMAND<NUC_CAPACITY,GRAPH(ELEC_DEMAND,0,2500,[1.05,1.05,1.05,1.05,1.07,1.07,1.08,1.12,1.17,1.2,1.24
"Min:0;Max:3"]),IF(ELEC_DEMAND<NUC_CAPACITY+GAS_CAPACITY-
NP_CCGTs_NOT_USED,GRAPH(ELEC_DEMAND+NP_CCGTs_NOT_USED-
NUC_CAPACITY,0,2000,[1.29,1.3,1.3,1.3,1.3,1.31,1.32,1.32,1.32,1.33,1.33,1.34,1.34,1.34,1.34,1.35,1.36,1.37,1.39,1.4,1.41,1.43,
1.45,1.47,1.48,1.49,1.52,1.53,1.56,1.6,1.64,1.66,1.71,1.73,1.76,1.8,1.86,1.91,1.96,2,2.06"Min:1;Max:3.5"]),IF(ELEC_DEMAND<
NUC_CAPACITY+GAS_CAPACITY-
NP_CCGTs_NOT_USED+COAL_CAPACITY,GRAPH(ELEC_DEMAND+NP_CCGTs_NOT_USED-
(NUC_CAPACITY+GAS_CAPACITY),0,4200,[2.58,2.61,2.71,2.82,2.97,3.21,3.53,4.05,5.05,6.09,8"Min:2;Max:8"]),1000)))
aux       ELECTRICITY_PRICE_1 =
IF(ELEC_DEMAND<NUC_CAPACITY,GRAPH(ELEC_DEMAND,0,2500,[1.05,1.05,1.05,1.05,1.07,1.07,1.08,1.12,1.17,1.2,1.24
"Min:0;Max:3"]),IF(ELEC_DEMAND<NUC_CAPACITY+GAS_CAPACITY,GRAPH(ELEC_DEMAND-
NUC_CAPACITY,0,2000,[1.29,1.3,1.3,1.3,1.3,1.31,1.32,1.32,1.32,1.33,1.33,1.34,1.34,1.34,1.34,1.35,1.36,1.37,1.39,1.4,1.41,1.43,
1.45,1.47,1.48,1.49,1.52,1.53,1.56,1.6,1.64,1.66,1.71,1.73,1.76,1.8,1.86,1.91,1.96,2,2.06"Min:1;Max:3.5;Zoom"]),IF(ELEC_DEMA
ND<NUC_CAPACITY+GAS_CAPACITY+COAL_CAPACITY,GRAPH(ELEC_DEMAND-
(NUC_CAPACITY+GAS_CAPACITY),0,4200,[2.58,2.61,2.71,2.82,2.97,3.21,3.53,4.05,5.05,6.09,8"Min:2;Max:8"]),1000)))
aux       FRAC_CONTRACT_MADE =
GRAPH(INCENTIVE_TO_CONTRACT,0,0.1,[0,0.35,0.59,0.72,0.81,0.86,0.9,0.94,0.97,0.99,1"Min:0;Max:1"])
aux       GAS_CAPACITY = ARRSUM(GENERATION_CAPACITY(*,GAS))-NP_CCGTs_NOT_USED
dim       GAS_DEMAND = (i=1..3)
aux       GAS_DEMAND =
NOT_CCGTs_GAS_DEMAND(1)*[1,0,0]+NOT_CCGTs_GAS_DEMAND(2)*[0,1,0]+ELECTRICITY_GENERATION_FACTO
R*[0,0,1]
aux       GAS_FOR_GENERATION = ELECTRICITY_GENERATION_BY_CCGTs*GAS_PER_KW    {THERMS}
aux       GAS_GROWTH_CONTRACT = GRAPH(TIME,1992,1,[-0.03,0.026,0.018,-
0.05,0.012,0.014,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0.009,0
.009,0.009,0.009,0.009,0.009"Min:-0.05;Max:0.05"])
aux       GAS_GROWTH_TARIFF =
GRAPH(TIME,1992,1,[0.015,0.034,0.024,0.021,0.02,0.018,0.012,0.012,0.0121,0.0121,0.0119,0.0118,0.0119,0.0119,0.0119,0.011
8,0.0119,0.0119,0.0119,0.0119,0.0119,0.0119,0.0119,0.0118,0.0118,0.0119,0.0119,0.0119,0.0118"Min:0;Max:0.04"])
dim       GC_MIX = (I=1..2)
aux       GC_MIX =
[1,0]*TECHNOLOGY_MIX(GAS)/(TECHNOLOGY_MIX(GAS)+TECHNOLOGY_MIX(COAL))+[0,1]*TECHNOLOGY_MIX(
COAL)/(TECHNOLOGY_MIX(GAS)+TECHNOLOGY_MIX(COAL))
dim       GEN_CAPXCOMP = (GEN_COMPANY)
aux       GEN_CAPXCOMP =
ARRSUM(GENERATION_CAPACITY(PG,GAS..NUCLEAR))*[1,0,0,0]+ARRSUM(GENERATION_CAPACITY(NP,GAS..NUC
LEAR))*[0,1,0,0]+ARRSUM(GENERATION_CAPACITY(IND,GAS..NUCLEAR))*[0,0,1,0]+ARRSUM(GENERATION_CAPAC
ITY(NUC,GAS..NUCLEAR))*[0,0,0,1]
aux       INCENTIVE_TO_CONTRACT = RISK_PERCEIVED
aux       INCREMENT_IN_RETURNS = 0*E_PRICE_P*PREMIUM_PAIED*RETURN_FRACTION_TO_SPLIT/100
{pounds}
aux       IND_ACC_RETURN = IND_BAISIS_ACP_RETURN*IND_MKT_SHARE_INF
dim       IND_EXP_LOLP = (EXPECTATIONS)
aux       IND_EXP_LOLP =
[1,0,0,0]*GRAPH(IND_EXP_MARGIN(EXP1),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.0032
7,0.00166,0.00108"Min:0;Max:0.06"])+[0,1,0,0]*GRAPH(IND_EXP_MARGIN(EXP2),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.0
2,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;Max:0.06"])+[0,0,1,0]*GRAPH(IND_EXP_MARGIN(EXP3),0,0
.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;Max:0.06"])+[0,0,0,1]*G
RAPH(IND_EXP_MARGIN(EXP4),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,
0.00108"Min:0;Max:0.06"])
dim       IND_EXP_MARGIN = (EXPECTATIONS)
aux       IND_EXP_MARGIN = (IND_NET_EXP_CAPACITY_3/ELECC_EXP_DEM(IND))-1
dim       IND_EXP_MP = (EXPECTATIONS)
aux       IND_EXP_MP = [1,0,0,0]*GRAPH(IND_MARGIN(EXP1),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,1,0,0]*GRAPH(IND_MARGIN(EXP
2),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,0,1,0]*GRAPH(IND_MARGIN(EXP
3),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,0,0,1]*GRAPH(IND_MARGIN(EXP
4),-0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])
dim       IND_EXP_PRICE = (EXPECTATIONS)
aux       IND_EXP_PRICE = IND_EXP_LOLP*(VOLL*IND_EXP_MP)
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aux      IND_INVESTMENT =
IF(IND_EXP_PRICE(EXP4)>IND_RETURN_HALFHOUR,2000,IF(IND_EXP_PRICE(EXP3)>IND_RETURN_HALFHOUR,150
0,IF(IND_EXP_PRICE(EXP2)>IND_RETURN_HALFHOUR,1000,IF(IND_EXP_PRICE(EXP1)>IND_RETURN_HALFHOUR,50
0,0))))
dim      IND_MARGIN = (EXPECTATIONS)
aux      IND_MARGIN = IND_EXP_MARGIN-[1,1,1,1]*DESIRED_MARGIN
aux      IND_MKT_SHARE_INF =
GRAPH(MKTSHARE(IND),0,0.0125,[0.8,0.892,0.935,0.958,0.97,0.98,0.983,0.988,0.993,0.995,0.995,1,1"Min:0.8;Max:1"])
dim      IND_NET_EXP_CAPACITY_3 = (EXPECTATIONS)
aux      IND_NET_EXP_CAPACITY_3 = ELECC_NET_EXP_CAPACITY(IND)*[1,1,1,1]+[500,1000,1500,2000]
aux      IND_RETURN_HALFHOUR = (IND_YEARLY_RETURN/(48*365))-(INCREMENT_IN_RETURNS/2)
aux      IND_YEARLY_RETURN = IND_INVEST_COSTS*(IND_ACC_RETURN/(1-(1+IND_ACC_RETURN)^(-
IND_ECONOMIC_LIFE_PLANT)))    {NP'S ACC RETURN, POUNDS/YEAR/Kw}
aux      LOLP =
GRAPH(MARGIN,0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;M
ax:0.07"])
aux      LOLP_1 =
GRAPH(MARGIN_P,0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0
;Max:0.07"])
aux      MARGIN = (TOTAL_CAPACITY/ELEC_DEMAND)-1
aux      MARGIN_GAP = REGULATOR_3Y_EXP_MARGIN-DESIRED_MARGIN
aux      MARGIN_P = ((TOTAL_CAPACITY-NP_CCGTs_NOT_USED)/ELEC_DEMAND)-1
dim      MKTSHARE = (GEN_COMPANY)
aux      MKTSHARE = GEN_CAPXCOMP/TOTAL_CAPACITY
aux      MOV_VEC1 = SHIFTLIF(CYCLES,PRICES_VECTOR)
aux      MOV_VEC1_1 = SHIFTLIF(CYCLES_1,VECTOR_CONTRACTS)
aux      MOV_VEC1_2 = SHIFTLIF(CYCLES_1,VECTOR_PREMIA)
aux      MOV_VEC1_3 = SHIFTLIF(CYCLES_2,NP_GAINS_VECTOR)
aux      MOV_VEC1_4 = SHIFTLIF(CYCLES_3,NP_POTENTIAL_VECT)
aux      MOV_VEC1_5 = SHIFTLIF(CYCLES_4,VECTOR_Z_REVENUES)
aux      MOV_VEC2 = SHIFTLIF(CYCLES,VARIANCES_VECTOR)
aux      MOV_VEC3 = SHIFTLIF(CYCLES,STRATEGIES_VECTOR)
aux      NEW_CAPACITY_TO_CONTRACT = MAX(CAPACITY_TO_CONTRACT-TOTAL_CAP_CONTRACTED,0)
aux      NOT_CCGTS_GAS_SUPPLIERS = ARRSUM(GAS_DEMAND)-GAS_DEMAND(3)-NP_GAS_SALES
aux      NP_ACC_RETURN = NP_BAISIS_ACP_RETURN*NP_FINANCE_COST
aux      NP_CCGTs_NOT_USED = GENERATION_CAPACITY(NP,GAS)*STRATEGIES_VECTOR(3)
dim      NP_EXP_LOLP = (EXPECTATIONS)
aux      NP_EXP_LOLP =
[1,0,0,0]*GRAPH(NP_EXP_MARGIN(EXP1),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327
,0.00166,0.00108"Min:0;Max:0.06"])+[0,1,0,0]*GRAPH(NP_EXP_MARGIN(EXP2),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,
0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;Max:0.06"])+[0,0,1,0]*GRAPH(NP_EXP_MARGIN(EXP3),0,0.02
5,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;Max:0.06"])+[0,0,0,1]*GR
APH(NP_EXP_MARGIN(EXP4),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.0
0108"Min:0;Max:0.06"])
dim      NP_EXP_MARGIN = (EXPECTATIONS)
aux      NP_EXP_MARGIN = (NP_NET_EXP_CAPACITY_3/ELECC_EXP_DEM(NP))-1
dim      NP_EXP_MP = (EXPECTATIONS)
aux      NP_EXP_MP = [1,0,0,0]*[1,0,0,0]*GRAPH(NP_MARGIN(EXP1),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,1,0,0]*GRAPH(NP_MARGIN(EXP2
),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,0,1,0]*GRAPII(NP_MARGIN(EXP3
),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,0,0,1]*GRAPH(NP_MARGIN(EXP4
),-0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])
dim      NP_EXP_PRICE = (EXPECTATIONS)
aux      NP_EXP_PRICE = NP_EXP_LOLP*(VOLL*NP_EXP_MP)
aux      NP_FINANCE_COST =
GRAPH(NP_FRAC_UNDER_CONS,0,0.02085,[1,1,1,1,1,1.01,1.03,1.07,1.14,1.24,1.4,1.64,1.99"Min:0;Max:2"])
aux      NP_FRAC_UNDER_CONS = CAP_CONSXC0MP(NP)/GEN_CAPXCOMP(NP)
aux      NP_GAS_SALES = NP_CCGTs_NOT_USED*GAS_PER_KW
aux      NP_GEN_STRATEGY =
IF(STRATEGIES_VECTOR(1)=0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.05,[0.27,0.246,0.228,0.211,0.2,0.186,0.178,0.175,0.
171,0.156,0.134,0.11,0.068,0.039,0.02,0.009,0.002,0,0.002,0,0"Min:0;Max:0.5"]))
aux      NP_GEN_STRATEGY_1 =
IF(STRATEGIES_VECTOR(3)>0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.
4,0.4,0.4,0.399,0.399,0.399,0.398,0.395,0.393,0.393,0.384,0.371,0.355,0.322,0.289,0.239,0.211,0.167,0.129,0.105,0.075,0.061,0.0
37,0.026,0.018,0.013,0.007,0,0"Min:0;Max:0.5"]))
doc      NP_GEN_STRATEGY_1 =
IF(STRATEGIES_VECTOR(2)>0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.
4,0.4,0.4,0.399,0.399,0.399,0.398,0.395,0.393,0.393,0.384,0.371,0.355,0.322,0.289,0.239,0.211,0.167,0.129,0.105,0.075,0.061,0.0
37,0.026,0.018,0.013,0.007,0,0"Min:0;Max:0.5"]))
aux      NP_GEN_STRATEGY_2 =
IF(STRATEGIES_VECTOR(2)>0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.
25,0.252,0.25,0.25,0.252,0.25,0.25,0.252,0.252,0.246,0.243,0.235,0.23,0.224,0.215,0.204,0.191,0.186,0.173,0.162,0.143,0.123,0.1
07,0.086,0.072,0.044,0.029,0.018,0.011,0.004,0.002,0.002"Min:0;Max:0.5"]))
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aux	NP_GEN_STRATEGY_3 =
IF(STRATEGIES_VECTOR(2)>0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.25,0.248,0.246,0.246,0.246,0.246,0.246,0.24
6,0.246,0.246,0.243,0.239,0.239,0.239,0.239,0.239,0.239,0.239,0.239,0.239,0.237,0.239,0.239,0.239,0.235,0.232,0.219,0.204,0.18
9,0.167,0.129,0.105,0.075,0.061,0.037,0.026,0.018,0.013,0.007,0,0"Min:0;Max:0.5"]))
doc	NP_GEN_STRATEGY_3 =
IF(STRATEGIES_VECTOR(2)>0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.
4,0.4,0.4,0.399,0.399,0.399,0.398,0.395,0.393,0.393,0.384,0.371,0.355,0.322,0.289,0.239,0.211,0.167,0.129,0.105,0.075,0.061,0.0
37,0.026,0.018,0.013,0.007,0,0"Min:0;Max:0.5"]))
aux	NP_GEN_STRATEGY_4 = IF(STRATEGIES_VECTOR(3)>0,0.0,0.15)
aux	NP_GEN_STRATEGY_5 = IF(STRATEGIES_VECTOR(3)>0 OR
MARGIN>0.25,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.599,0.599,0.599,0.599,0.599,0.599,0.599,0.599,0.599,0.599,0.
599,0.593,0.587,0.579,0.57,0.559,0.542,0.53,0.507,0.488,0.467,0.445,0.419,0.39,0.355,0.322,0.289,0.239,0.211,0.167,0.129,0.105
,0.075,0.061,0.037,0.026,0.018,0.013,0.007,0,0"Min:0;Max:0.65"]))
doc	NP_GEN_STRATEGY_5 =
IF(STRATEGIES_VECTOR(2)>0,0,GRAPH(FRAC_CONTRACT_MADE,0,0.025,[0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.4,0.
4,0.4,0.4,0.399,0.399,0.399,0.398,0.395,0.393,0.393,0.384,0.371,0.355,0.322,0.289,0.239,0.211,0.167,0.129,0.105,0.075,0.061,0.0
37,0.026,0.018,0.013,0.007,0,0"Min:0;Max:0.5"]))
aux	NP_GEN_STRATEGY_6 =
IF(STRATEGIES_VECTOR(3)>0,0,MAX(0.15,GRAPH(VARIANCE_INDEX,0,0.075,[0.003,0.011,0.023,0.039,0.062,0.09,0.116,
0.143,0.167,0.186,0.2,0.212,0.223,0.23,0.236,0.243,0.246,0.247,0.249,0.25,0.25"Min:0;Max:0.25;Zoom"])))
aux	NP_INVESTMENT =
IF(NP_EXP_PRICE(EXP4)>NP_RETURN_HALFHOUR,2000,IF(NP_EXP_PRICE(EXP3)>NP_RETURN_HALFHOUR,1500,IF(
NP_EXP_PRICE(EXP2)>NP_RETURN_HALFHOUR,1000,IF(NP_EXP_PRICE(EXP1)>NP_RETURN_HALFHOUR,500,0))))
dim	NP_MARGIN = (EXPECTATIONS)
aux	NP_MARGIN = NP_EXP_MARGIN-[1,1,1,1]*DESIRED_MARGIN
aux	NP_MKT_SHARE = MKTSHARE(NP)
dim	NP_NET_EXP_CAPACITY_3 = (EXPECTATIONS)
aux	NP_NET_EXP_CAPACITY_3 = ELECC_NET_EXP_CAPACITY(NP)*[1,1,1,1]+[500,1000,1500,2000]
aux	NP_POOL_REVENUES = TIMESTEP*(POTENCIAL_CONTRACT_MARKET-
TOTAL_CAP_ON_CONTRACT)*NP_MKT_SHARE*E_PRICE_P*8760/100		{THOUSAND STERLING PER YEAR}
doc	NP_POOL_REVENUES = mW to kW and pence to pounds and then to thousand pounds
(1000)*(1/100)*(1/1000)
aux	NP_PROFIT_FROM_PREMIUM = TIMESTEP*TOTAL_PROF_PREMIUM*NP_MKT_SHARE*8760/100
{THOUSAND STERLING PER YEAR}
aux	NP_RELATIVE_SALES = NP_GAS_SALES/TOTAL_GAS_SUPPLY
aux	NP_RETURN_HALFHOUR = NP_YEARLY_RETURN/(48*365)
aux	NP_YEARLY_RETURN = NP_INVEST_COSTS*(NP_ACC_RETURN/(1-(1+NP_ACC_RETURN)^(-
NP_ECONOMIC_LIFE_PLANT)))	{NP'S ACC RETURN, POUNDS/YEAR/Kw}
aux	NUC_CAPACITY = ARRSUM(GENERATION_CAPACITY(*,NUCLEAR))
aux	PERCENT_CONTRACTED = TOTAL_CAP_ON_CONTRACT/ELEC_DEMAND
aux	PERCENTAGE_GAIN = IF(TIME<1994,0,(VECTOR_Z_REVENUES(2)-
VECTOR_Z_REVENUES(3))/VECTOR_Z_REVENUES(3))
aux	PG_ACC_RETURN = PG_BAISIS_ACP_RETURN*PG_FINANCE_COST
dim	PG_EXP_LOLP = (EXPECTATIONS)
aux	PG_EXP_LOLP =
[1,0,0,0]*GRAPH(PG_EXP_MARGIN(EXP1),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327
,0.00166,0.00108"Min:0;Max:0.06"])+[0,1,0,0]*GRAPH(PG_EXP_MARGIN(EXP2),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,
0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;Max:0.06"])+[0,0,1,0]*GRAPH(PG_EXP_MARGIN(EXP3),0,0.02
5,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.00108"Min:0;Max:0.06"])+[0,0,0,1]*GR
APH(PG_EXP_MARGIN(EXP4),0,0.025,[0.057,0.047,0.037,0.031,0.025,0.02,0.014,0.0102,0.00685,0.00417,0.00327,0.00166,0.0
0108"Min:0;Max:0.06"])
dim	PG_EXP_MARGIN = (EXPECTATIONS)
aux	PG_EXP_MARGIN = (PG_NET_EXP_CAPACITY_3/ELECC_EXP_DEM(PG))-1
dim	PG_EXP_MP = (EXPECTATIONS)
aux	PG_EXP_MP = [1,0,0,0]*GRAPH(PG_MARGIN(EXP1),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,1,0,0]*GRAPH(PG_MARGIN(EXP2
),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,0,1,0]*GRAPH(PG_MARGIN(EXP3
),-
0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])+[0,0,0,1]*GRAPH(PG_MARGIN(EXP4
),-0.05,0.0166,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0;Max:1.5"])
dim	PG_EXP_PRICE = (EXPECTATIONS)
aux	PG_EXP_PRICE = PG_EXP_LOLP*(VOLL*PG_EXP_MP)
aux	PG_FINANCE_COST =
GRAPH(PG_FRAC_UNDER_CONS,0,0.0167,[1,1,1,1,1,1.01,1.03,1.07,1.14,1.24,1.4,1.64,1.99"Min:0;Max:2"])
aux	PG_FRAC_UNDER_CONS = CAP_CONSXCOMP(PG)/GEN_CAPXCOMP(PG)
aux	PG_INVESTMENT =
IF(PG_EXP_PRICE(EXP4)>PG_RETURN_HALFHOUR,2000,IF(PG_EXP_PRICE(EXP3)>PG_RETURN_HALFHOUR,1500,IF(
PG_EXP_PRICE(EXP2)>PG_RETURN_HALFHOUR,1000,IF(PG_EXP_PRICE(EXP1)>PG_RETURN_HALFHOUR,500,0))))
dim	PG_MARGIN = (EXPECTATIONS)
aux	PG_MARGIN = PG_EXP_MARGIN-[1,1,1,1]*DESIRED_MARGIN
dim	PG_NET_EXP_CAPACITY_3 = (EXPECTATIONS)
aux	PG_NET_EXP_CAPACITY_3 = ELECC_NET_EXP_CAPACITY(PG)*[1,1,1,1]+[500,1000,1500,2000]
aux	PG_RETURN_HALFHOUR = PG_YEARLY_RETURN/(48*365)
aux	PG_YEARLY_RETURN = PG_INVEST_COSTS*(PG_ACC_RETURN/(1-(1+PG_ACC_RETURN)^(-
PG_ECONOMIC_LIFE_PLANT)))	{PG'S ACC RETURN, POUNDS/YEAR/Kw}
```

```
aux	POTENCIAL_CONTRACT_MARKET = ELEC_DEMAND
aux	POTENTIAL_GAIN_FROM_POOL = TIMESTEP*NP_CCGTs_NOT_USED*(E_PRICE_P-E_PRICE_P1)*8760/100
{THOUSAND STERLING PER YEAR}
aux	PREMIUM_PAIED =
GRAPH(PRICE_VARIANCE,0,0.05,[0.01,0.03,0.05,0.09,0.14,0.2,0.25,0.31,0.37,0.45,0.52,0.62,0.72,0.81,0.92,1.01,1.11,1.18,1.24,
1.32,1.37,1.42,1.45,1.48,1.49,1.5,1.5,1.5,1.5,1.5,1.5"Min:0;Max:1.5"])
aux	PREMIUM_PAIED_1 =
GRAPH(PRICE_VARIANCE,0,0.05,[0,0.02,0.06,0.12,0.2,0.3,0.36,0.42,0.45,0.48,0.49,0.5,0.51,0.52,0.55,0.59,0.66,0.73,0.84,0.98,
1.16,1.35,1.44,1.49,1.5,1.5,1.5,1.5,1.5,1.5,1.5"Min:0;Max:1.5"])
aux	PRICE = VOLL*LOLP    {CAPACITY ELEMENT OF THE PRICE}
aux	PRICE_MEAN = ARRAVG(ACT_PRICES)
aux	PRICE_UNCERTAINTY = IF(ABS((ACT_PRICES(1)-AVERAGE_PRICE)/PRICE_VARIANCE)>1.67,1,0)
{1,uncertainty}
aux	PRICE_VARIANCE = IF(TIME<1993,0,ARRSTDDEV(ACT_PRICES)^2)
aux	PRICE_VS_VOLUME =
GRAPH(NP_RELATIVE_SALES,0,0.05,[1,0.916,0.845,0.787,0.729,0.689,0.655,0.629,0.6,0.576,0.553,0.539,0.524,0.516,0.508,0.
505,0.505,0.503,0.503,0.503,0.503"Min:0.4;Max:1"])
aux	REGULATOR_3Y_EXP_CAPACITY = TOTAL_CAPACITY+CAPACITY_CHANGE
aux	REGULATOR_3Y_EXP_DEMAND =
ELEC_DEMAND*(1+REGULATOR_EXP_DEMAND_GROWTH+(RANDOM(0 ,1 ,457217)*REGULATOR_UNCERTAINTY))
aux	REGULATOR_3Y_EXP_MARGIN = (REGULATOR_3Y_EXP_CAPACITY/REGULATOR_3Y_EXP_DEMAND)-1
aux	RET_INDEP =
GRAPH(TIME,1992,1,[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1"])
aux	RET_NP =
GRAPH(TIME,1992,1,[0,0,718,718,718,1030,1030,1030,1066,1066,1066,1015,1015,1015,986,986,986,1697,1697,1697,837,837,
837,0,0,0,1388,1388,1388,0,0,0,0,0,0,0,0,0"Min:0;Max:2030"])
aux	RET_NUC =
GRAPH(TIME,1992,1,[233,233,343,343,343,413,413,413,137,137,137,103,103,103,1710,1710,1710,0,0,0,0,0,0,0,0,297,297,29
7,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1800"])
aux	RET_PG =
GRAPH(TIME,1992,1,[306,306,472,472,472,115,115,115,998,998,998,1354,1354,1354,0,0,0,1319,1319,1319,0,0,0,0,0,1285,12
85,1285,0,0,0,0,0,0,0,0,0,0"Min:1500;Max:1"])
dim	RETIREMENT_YEARS_INDEP = (y=YEAR1..YEAR3)
aux	RETIREMENT_YEARS_INDEP =
[1,0,0]*GRAPH(TIME,1992,1,[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1"])+[0,1,0]*G
RAPH(TIME+1,1992,1,[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1"])+[0,0,1]*GRAPH
(TIME+2,1992,1,[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1"])
dim	RETIREMENT_YEARS_NP = (y=YEAR1..YEAR3)
aux	RETIREMENT_YEARS_NP =
[1,0,0]*GRAPH(TIME,1992,1,[0,0,718,718,718,1030,1030,1030,1066,1066,1066,1015,1015,1015,986,986,986,1697,1697,1697,8
37,837,837,0,0,0,1388,1388,1388,0,0,0,0,0,0,0,0,0"Min:0;Max:2030"])+[0,1,0]*GRAPH(TIME+1,1992,1,[0,0,718,718,718,1030,
1030,1030,1066,1066,1066,1015,1015,1015,986,986,986,1697,1697,1697,837,837,837,0,0,0,1388,1388,1388,0,0,0,0,0,0,0,0,0"
Min:0;Max:2030"])+[0,0,1]*GRAPH(TIME+2,1992,1,[0,0,718,718,718,1030,1030,1030,1066,1066,1066,1015,1015,1015,986,986
,986,1697,1697,1697,837,837,837,0,0,0,1388,1388,1388,0,0,0,0,0,0,0,0,0"Min:0;Max:2030"])
dim	RETIREMENT_YEARS_NUC = (y=YEAR1..YEAR3)
aux	RETIREMENT_YEARS_NUC =
[1,0,0]*GRAPH(TIME,1992,1,[233,233,343,343,343,413,413,413,137,137,137,103,103,103,1710,1710,1710,0,0,0,0,0,0,0,0,297,
297,297,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1800"])+[0,1,0]*GRAPH(TIME+1,1992,1,[233,233,343,343,343,413,413,413,137,137,137,
103,103,103,1710,1710,1710,0,0,0,0,0,0,0,0,297,297,297,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1800"])+[0,0,1]*GRAPH(TIME+2,1992,
1,[233,233,343,343,343,413,413,413,137,137,137,103,103,103,1710,1710,1710,0,0,0,0,0,0,0,0,297,297,297,0,0,0,0,0,0,0,0,0,0"
Min:0;Max:1800"])
dim	RETIREMENT_YEARS_PG = (y=YEAR1..YEAR3)
aux	RETIREMENT_YEARS_PG =
[1,0,0]*GRAPH(TIME,1992,1,[306,306,472,472,472,115,115,115,998,998,998,1354,1354,1354,0,0,0,1319,1319,1319,0,0,0,0,0,
1285,1285,1285,0,0,0,0,0,0,0,0,0,0"Min:1500;Max:1"])+[0,1,0]*GRAPH(TIME+1,1992,1,[306,306,472,472,472,115,115,115,998,
998,998,1354,1354,1354,0,0,0,1319,1319,1319,0,0,0,0,0,1285,1285,1285,0,0,0,0,0,0,0,0,0,0"Min:1500;Max:1"])+[0,0,1]*GRAP
H(TIME+2,1992,1,[306,306,472,472,472,115,115,115,998,998,998,1354,1354,1354,0,0,0,1319,1319,1319,0,0,0,0,0,1285,1285,
1285,0,0,0,0,0,0,0,0,0,0"Min:1500;Max:1"])
aux	RETURN_GAS_BUSINESS = NP_GAS_SALES*(SPOT_GAS_PRICE_1-20)*10*TIMESTEP      {THOUSAND
STERLING PER YEAR}
doc	RETURN_GAS_BUSINESS = Pence converted to thousand pounds.Gas is given in million therms. Gas is sold only during
TIMESTEP. (1/100)*(1/1000)*1'000.000
aux	RISK_PERCEIVED = PRICE_VARIANCE
aux	SPOT_GAS_PRICE =
GRAPH(NOT_CCGTS_GAS_SUPPLIERS+NP_GAS_SALES,0,1000,[24.8,23.6,22.6,22,21.4,20.9,20.2,19,17.7,15.9,15.4,14.6,14.
2,13.7,13.5,13.3,13.2,13.2,13.1,13.1,13,12.9,12.9,12.9,12.8,12.8,12.8,12.8,12.8,12.7,12.6"Min:10;Max:30"])
aux	SPOT_GAS_PRICE_1 = AVERAGE_GAS_PRICE*PRICE_VS_VOLUME
dim	TECHNOLOGY_MIX = (SOURCE)
aux	TECHNOLOGY_MIX =
([1,0,0]*ARRSUM(GENERATION_CAPACITY(*,GAS))+[0,1,0]*ARRSUM(GENERATION_CAPACITY(*,COAL))+[0,0,1]*AR
RSUM(GENERATION_CAPACITY(*,NUCLEAR)))/ARRSUM(GENERATION_CAPACITY(*,*))
aux	TOTAL_CAP_CONTRACTED = ARRSUM(VECTOR_CONTRACTS)
aux	TOTAL_CAP_ON_CONTRACT = NEW_CAPACITY_TO_CONTRACT+TOTAL_CAP_CONTRACTED
aux	TOTAL_CAPACITY = ARRSUM(GENERATION_CAPACITY)
aux	TOTAL_GAS_SUPPLY = NP_GAS_SALES+NOT_CCGTS_GAS_SUPPLIERS
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aux	TOTAL_PROF_PREMIUM =
(NEW_CAPACITY_TO_CONTRACT*PREMIUM_PAIED)+SPROD(VECTOR_CONTRACTS, VECTOR_PREMIA)
aux	TOTAL_RETIREMENT = ARRSUM(ELECC_RETIREMENT_IN_3YEARS)
aux	VARIANCE_INDEX =
PRICE_VARIANCE/((VARIANCES_VECTOR(2)+VARIANCES_VECTOR(3)+VARIANCES_VECTOR(4)+VARIANCES_VEC
TOR(5)+VARIANCES_VECTOR(6))/5)
aux	VOLL_ADJUSTMENT = GRAPH(MARGIN_GAP,-
0.05,0.008333,[1.5,1.34,1.21,1.12,1.04,1.01,1,0.99,0.96,0.88,0.79,0.66,0.5"Min:0.5;Max:1.5"])
aux	Z_POTENTIAL =
IF(TIME>1992.4,(POTENTIAL_GAIN_FROM_POOL+ARRSUM(NP_POTENTIAL_VECT))/5,ARRSUM(NP_POTENTIAL_VE
CT)/5)
aux	Z_REVENUES =
IF(TIME>1992.4,(NP_NET_GAINS+ARRSUM(NP_GAINS_VECTOR))/5,ARRSUM(NP_GAINS_VECTOR)/5)
const	ACCEPTABLE_RISK = 0.25
const	AVERAGE_GAS_PRICE = 24		{PENCE PER THERM}
const	DESIRED_MARGIN = 0.21
const	ELEC_DEM_GROWTH = 0.011
dim	ELECC_EXP_GROWTH = (GEN_COMPANY)
const	ELECC_EXP_GROWTH = [0.033,0.033,0.033,0]
dim	ELECC_INFORMATION_BIAS = (g=PG..NUC)
const	ELECC_INFORMATION_BIAS = 1*[1,0,0,0]+1*[0,1,0,0]+1*[0,0,1,0]+[0,0,0,0]
const	GAS_PER_KW = 0.580			{MILLION THERMS PER 1 mW AT .9 LOAD}
dim	GC_MIX1 = (I=1..2)
const	GC_MIX1 = [0.5,0.5]
const	IND_BAISIS_ACP_RETURN = 0.16
doc	IND_BAISIS_ACP_RETURN = MINIMUM RETURN ON INVESTMENT REQUIRED
const	IND_ECONOMIC_LIFE_PLANT = 25  {YEARS}
const	IND_INVEST_COSTS = 400   {POUNDS/Mw}
doc	IND_INVEST_COSTS = COVER BY CAPACITY ELEMENT ONLY
dim	INITIAL_CAPACITY_UNDER_CONS = (GEN_COMPANY,SOURCE)
const	INITIAL_CAPACITY_UNDER_CONS = ([[780.7,0,0],[1549.3,0,0],[3046.3,0,0],[0,0,418]])*TIMESTEP
const	LOAD_FACTOR = 1	{ALREADY ACCOUNTED IN CONVERSION}
const	NP_BAISIS_ACP_RETURN = 0.13
doc	NP_BAISIS_ACP_RETURN = MINIMUM RETURN ON INVESTMENT REQUIRED
dim	NP_CCGTs_FRAC_not_USED = (i=1..10)
const	NP_CCGTs_FRAC_not_USED = [0.15,0,0.15,0,0,0,0,0,0,0]
const	NP_ECONOMIC_LIFE_PLANT = 25  {YEARS}
const	NP_INVEST_COSTS = 400   {POUNDS/Mw}
doc	NP_INVEST_COSTS = COVER BY CAPACITY ELEMENT ONLY
const	PG_BAISIS_ACP_RETURN = 0.13
doc	PG_BAISIS_ACP_RETURN = MINIMUM REQUIRED ON INVESTMENT
const	PG_ECONOMIC_LIFE_PLANT = 25  {YEARS}
const	PG_INVEST_COSTS = 400   {POUND/Kw}
doc	PG_INVEST_COSTS = COVER BY CAPACITY ELEMENT ONLY
const	REGULATOR_EXP_DEMAND_GROWTH = 0.033
doc	REGULATOR_EXP_DEMAND_GROWTH = FRACCTION OF CURRENT DEMAND GROWTH FOR THE NEXT 3
YEARS
const	REGULATOR_UNCERTAINTY = 0.05
doc	REGULATOR_UNCERTAINTY = 5% UNCERTAINTY FORECAST OF 3 YEARS DEMAND
const	RETURN_FRACTION_TO_SPLIT = 0.7
dim	TECH_CHOOSE_INV = (GEN_COMPANY,SOURCE)
const	TECH_CHOOSE_INV = [[1,0,0],[1,0,0],[1,0,0],[0,0,1]]
dim	UNIT_1_VECTOR = (I=1..5)
const	UNIT_1_VECTOR = [1,0,0,0,0]
dim	UNIT_1_VECTOR_1 = (I=1..5)
const	UNIT_1_VECTOR_1 = [1,0,0,0,0]
dim	UNIT_VECTOR = (i=1..10)
const	UNIT_VECTOR = [1,0,0,0,0,0,0,0,0,0]
dim	UNIT_VECTOR_1 = (i=1..10)
const	UNIT_VECTOR_1 = [1,0,0,0,0,0,0,0,0,0]
dim	UNIT_VECTOR_2 = (i=1..10)
const	UNIT_VECTOR_2 = [1,0,0,0,0,0,0,0,0,0]
const	VOLL_1 = 2
```

A2 APPENDIX II
AN SD PLATFORM FOR COLOMBIAN
(Prototype 2 - English version)

A.2.1 DEFINITION OF VARIABLES

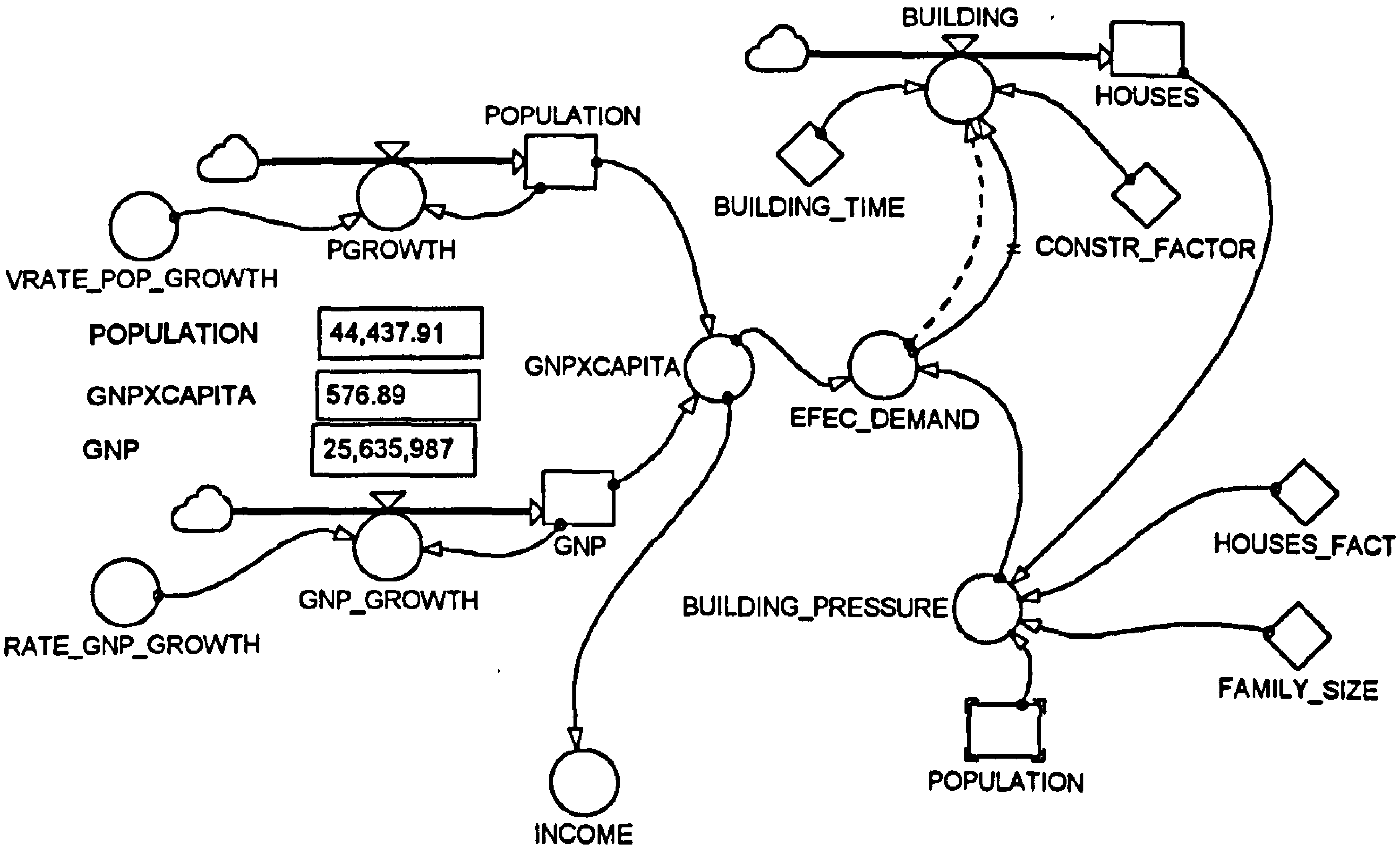
COLOMBIAN SOCIOECONOMIC VARIABLES

Exogenous variables.

VRATE_POP_GROWTH: Variable rate of population growth.
VRATE_GNP_GROWTH: Variable rate of GNP growth.
FAMILY_SIZE: Size of a typical family.
HOUSES_FACT: Percentage of households per family.
CONSTR_FACTOR: Percentage of houses actually built.
BUILDING_TIME: Average building time.

Endogenous variables.

PGROWTH: Population growth.
POPULATION: Colombian population.
GNP_GROWTH: GNP growth.
GNP: GNP.
GNPXCAPITA: GNP per capita.
INCOME: Income.
BUILDING_PRESSURE: Building pressure (deficit of houses).
EFEC_DEMAND: Effective demand for houses.
BUILDING: Number of houses in construction.
HOUSES: Number of houses in Colombia.



RESIDENTIAL SECTOR

Some model components for this sector have fourteen dimension, the order of vector's input are:

1. COOKE: Cooking with electricity.
2. COOKEE: Cooking with electrically efficient appliances.
3. COOKNG: Cooking with natural gas.

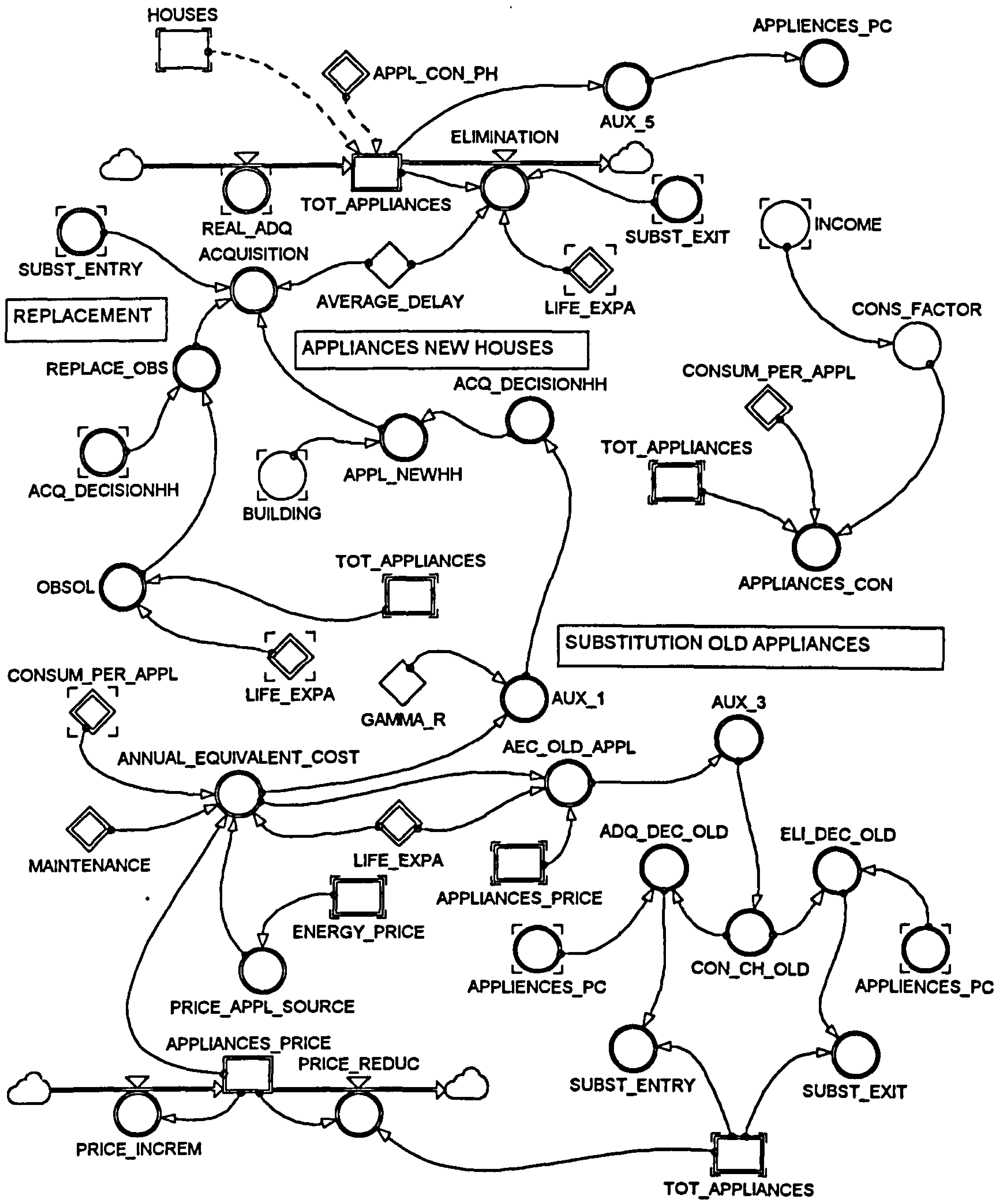
4. COOKLPG: Cooking with liquefied petroleum gas.
5. COOKW: Cooking with wood.
6. HEATHE: Water heating with electricity.
7. HEATHGN: Water heating with natural gas.
8. HEATHGLP : Water heating with liquefied petroleum gas.
9. HEATHS: Water heating with solar energy.
10. LIGHTE: Lighting with traditional electric bulbs.
11. LIGHTEE: Lighting with efficient electric bulbs.
12. FRIDGE: Refrigeration with electricity.
13. FRIDGE: Refrigeration with electrically efficient appliances.
14. OTHER: Other appliances

Exogenous variables.

APPL_CON_PH: Initial appliances percentage per household.
AVERAGE_DELAY: Average delay between the decision to acquire an appliance and its actual acquisition.
CONSUM_PER_APPL: Energy consumption of appliances in equivalent kilowatts per year.
MAINTENANCE: Average annual maintenance cost per appliance.
LIFE_EXPA: Expected appliance life.
GAMMA_R: Gamma factor for the residential sector.

Endogenous variables.

APPLIENCES_PC: Appliance distribution between different end-uses.
AUX_5: Same as TOT_APPLIANCES but with numerical dimension.
TOT_APPLIANCES: Total Appliances.
ELIMINATION: Total appliances discarded.
CONS_FACTOR: Percentage of both greater or smallest energy consumption according to economic situation of users.
APPLIANCES_CON: Total energy consumption of appliances.
ANNUAL_EQUIVALENT_COST: Annual equivalent cost.
AEC_OLD_APPL: Annual equivalent cost of old appliances.
AUX_3: Raise the annual equivalent cost of the old appliances to -1.
CON_CH_OLD: Consumers' choice equation.
ADQ_DEC_OLD: Adjust the APPLIENCES_PC to the appliances percentages chosen to acquire.
ELI_DEC_OLD: Adjust the APPLIENCES_PC to the appliances percentages chosen to replace.
SUBST_ENTRY: Total appliances that will be acquired because of substitution.
SUBST_EXIT: Total appliances that will be discarded because of substitution.
PRICE_INCREM: Appliances price increment.
APPLIANCES_PRICE: Appliances price.
PRICE_REDUC: Appliances price reduction.
PRICE_APPL_SOURCE: The energy vector of prices, containing 6 components, is transformed to one with 14 components.
AUX_1: Raise the annual equivalent cost to gamma factor.
ACQ_DECISIONHH: Appliances acquisition decision for new household.
APPL_NEWHH: Total appliances for new household.
ACQUISITION: Acquisition before restrictions.
OBSOL: Total obsolete appliances (life expectancy).
REPLACE_OBS: Total obsolete appliances (economic obsolescence).



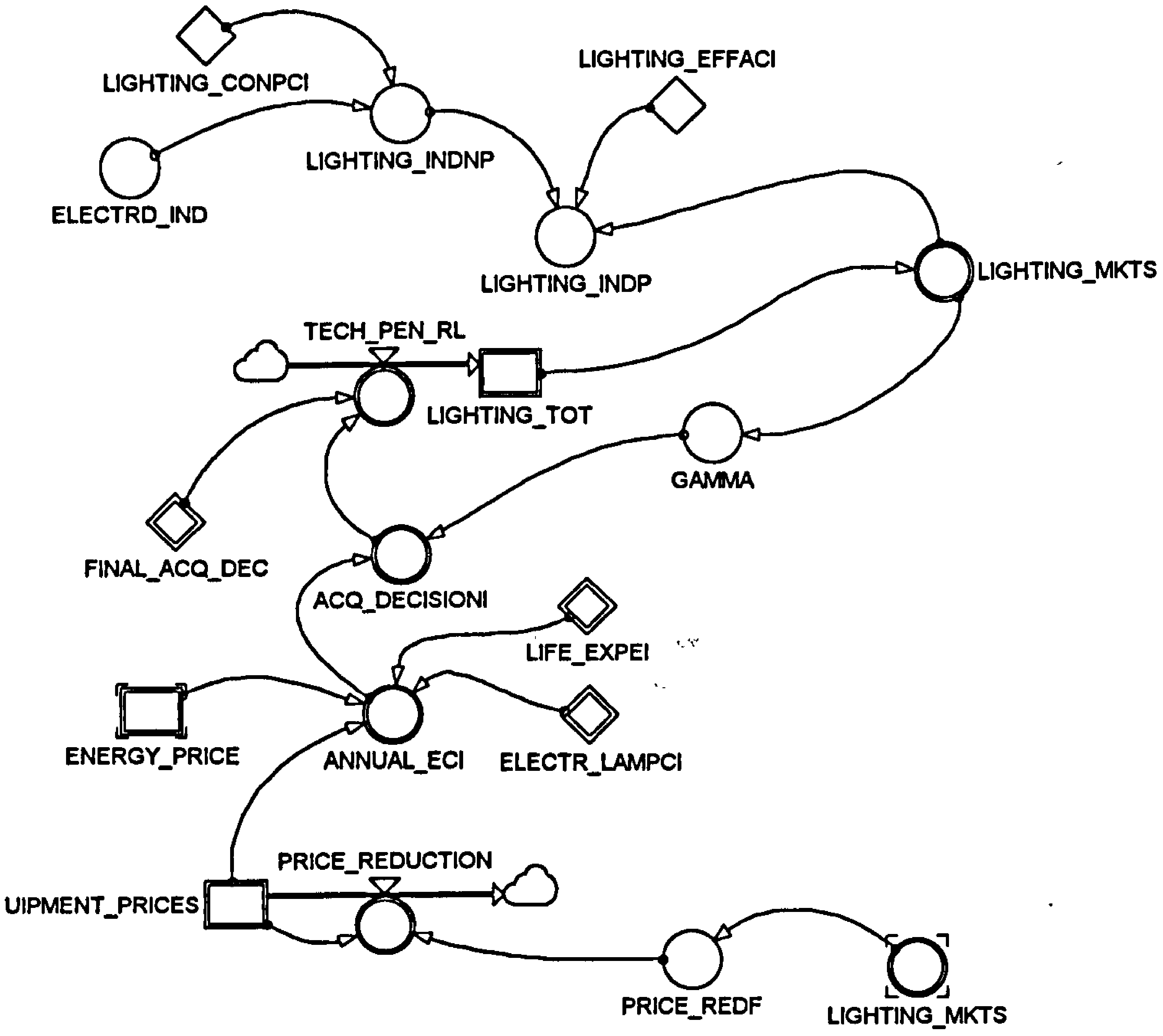
INDUSTRY

Exogenous variables.

ELECTRD_IND: Electricity demand projection for industry.
LIGHTING_CONPCI: Lighting consumption as a percentage of the total electricity demand by the industrial sector.
LIGHTING_EFFACI: Lighting efficient factor in the industry.
FINAL_ACQ_DEC: Lamps actually acquired.
LIFE_EXPI: Life expectancy of lamps in industry.
ELECTR_LAMPCI: Electric consumption by lamps in industry.

Endogenous variables.

LIGHTING_INDNP: Electricity consumption by industry without substitution policies.
LIGHTING_INDP: Electricity consumption by industry with substitution policies.
LIGHTING_MKTS: Market distribution: efficient and not efficient lamps.
GAMMA: Parameter gamma for industrial sector.
TECH_PEN_RL: Technological penetration to lighting in the industry.
LIGHTING_TOT: Cumulative technological factors to industry.
ACQ_DECISIONI: Acquisition decision in industry.
EQUIPMENT_PRICES: Lamp's price.
PRICE_REDUCTION: Reduction of lamp's price.
PRICE_REDF: Reduction factor of lamp's price.
ANNUAL_ECI: Annual equivalent cost for industry.



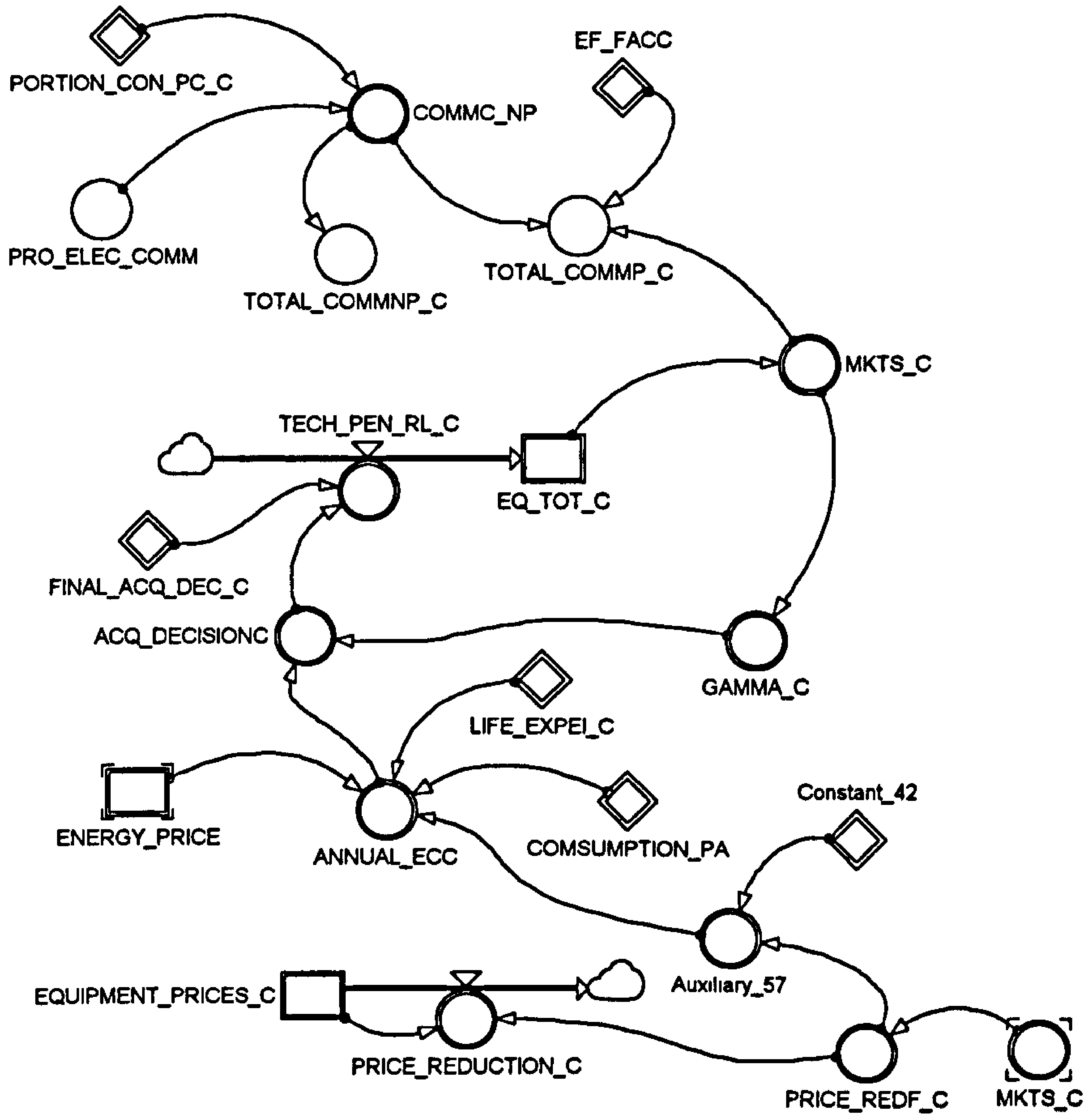
COMMERCE

Exogenous variables.

PRO_ELEC_COMM: Electricity demand projection for commerce.
PORTION_CON_PC_C: Electricity demand share in commerce: lighting, refrigeration and air conditioning.
EF_FACC: Efficiency factor for commerce.
FINAL_ACQ_DEC_C: Equipment actually acquired.
LIFE_EXPEI_C: Life expectancy of equipment the commerce.
COMSUMPTION_PA: Electric consumption per appliance in commerce.
Constant_42: Keep fixed the initial equipment price year to year.

Endogenous variables.

COMMC_NP: Electricity consumption by commerce without substitution policies.
TOTAL_COMMNP_C: Total electricity consumption by commerce without substitution policies.
TOTAL_COMMP_C: Total electricity consumption by commerce with substitution policies.
MKTS_C: Market distribution: efficient and not efficient equipment.
GAMMA_C: Gamma factor for commerce.
TECH_PEN_RL_C: Technological penetration of equipment in the commerce.
EQ_TOT_C: Cumulative technological factors to commerce.
ACQ_DECISIONC: Acquisition decision.
EQUIPMENT_PRICES_C: Equipment's price.
PRICE_REDUCTION_C: Reduction of equipment's price.
PRICE_REDF_C: Reduction factor of equipment's price.
Auxiliary_57: Equipment's price.
ANNUAL_ECC: Annual equivalent cost.



GOVERNMENT

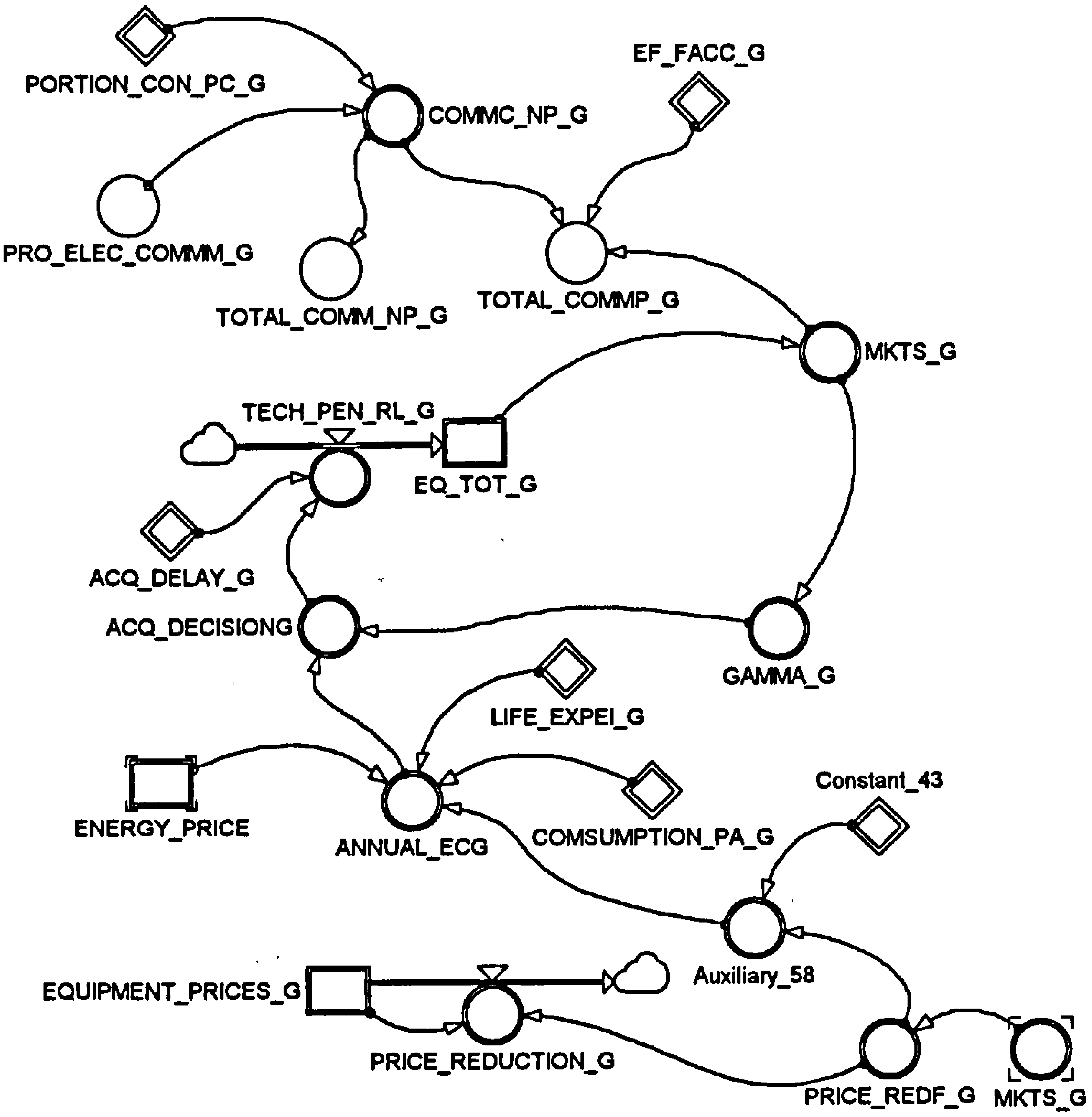
Exogenous variables.

PRO_ELEC_COMMM_G: Electricity demand projection for government.
PORTION_CON_PC_G: Electricity demand share: lighting and air conditioning.
EF_FACC_G: Efficiency factor (government).
ACQ_DELAY_G: Percentage of equipment actually acquired.
LIFE_EXPEI_G: Life expectancy of equipment.
COMSUMPTION_PA_G: Electricity consumption per appliance in government.

Constant_43: Keep fixed the initial equipment price year to year.

Endogenous variables.

COMMC_NP_G: Electricity consumption without substitution policies.
TOTAL_COMM_NP_G: Total electricity consumption without substitution policies.
TOTAL_COMMP_G: Total electricity consumption with substitution policies.
MKTS_G: Market distribution: efficient and not efficient equipment.
GAMMA_G: Gamma factor for government.
TECH_PEN_RL_G: Technological penetration of equipment in the government.
EQ_TOT_G: Cumulative technological factors to government.
ACQ_DECISIONG: Acquisition decision.
EQUIPMENT_PRICES_G: Equipment's price.
PRICE_REDUCTION_G: Reduction of equipment's price.
PRICE_REDF_G: Reduction factor of equipment's price.
Auxiliary_58: Equipment's price.
ANNUAL_ECG: Annual equivalent cost.



ELECTRICITY SUPPLY

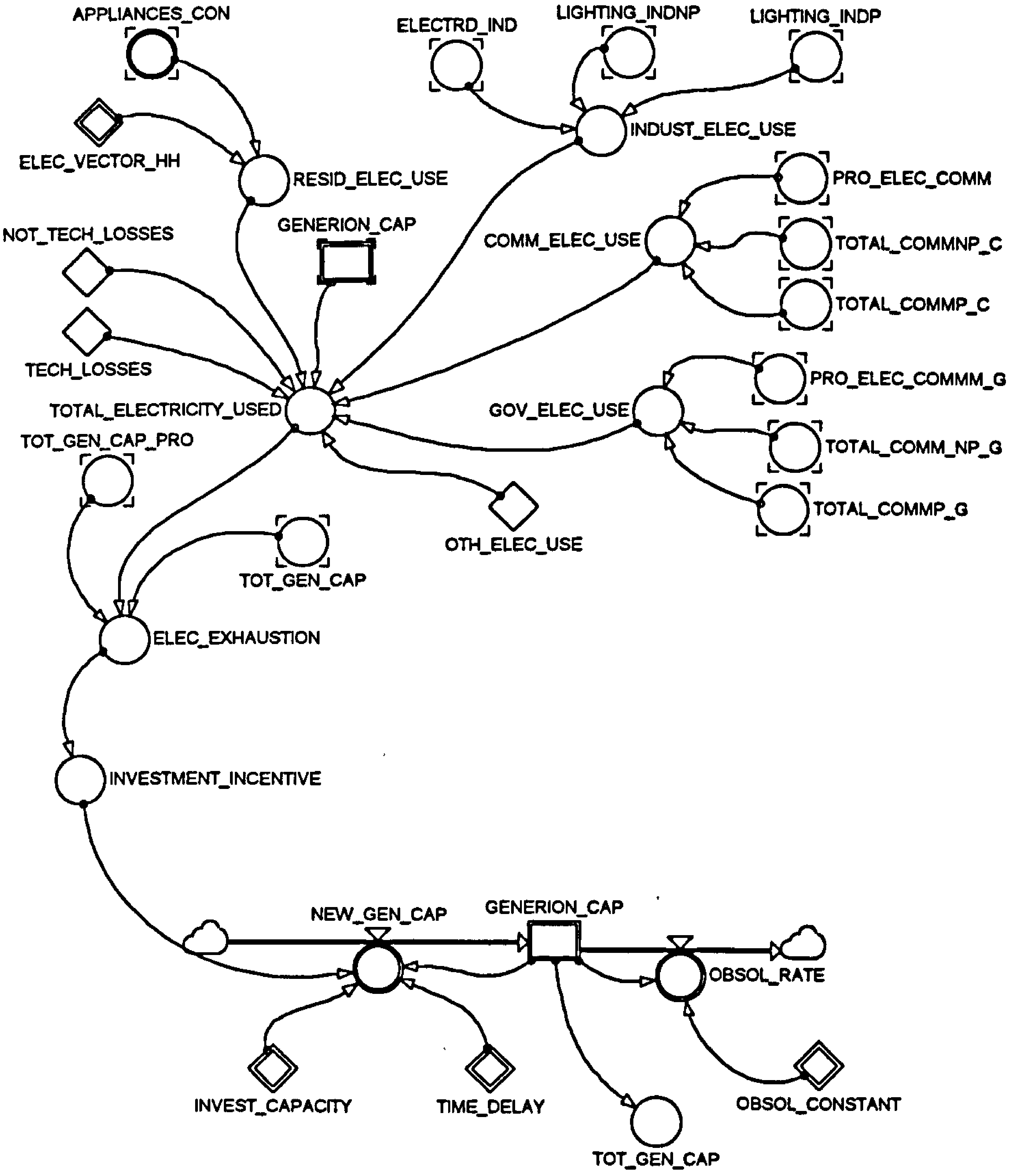
Exogenous variables.

ELEC_VECTOR_HH: Electricity vector to household.
TECH_LOSSES: Percentage of technical losses.
NOT_TECH_LOSSES: Percentage of not technical losses.

OTH_ELEC_USE: Total electricity consumption of all other sectors not explicitly modelled.
OBSOL_CONSTANT: Vector containing the life expectancies of each power generation technology (i.e. hydro, ccgt and coal).
INVEST_CAPACITY: Investment capacity according to power generation technology.
TIME_DELAY: Time delay between the decision of building new power generation capacity and its actual entry date in operation.

Endogenous variables.

RESID_ELEC_USE: Electricity used by the residential sector.
INDUST_ELEC_USE: Electricity used by industry.
COMM_ELEC_USE: Electricity used by commerce.
GOV_ELEC_USE: Electricity used by government.
TOTAL_ELECTRICITY_USED: Total electricity used in Colombia.
ELEC_EXHAUSTION: Percentage capacity not used.
INVESTMENT_INCENTIVE: Indicates whether capacity is needed.
NEW_GEN_CAP: New generation capacity according to technology type.
GENERION_CAP: Generation capacity available according to technology type.
TOT_GEN_CAP: Total generation capacity of Colombia.
OBSOL_RATE: Obsolete capacity.

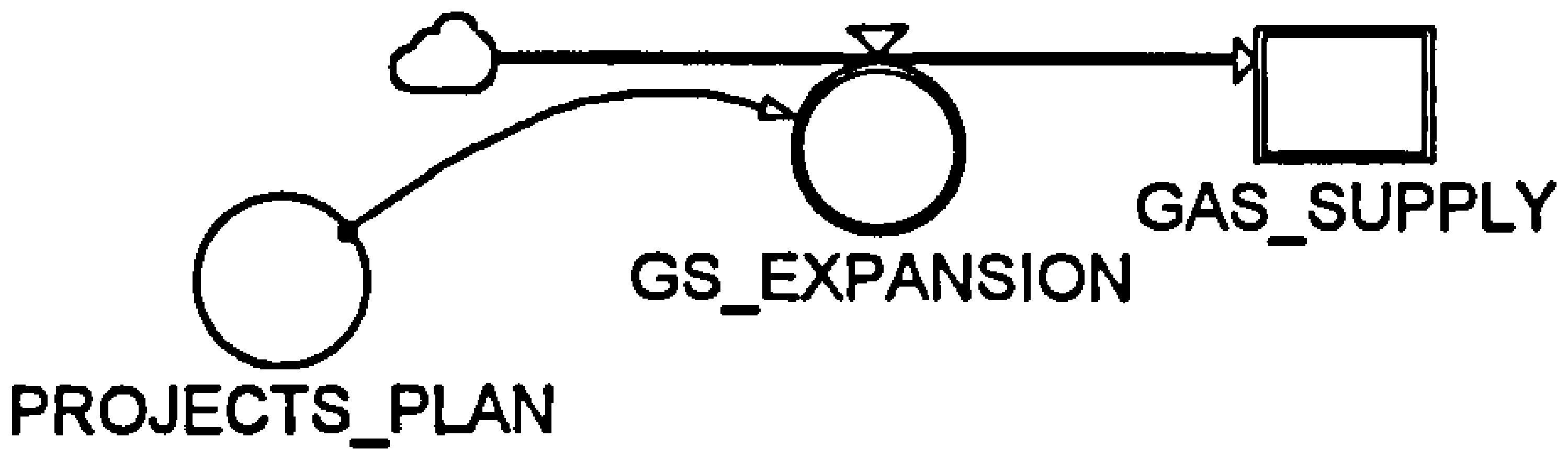


NATURAL GAS, COAL AND WOOD SUPPLY

Exogenous variables.

PROJECTS_PLAN: Plans for new supply.

Endogenous variables.
GS_EXPANSION: New gas available for both the residential sector and the power supply industry.
GAS_SUPPLY: Total gas supply according to end-use.



ENERGY PRICE

Vectors in this section have six components. The order is as follows:

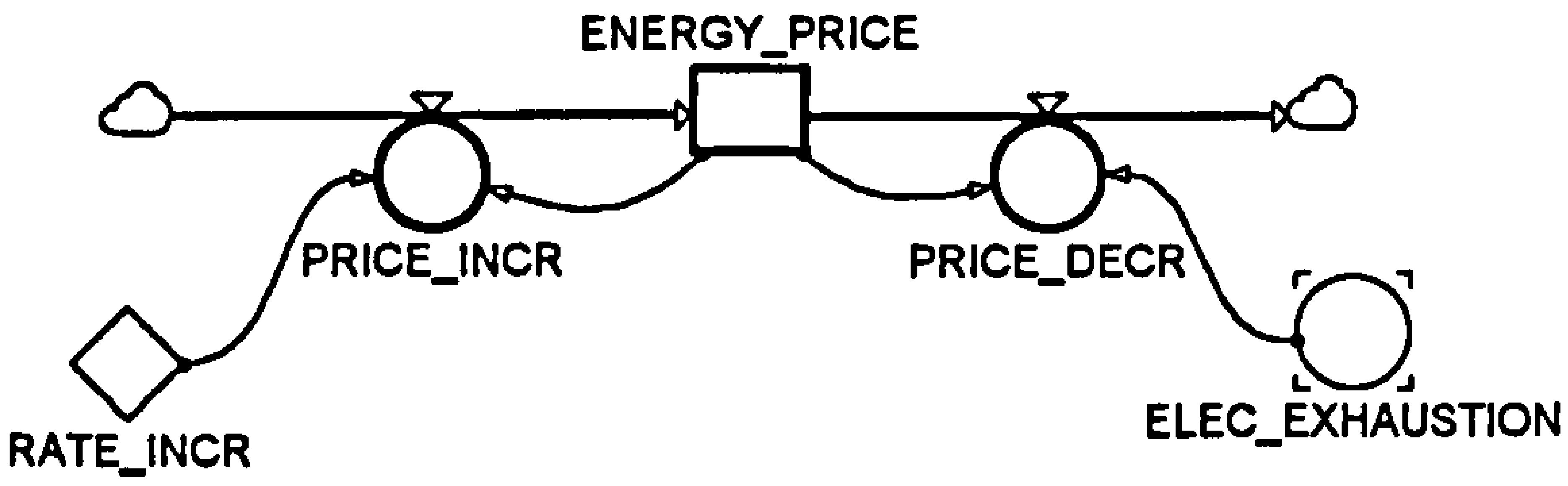
- Electricity
- Natural gas
- Liquefied petroleum gas
- Coal
- Oil
- Wood

Exogenous variables.

RATE_INCR: Price increment rate.

Endogenous variables.

PRICE_INCR: Price increase.
PRICE_DECR: Price decrease.
ENERGY_PRICE: Energy price.



INCREASE CAPACITY AND PROJECTED BALANCE

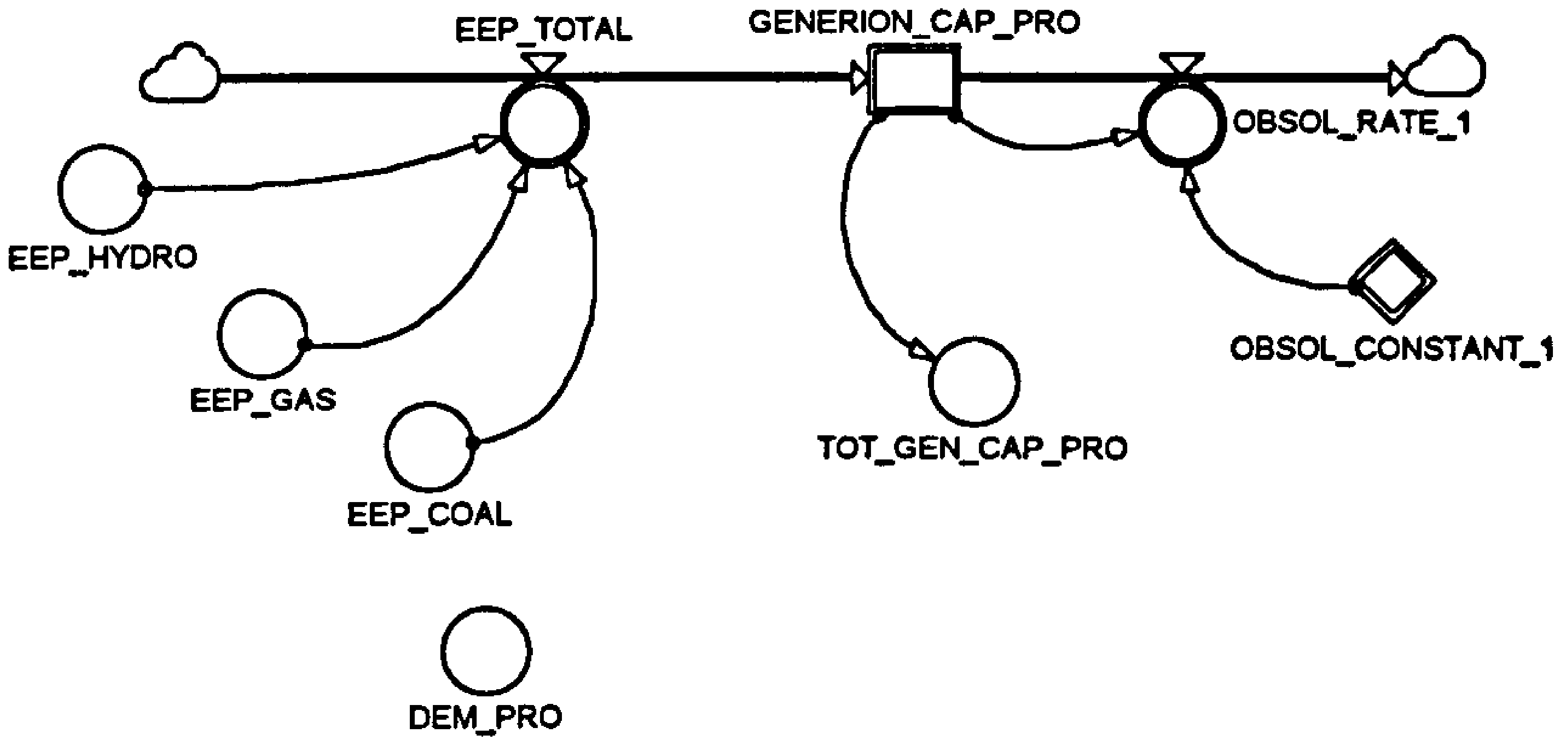
Exogenous variables.

EEP_HYDRO: Expansion plan of hydroelectricity technologies.
EEP_GAS: Expansion plan of gas-based electricity generation technologies.

EEP_COAL: Expansion plan of coal-based electricity generation technologies.
DEM_PRO: Total demand projected.
OBSOL_CONSTANT_1: Vector of life plant expectancies according to technology type.

Endogenous variables:

EEP_TOTAL: New power generation plant.
OBSOL_RATE_1: Obsolete capacity.
GENERION_CAP_PRO: Generation capacity projected according to technology type.
TOT_GEN_CAP_PRO: Total Projected generation capacity of Colombia.



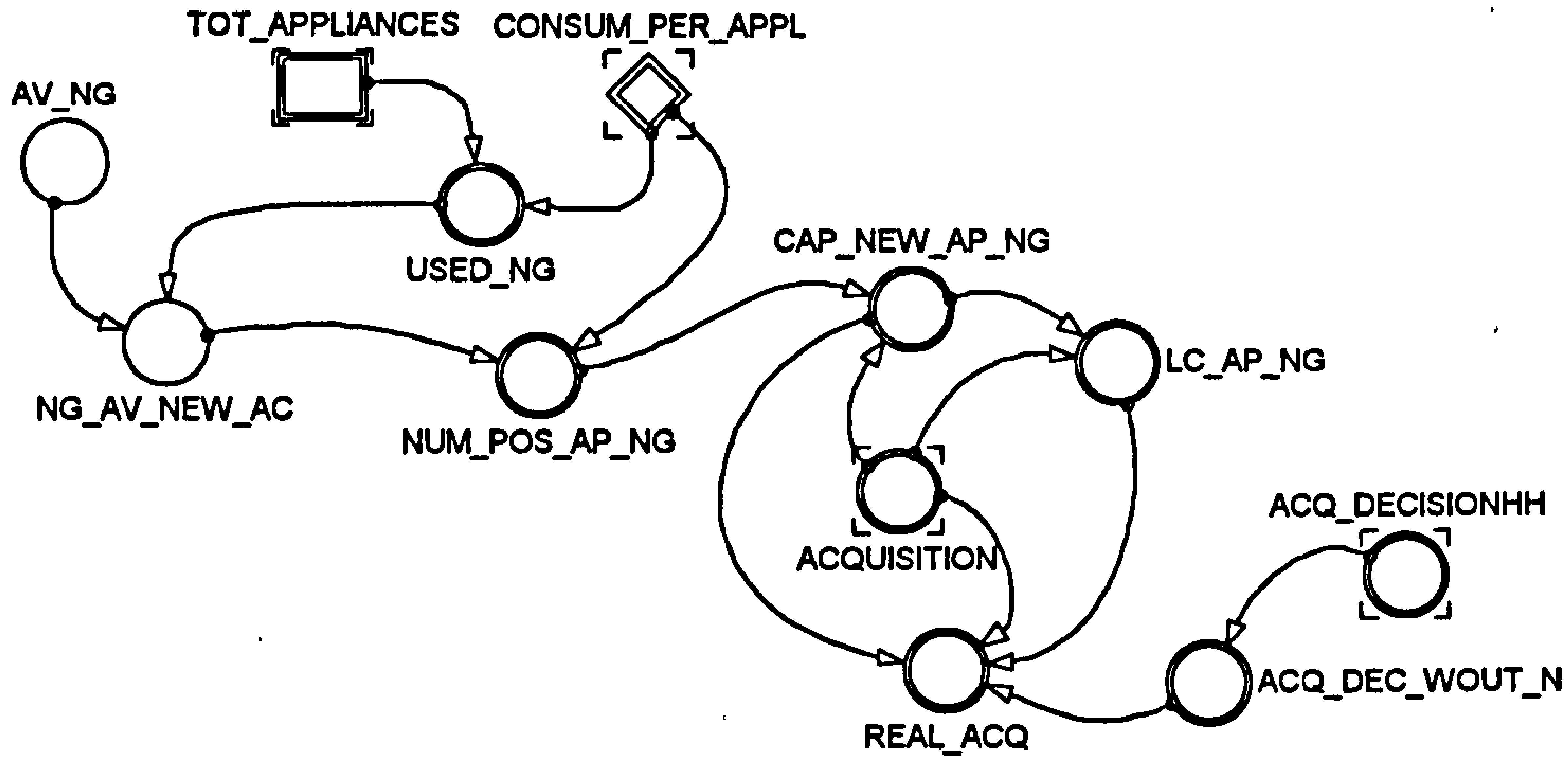
RESTRICTION OF NATURAL GAS CONSUMPTION BECAUSE OF CAPACITY LIMITATION

Exogenous variables.

AV_NG: Natural gas Availability.

Endogenous variables:

USED_NG: Natural gas used.
NG_AV_NEW_AC: Natural gas available for new appliances.
NUM_POS_AP_NG: Maximum number of gas-based appliances.
CAP_NEW_AP_NG: Maximum new gas-based appliances.
LC_AP_NG: Gas-based appliances that must be replace by others fuelled by different energy source.
REAL_ACQ: Actual gas-based appliances acquired.
ACQ_DEC_WOUT_NG: Acquisition of appliances not using natural gas as source.



A.2.2 THE COLOMBIAN PLATFORM

```
dim      APPLIANCES_PRICE = (VAPPLIANCES)
init     APPLIANCES_PRICE =
[72000,86400,63270,63270,100000,67200,127200,127200,750000,5000,1000,11550,11550,10000]
flow     APPLIANCES_PRICE = -dt*PRICE_REDUC
         +dt*PRICE_INCREM
dim      DELAYS_REQ = (1..3)
init     DELAYS_REQ = [0,0,0]
flow     DELAYS_REQ = +dt*EEP_TOTAL
dim      ENERGY_PRICE = (SOURCE)
init     ENERGY_PRICE = [34.94,4.5,4.95,.77,1.16,24] {292.39}
flow     ENERGY_PRICE = -dt*PRICE_DECR
         +dt*PRICE_INCR
doc      ENERGY_PRICE = UNITS USED COL$/kWh EQUIVALENT.  PRICES 1993. PEN 1994,PG136. LPG 10% MORE
EXPENSIVE THAN NG.
dim      EQUIPMENT_PRICES = (1..2)
init     EQUIPMENT_PRICES = [20000,5000]
flow     EQUIPMENT_PRICES = -dt*PRICE_REDUCTION
doc      EQUIPMENT_PRICES = LIGHTING EFFICIENT, LIGHTING NOT EFFICIENT,...
dim      EQUIPMENT_PRICES_C = (1..6)
init     EQUIPMENT_PRICES_C = [20000,5000,100000,100000,100000,100000]
flow     EQUIPMENT_PRICES_C = -dt*PRICE_REDUCTION_C
doc      EQUIPMENT_PRICES_C = LIGHTING EFFICIENT, LIGHTING NOT EFFICIENT, FRIDGES EFFICIENT,
FRIDGES NOT EFFICIENT, AA EFFICIENT, AA NOT EFFICIENT
dim      EQUIPMENT_PRICES_G = (1..4)
init     EQUIPMENT_PRICES_G = [20000,5000,100000,100000]
flow     EQUIPMENT_PRICES_G = -dt*PRICE_REDUCTION_G
doc      EQUIPMENT_PRICES_G = LIGHTING EFFICIENT, LIGHTING NOT EFFICIENT, FRIDGES EFFICIENT,
FRIDGES NOT EFFICIENT, AA EFFICIENT, AA NOT EFFICIENT
dim      GAS_SUPPLY = (1..2)
init     GAS_SUPPLY = [0,0]
flow     GAS_SUPPLY = +dt*GS_EXPANSION
doc      GAS_SUPPLY = [RESIDENTIAL,ELECTRICITY GENERATION]
dim      GENERION_CAP = (ELECGT)
init     GENERION_CAP = [7863,0,2217]*[.7,.7,.7]*365*24
flow     GENERION_CAP = +dt*NEW_GEN_CAP
         -dt*OBSOL_RATE
doc      GENERION_CAP = PLAN DE EXPANSION DE REFERENCIA UPME-ISA/95.
dim      GENERION_CAP_P = (1..3)
init     GENERION_CAP_P = [7863,0,2217]*[.7,.7,.7]*365*24   {Mwh 1994}
flow     GENERION_CAP_P = +dt*ADD_CAP_REQ
         -dt*OBSOL_RATE_1
doc      GENERION_CAP_P = UPME-ISA/95.
init     GNP = 10718793 {BILLIONS}
flow     GNP = +dt*GNP_GROWTH
doc      GNP = 10.72 billion dollars (1993). One billion equals 1000 millions.
init     HOUSES = 5192.6 {thousands of houses in 1991}
flow     HOUSES = +dt*BUILDING
dim      LIGHTING_TOT = (1..2)
init     LIGHTING_TOT = [.1,.9]
flow     LIGHTING_TOT = +dt*TECH_PEN_RL
```

```
dim     LIGHTING_TOT_C = (1..6)
init    LIGHTING_TOT_C = [.1,.9,0,.100,0,.100]
flow    LIGHTING_TOT_C = +dt*TECH_PEN_RL_C
doc     LIGHTING_TOT_C = EFF, NOT EFF
dim     LIGHTING_TOT_G = (1..4)
init    LIGHTING_TOT_G = [.1,.9,0,1]
flow    LIGHTING_TOT_G = +dt*TECH_PEN_RL_G
doc     LIGHTING_TOT_G = EFF, NOT EFF
init    POPULATION = 34200  {MILLIONS 1992}
flow    POPULATION = +dt*PGROWTH
dim     TOT_APPLIANCES = (VAPPLIANCES)
init    TOT_APPLIANCES = APPL_CON_PH*HOUSES*[1,1,1,1,1,.1,.1,.1,.1,1,1,1,1,1]
flow    TOT_APPLIANCES = -dt*ELIMINATION
        +dt*REAL_ADQ
doc     TOT_APPLIANCES = TOTAL APPLIANCES
dim     ADD_CAP_REQ = (1..3)
aux     ADD_CAP_REQ =
DELAYPPL(EEP_TOTAL(1),DELAY_PARAM)*[1,0,0]+DELAYPPL(EEP_TOTAL(2),DELAY_PARAM)*[0,1,0]+DELAYPPL(
EEP_TOTAL(3),DELAY_PARAM)*[0,0,1]
aux     BUILDING = DELAYMTR(EFEC_DEMAND,BUILDING_TIME,3)*CONSTR_FACTOR
dim     EEP_TOTAL = (1..3)
aux     EEP_TOTAL = [1,0,0]*EEP_HYDRO+[0,1,0]*EEP_GAS+[0,0,1]*EEP_COAL
dim     ELIMINATION = (VAPPLIANCES)
aux     ELIMINATION = TOT_APPLIANCES/LIFE_EXPA+SUBST_EXIT*AVERAGE_DELAY
aux     GNP_GROWTH = GNP*VRATE_GNP_GROWTH
dim     GS_EXPANSION = (1..2)
aux     GS_EXPANSION = [.5,.5]*PROJECTS_PLAN
dim     NEW_GEN_CAP = (ELECGT)
aux     NEW_GEN_CAP =
INVESTMENT_INCENTIVE*GENERION_CAP*INVEST_CAPACITY/TIME_DELAY*[1,1,1]+[0,500,0]
dim     OBSOL_RATE = (ELECGT)
aux     OBSOL_RATE = GENERION_CAP*OBSOL_CONSTANT
dim     OBSOL_RATE_1 = (1..3)
aux     OBSOL_RATE_1 = GENERION_CAP_P*OBSOL_CONSTANT_1*0
aux     PGROWTH = POPULATION*VRATE_POP_GROWTH
dim     PRICE_DECR = (SOURCE)
aux     PRICE_DECR = ENERGY_PRICE*0.015*ELEC_EXHAUSTION*0
dim     PRICE_INCR = (SOURCE)
aux     PRICE_INCR = ENERGY_PRICE*RATE_INCR
dim     PRICE_INCREM = (VAPPLIANCES)
aux     PRICE_INCREM = [0.01,0.02,0.01,0.015,0.005,.01,.01,.01,.01,.01,.01,.01,.01,.01]*APPLIANCES_PRICE
dim     PRICE_REDUC = (VAPPLIANCES)
aux     PRICE_REDUC = APPLIANCES_PRICE*0.01*TOT_APPLIANCES^0.05
dim     PRICE_REDUCTION = (1..2)
aux     PRICE_REDUCTION = [1,0]*EQUIPMENT_PRICES*PRICE_REDF
dim     PRICE_REDUCTION_C = (1..6)
aux     PRICE_REDUCTION_C = EQUIPMENT_PRICES_C*PRICE_REDF_C
dim     PRICE_REDUCTION_G = (1..4)
aux     PRICE_REDUCTION_G = EQUIPMENT_PRICES_G*PRICE_REDF_G
dim     REAL_ADQ = (VAPPLIANCES)
aux     REAL_ADQ = [0,0,1,0,0,0,0,0,0,0,0,0,0,0]*CAP_NUE_AP_GN(1)+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*CAP_NUE_AP_GN(2)+ [1,1,0,1,1,1,0,1,1,1,1,1,1,1]*ACQUISITION+
([1,0,0,0,0,0,0,0,0,0,0,0,0,0]*DEC_ADQ_SIN_GN(1)+ [0,1,0,0,0,0,0,0,0,0,0,0,0,0]*DEC_ADQ_SIN_GN(2)+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*DEC_ADQ_SIN_GN(4)+ [0,0,0,0,1,0,0,0,0,0,0,0,0,0]*DEC_ADQ_SIN_GN(5))* AP_GN_FALT(1)+
([0,0,0,0,0,1,0,0,0,0,0,0,0,0]*DEC_ADQ_SIN_GN(6)+ [0,0,0,0,0,0,0,1,0,0,0,0,0,0]*DEC_ADQ_SIN_GN(8)+
[0,0,0,0,0,0,0,0,1,0,0,0,0,0]*DEC_ADQ_SIN_GN(9))*AP_GN_FALT(2)
dim     TECH_PEN_RL = (1..2)
aux     TECH_PEN_RL = ACQ_DECISIONI*FINAL_ACQ_DEC
dim     TECH_PEN_RL_C = (1..6)
aux     TECH_PEN_RL_C = ACQ_DECISIONC*FINAL_ACQ_DEC_C
dim     TECH_PEN_RL_G = (1..4)
aux     TECH_PEN_RL_G = ACQ_DECISIONG*ACQ_DELAY_G
dim     ACQ_DECISIONC = (1..6)
aux     ACQ_DECISIONC = [1,0,0,0,0,0]*ANNUAL_ECC(1)^(-GAMMA_C(1))/SUM(I=1..2;ANNUAL_ECC(I)^(-
GAMMA_C(1)))+ [0,1,0,0,0,0]*ANNUAL_ECC(2)^(-GAMMA_C(1))/SUM(I=1..2;ANNUAL_ECC(I)^(-GAMMA_C(1)))+
[0,0,1,0,0,0]*ANNUAL_ECC(3)^(-GAMMA_C(2))/SUM(I=3..4;ANNUAL_ECC(I)^(-GAMMA_C(2)))+
[0,0,0,1,0,0]*ANNUAL_ECC(4)^(-GAMMA_C(2))/SUM(I=3..4;ANNUAL_ECC(I)^(-GAMMA_C(2)))+
[0,0,0,0,1,0]*ANNUAL_ECC(5)^(-GAMMA_C(3))/SUM(I=5..6;ANNUAL_ECC(I)^(-GAMMA_C(3)))+
[0,0,0,0,0,1]*ANNUAL_ECC(6)^(-GAMMA_C(3))/SUM(I=5..6;ANNUAL_ECC(I)^(-GAMMA_C(3)))
dim     ACQ_DECISIONG = (1..4)
aux     ACQ_DECISIONG = [1,0,0,0]*ANNUAL_ECG(1)^(-GAMMA_G(1))/SUM(I=1..2;ANNUAL_ECG(I)^(-
GAMMA_G(1)))+ [0,1,0,0]*ANNUAL_ECG(2)^(-GAMMA_G(1))/SUM(I=1..2;ANNUAL_ECG(I)^(-GAMMA_G(1)))+
[0,0,1,0]*ANNUAL_ECG(3)^(-GAMMA_G(2))/SUM(I=3..4;ANNUAL_ECG(I)^(-GAMMA_G(2)))+
[0,0,0,1]*ANNUAL_ECG(4)^(-GAMMA_G(2))/SUM(I=3..4;ANNUAL_ECG(I)^(-GAMMA_G(2)))
dim     ACQ_DECISIONHH = (1..14)
```

```
aux	ACQ_DECISIONHH = ([1,0,0,0,0,0,0,0,0,0,0,0,0,0]*AUX_1(1)/SUM(I=1..5;AUX_1(I))+
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*AUX_1(2)/SUM(I=1..5;AUX_1(I))+ [0,0,1,0,0,0,0,0,0,0,0,0,0,0]*AUX_1(3)/SUM(I=1..5;AUX_1(I))+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*AUX_1(4)/SUM(I=1..5;AUX_1(I))+ [0,0,0,0,1,0,0,0,0,0,0,0,0,0]*AUX_1(5)/SUM(I=1..5;AUX_1(I))+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*AUX_1(6)/SUM(I=6..9;AUX_1(I))+ [0,0,0,0,0,0,1,0,0,0,0,0,0,0]*AUX_1(7)/SUM(I=6..9;AUX_1(I))+
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*AUX_1(8)/SUM(I=6..9;AUX_1(I))+ [0,0,0,0,0,0,0,0,1,0,0,0,0,0]*AUX_1(9)/SUM(I=6..9;AUX_1(I))+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*AUX_1(10)/SUM(I=10..11;AUX_1(I))+
[0,0,0,0,0,0,0,0,0,0,1,0,0,0]*AUX_1(11)/SUM(I=10..11;AUX_1(I))+
[0,0,0,0,0,0,0,0,0,0,0,1,0,0]*AUX_1(12)/SUM(I=12..13;AUX_1(I))+
[0,0,0,0,0,0,0,0,0,0,0,0,1,0]*AUX_1(13)/SUM(I=12..13;AUX_1(I))+ [0,0,0,0,0,0,0,0,0,0,0,0,0,1]*AUX_1(14))
dim	ACQ_DECISIONI = (1..2)
aux	ACQ_DECISIONI = [1,0]*ANNUAL_ECI(1)^(-GAMMA)/SUM(I=1..2;ANNUAL_ECI(I)^(-
GAMMA))+[0,1]*ANNUAL_ECI(2)^(-GAMMA)/SUM(I=1..2;ANNUAL_ECI(I)^(-GAMMA))
dim	ACQUISITION = (VAPPLIANCES)
aux	ACQUISITION = APPL_NEWHH+SUBST_ENTRY*AVERAGE_DELAY+REPLACE_OBS
dim	ADQ_DEC_OLD = (1..14)
aux	ADQ_DEC_OLD = [1,0,0,0,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(1)-CON_CH_OLD(1)<0, APPLIENCES_PC(1)-
CON_CH_OLD(1),0)) + [0,1,0,0,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(2)-CON_CH_OLD(2)<0, APPLIENCES_PC(2)-
CON_CH_OLD(2),0))+ [0,0,1,0,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(3)-CON_CH_OLD(3)<0, APPLIENCES_PC(3)-
CON_CH_OLD(3),0))+ [0,0,0,1,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(4)-CON_CH_OLD(4)<0, APPLIENCES_PC(4)-
CON_CH_OLD(4),0))+ [0,0,0,0,1,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(5)-CON_CH_OLD(5)<0, APPLIENCES_PC(5)-
CON_CH_OLD(5),0))+ [0,0,0,0,0,1,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(6)-CON_CH_OLD(6)<0, APPLIENCES_PC(6)-
CON_CH_OLD(6),0))+ [0,0,0,0,0,0,1,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(7)-CON_CH_OLD(7)<0, APPLIENCES_PC(7)-
CON_CH_OLD(7),0))+ [0,0,0,0,0,0,0,1,0,0,0,0,0,0]*(IF(APPLIENCES_PC(8)-CON_CH_OLD(8)<0, APPLIENCES_PC(8)-
CON_CH_OLD(8),0))+ [0,0,0,0,0,0,0,0,1,0,0,0,0,0]*(IF(APPLIENCES_PC(9)-CON_CH_OLD(9)<0, APPLIENCES_PC(9)-
CON_CH_OLD(9),0))+ [0,0,0,0,0,0,0,0,0,1,0,0,0,0]*(IF(APPLIENCES_PC(10)-CON_CH_OLD(10)<0, APPLIENCES_PC(10)-
CON_CH_OLD(10),0))+ [0,0,0,0,0,0,0,0,0,0,1,0,0,0]*(IF(APPLIENCES_PC(11)-CON_CH_OLD(11)<0, APPLIENCES_PC(11)-
CON_CH_OLD(11),0))+ [0,0,0,0,0,0,0,0,0,0,0,1,0,0]*(IF(APPLIENCES_PC(12)-CON_CH_OLD(12)<0, APPLIENCES_PC(12)-
CON_CH_OLD(12),0))+ [0,0,0,0,0,0,0,0,0,0,0,0,1,0]*(IF(APPLIENCES_PC(13)-CON_CH_OLD(13)<0, APPLIENCES_PC(13)-
CON_CH_OLD(13),0)) + [0,0,0,0,0,0,0,0,0,0,0,0,0,1]*0
dim	AEC_OLD_APPL = (VAPPLIANCES)
aux	AEC_OLD_APPL = ANNUAL_EQUIVALENT_COST-.5*APPLIANCES_PRICE/LIFE_EXPA
dim	ANNUAL_ECC = (1..6)
aux	ANNUAL_ECC = Auxiliary_57/LIFE_EXPEI_C+ENERGY_PRICE(ELECTRICITY)*COMSUMPTION_PA
dim	ANNUAL_ECG = (1..4)
aux	ANNUAL_ECG = Auxiliary_58/LIFE_EXPEI_G+ENERGY_PRICE(ELECTRICITY)*COMSUMPTION_PA_G
dim	ANNUAL_ECI = (1..2)
aux	ANNUAL_ECI = EQUIPMENT_PRICES*LIFE_EXPEI+ENERGY_PRICE(ELECTRICITY)*ELECTR_LAMPCI
dim	ANNUAL_EQUIVALENT_COST = (VAPPLIANCES)
aux	ANNUAL_EQUIVALENT_COST =
CONSUM_PER_APPL*PRICE_APPL_SOURCE+MAINTENENCE+APPLIANCES_PRICE/LIFE_EXPA
dim	AP_GN_FALT = (1..2)
aux	AP_GN_FALT = [1,0]*MAX(ACQUISITION(COOKNG)-
CAP_NUE_AP_GN(1),0)+[0,1]*MAX(ACQUISITION(HEATHNG)-CAP_NUE_AP_GN(2),0)
dim	APPL_NEWHH = (VAPPLIANCES)
aux	APPL_NEWHH = ([1,0,0,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(1)+
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(2)+ [0,0,1,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(3)+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(4)+ [0,0,0,0,1,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(5)+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(6)+ [0,0,0,0,0,0,1,0,0,0,0,0,0,0]*ACQ_DECISIONHH(7)+
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*ACQ_DECISIONHH(8)+ [0,0,0,0,0,0,0,0,1,0,0,0,0,0]*ACQ_DECISIONHH(9)+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*ACQ_DECISIONHH(10)+ [0,0,0,0,0,0,0,0,0,0,1,0,0,0]*ACQ_DECISIONHH(11)+
[0,0,0,0,0,0,0,0,0,0,0,1,0,0]*ACQ_DECISIONHH(12)+ [0,0,0,0,0,0,0,0,0,0,0,0,1,0]*ACQ_DECISIONHH(13)+
[0,0,0,0,0,0,0,0,0,0,0,0,0,1]*ACQ_DECISIONHH(14))*(BUILDING)*[1,1,1,1,1,.1,.1,.1,.1,1,1,1,1,1]
dim	APPLIANCES_CON = (VAPPLIANCES)
aux	APPLIANCES_CON = CONSUM_PER_APPL*CONS_FACTOR*TOT_APPLIANCES
dim	APPLIENCES_PC = (1..14)
aux	APPLIENCES_PC = ([1,0,0,0,0,0,0,0,0,0,0,0,0,0]*AUX_5(1)/SUM(I=1..5;AUX_5(I))+
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*AUX_5(2)/SUM(I=1..5;AUX_5(I))+ [0,0,1,0,0,0,0,0,0,0,0,0,0,0]*AUX_5(3)/SUM(I=1..5;AUX_5(I))+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*AUX_5(4)/SUM(I=1..5;AUX_5(I))+ [0,0,0,0,1,0,0,0,0,0,0,0,0,0]*AUX_5(5)/SUM(I=1..5;AUX_5(I))+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*AUX_5(6)/SUM(I=6..9;AUX_5(I))+ [0,0,0,0,0,0,1,0,0,0,0,0,0,0]*AUX_5(7)/SUM(I=6..9;AUX_5(I))+
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*AUX_5(8)/SUM(I=6..9;AUX_5(I))+ [0,0,0,0,0,0,0,0,1,0,0,0,0,0]*AUX_5(9)/SUM(I=6..9;AUX_5(I))+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*AUX_5(10)/SUM(I=10..11;AUX_5(I))+
[0,0,0,0,0,0,0,0,0,0,1,0,0,0]*AUX_5(11)/SUM(I=10..11;AUX_5(I))+
[0,0,0,0,0,0,0,0,0,0,0,1,0,0]*AUX_5(12)/SUM(I=12..13;AUX_5(I))+
[0,0,0,0,0,0,0,0,0,0,0,0,1,0]*AUX_5(13)/SUM(I=12..13;AUX_5(I))+ [0,0,0,0,0,0,0,0,0,0,0,0,0,1]*AUX_5(14))
doc	APPLIENCES_PC = +APPLIANCES_SUBSTITUTION!!!!!
dim	AUX_1 = (1..14)
aux	AUX_1 = [1,0,0,0,0,0,0,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(COOKE))^(GAMMA_R)+
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(COOKEE))^(GAMMA_R)+
[0,0,1,0,0,0,0,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(COOKNG))^(GAMMA_R)+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(COOKLPG))^(GAMMA_R)+
[0,0,0,0,1,0,0,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(COOKW))^(GAMMA_R)+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(HEATHE))^(GAMMA_R)+
[0,0,0,0,0,0,1,0,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(HEATHNG))^(GAMMA_R)+
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(HEATHLPG))^(GAMMA_R)+
[0,0,0,0,0,0,0,0,1,0,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(HEATHS))^(GAMMA_R)+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*(ANNUAL_EQUIVALENT_COST(LIGHTE))^(GAMMA_R)+
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[0,0,0,0,0,0,0,0,0,1,0,0,0]*(ANNUAL_EQUIVALENT_COST(LIGHTEE))^(GAMMA_R)+
[0,0,0,0,0,0,0,0,0,0,1,0,0]*(ANNUAL_EQUIVALENT_COST(FRIDGE))^(GAMMA_R)+
[0,0,0,0,0,0,0,0,0,0,0,1,0]*(ANNUAL_EQUIVALENT_COST(FRIDGEE))^(GAMMA_R)+
[0,0,0,0,0,0,0,0,0,0,0,0,1]*(ANNUAL_EQUIVALENT_COST(OTHERS))^(GAMMA_R)
dim       AUX_3 = (1..14)
aux       AUX_3 = [1,0,0,0,0,0,0,0,0,0,0,0,0]*(AEC_OLD_APPL(COOKE))^(-1)+
[0,1,0,0,0,0,0,0,0,0,0,0,0]*(AEC_OLD_APPL(COOKEE))^(-1)+ [0,0,1,0,0,0,0,0,0,0,0,0,0]*(AEC_OLD_APPL(COOKNG))^(-
1)+ [0,0,0,1,0,0,0,0,0,0,0,0,0]*(AEC_OLD_APPL(COOKLPG))^(-1)+
[0,0,0,0,1,0,0,0,0,0,0,0,0]*(AEC_OLD_APPL(COOKW))^(-1)+ [0,0,0,0,0,1,0,0,0,0,0,0,0]*(AEC_OLD_APPL(HEATHE))^(-1)+
[0,0,0,0,0,0,1,0,0,0,0,0,0]*(AEC_OLD_APPL(HEATHNG))^(-1)+
[0,0,0,0,0,0,0,1,0,0,0,0,0]*(AEC_OLD_APPL(HEATHLPG))^(-1)+ [0,0,0,0,0,0,0,0,1,0,0,0,0]*(AEC_OLD_APPL(HEATHS))^(-
1)+ [0,0,0,0,0,0,0,0,0,1,0,0,0,0]*(AEC_OLD_APPL(LIGHTE))^(-1)+
[0,0,0,0,0,0,0,0,0,1,0,0,0]*(AEC_OLD_APPL(LIGHTEE))^(-1)+ [0,0,0,0,0,0,0,0,0,0,1,0,0]*(AEC_OLD_APPL(FRIDGE))^(-
1)+ [0,0,0,0,0,0,0,0,0,0,0,1,0]*(AEC_OLD_APPL(FRIDGEE))^(-1)+
[0,0,0,0,0,0,0,0,0,0,0,0,1]*(AEC_OLD_APPL(OTHERS))^(-1)
dim       AUX_5 = (1..14)
aux       AUX_5 = ([1,0,0,0,0,0,0,0,0,0,0,0,0]*TOT_APPLIANCES(COOKE)+
[0,1,0,0,0,0,0,0,0,0,0,0,0]*TOT_APPLIANCES(COOKEE)+ [0,0,1,0,0,0,0,0,0,0,0,0,0]*TOT_APPLIANCES(COOKNG)+
[0,0,0,1,0,0,0,0,0,0,0,0,0]*TOT_APPLIANCES(COOKLPG)+ [0,0,0,0,1,0,0,0,0,0,0,0,0]*TOT_APPLIANCES(COOKW)+
[0,0,0,0,0,1,0,0,0,0,0,0,0]*TOT_APPLIANCES(HEATHE)+ [0,0,0,0,0,0,1,0,0,0,0,0,0]*TOT_APPLIANCES(HEATHNG)+
[0,0,0,0,0,0,0,1,0,0,0,0,0]*TOT_APPLIANCES(HEATHLPG)+ [0,0,0,0,0,0,0,0,1,0,0,0,0]*TOT_APPLIANCES(HEATHS)+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*TOT_APPLIANCES(LIGHTE)+ [0,0,0,0,0,0,0,0,0,0,1,0,0,0]*TOT_APPLIANCES(LIGHTEE)+
[0,0,0,0,0,0,0,0,0,0,1,0,0]*TOT_APPLIANCES(FRIDGE)+ [0,0,0,0,0,0,0,0,0,0,0,1,0]*TOT_APPLIANCES(FRIDGEE)+
[0,0,0,0,0,0,0,0,0,0,0,0,1]*TOT_APPLIANCES(OTHERS))
dim       Auxiliary_57 = (1..6)
aux       Auxiliary_57 = PRICE_REDF_C*Constant_42
dim       Auxiliary_58 = (1..4)
aux       Auxiliary_58 = PRICE_REDF_G*Constant_43
aux       BUILDING_PRESURE = MAX(((POPULATION/FAMILY_SIZE)-HOUSES)*HOUSES_FACT,0)
dim       CAP_NUE_AP_GN = (1..2)
aux       CAP_NUE_AP_GN = [1,0]*(IF(NUM_POS_AP_GN(1)-
ACQUISITION(COOKNG)>0,ACQUISITION(COOKNG),NUM_POS_AP_GN(1)))+[0,1]*(IF(NUM_POS_AP_GN(2)-
ACQUISITION(HEATHNG)>0,ACQUISITION(HEATHNG),NUM_POS_AP_GN(2)))
aux       COMM_ELEC_USE = (PRO_ELEC_COMM-TOTAL_COMMNP_C+TOTAL_COMMP_C)*1000
doc       COMM_ELEC_USE = Mwh/year
dim       COMMC_NP = (1..3)
aux       COMMC_NP = PRO_ELEC_COMM*PORTION_CON_PC_C
dim       COMMC_NP_G = (1..2)
aux       COMMC_NP_G = PRO_ELEC_COMM_G*PORTION_CON_PC_G
dim       CON_CH_OLD = (1..14)
aux       CON_CH_OLD = ([1,0,0,0,0,0,0,0,0,0,0,0,0]*AUX_3(1)/SUM(I=1..5;AUX_3(I))+
[0,1,0,0,0,0,0,0,0,0,0,0,0]*AUX_3(2)/SUM(I=1..5;AUX_3(I))+ [0,0,1,0,0,0,0,0,0,0,0,0,0]*AUX_3(3)/SUM(I=1..5;AUX_3(I))+
[0,0,0,1,0,0,0,0,0,0,0,0,0]*AUX_3(4)/SUM(I=1..5;AUX_3(I))+ [0,0,0,0,1,0,0,0,0,0,0,0,0]*AUX_3(5)/SUM(I=1..5;AUX_3(I))+
[0,0,0,0,0,1,0,0,0,0,0,0,0]*AUX_3(6)/SUM(I=6..9;AUX_3(I))+ [0,0,0,0,0,0,1,0,0,0,0,0,0]*AUX_3(7)/SUM(I=6..9;AUX_3(I))+
[0,0,0,0,0,0,0,1,0,0,0,0,0]*AUX_3(8)/SUM(I=6..9;AUX_3(I))+ [0,0,0,0,0,0,0,0,1,0,0,0,0]*AUX_3(9)/SUM(I=6..9;AUX_3(I))+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*AUX_3(10)/SUM(I=10..11;AUX_3(I))+
[0,0,0,0,0,0,0,0,0,1,0,0,0]*AUX_3(11)/SUM(I=10..11;AUX_3(I))+
[0,0,0,0,0,0,0,0,0,0,1,0,0]*AUX_3(12)/SUM(I=12..13;AUX_3(I))+
[0,0,0,0,0,0,0,0,0,0,0,1,0]*AUX_3(13)/SUM(I=12..13;AUX_3(I))+ [0,0,0,0,0,0,0,0,0,0,0,0,1]*AUX_3(14))
aux       CONS_FACTOR =
GRAPH(INCOME,300,30,[0.906,0.912,0.921,0.932,0.954,0.992,1.039,1.067,1.089,1.097,1.1"Min:0.9;Max:1.1"])
dim       DEC_ADQ_SIN_GN = (1..14)
aux       DEC_ADQ_SIN_GN = [1,0,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(1)/(SUM(I=1..5;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(3))+ [0,1,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(2)/(SUM(I=1..5;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(3))+  [0,0,0,1,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(4)/(SUM(I=1..5;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(3))+ [0,0,0,0,1,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(5)/(SUM(I=1..5;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(3))+ [0,0,0,0,0,1,0,0,0,0,0,0,0]*ACQ_DECISIONHH(6)/(SUM(I=6..9;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(7))+ [0,0,0,0,0,0,0,1,0,0,0,0,0]*ACQ_DECISIONHH(8)/(SUM(I=6..9;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(7))+ [0,0,0,0,0,0,0,0,1,0,0,0,0]*ACQ_DECISIONHH(9)/(SUM(I=6..9;ACQ_DECISIONHH(I))-
ACQ_DECISIONHH(7))
aux       DELAY_PARAM = IF(1-(TOT_GEN_CAP_P/TOTAL_ELECTRICITY_USED)<0.12,1,1)
aux       DEM_PRO =
GRAPH(TIME,1993,1,[36957,39598,41878,44339,47365,50732,53477,57000,61056,65389,69984,74996,80336,85975,91988,984
09,105267,112565"Min:36000;Max:115000;Zoom"])*1E3
aux       EEP_COAL = GRAPHSTEP(TIME,1993,1,[0,0,0,0,150,0,300,0,0,0,0,0,0,0,0,0,0"Min:0;Max:1200;Zoom"])*365*24
aux       EEP_GAS =
GRAPHSTEP(TIME,1993,1,[0.34,0.3,0.32,0.34,0.35,10,0,10,0,78,240,1160,590,600,750,0,0,0"Min:0;Max:1200;Zoom"])*365*24
aux       EEP_HYDRO =
GRAPHSTEP(TIME,1993,1,[0.34,0.3,0.32,0.34,0.35,0,732,375,0.36,78,240,1160,590,0,0,0,0,0"Min:0;Max:1200;Zoom"])*365*24
aux       EFEC_DEMAND =
GRAPH(GNPXCAPITA,200,50,[0.68,0.72,0.81,0.85,0.87,0.89,0.93,1,1"Min:0;Max:1;Zoom"])*BUILDING_PRESURE
aux       ELEC_EXHAUSTION = 1-(TOTAL_ELECTRICITY_USED/TOT_GEN_CAP)*1-
(TOTAL_ELECTRICITY_USED/TOT_GEN_CAP_P)*0
aux       ELECTRD_IND =
GRAPH(TIME,1993,1,[8873,9117,9543,10259,11034,11830,12696,13617,14604,15668,16797,18029,19369,20782,22297,23923,
25669,27541"Min:0;Max:40000;Zoom"])
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doc     ELECTRD_IND = Gwh/year UPME.
dim     ELI_DEC_OLD = (1..14)
aux     ELI_DEC_OLD = [1,0,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(1)-CON_CH_OLD(1)>0, APPLIENCES_PC(1)-
CON_CH_OLD(1),0)) + [0,1,0,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(2)-CON_CH_OLD(2)>0, APPLIENCES_PC(2)-
CON_CH_OLD(2),0))+ [0,0,1,0,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(3)-CON_CH_OLD(3)>0, APPLIENCES_PC(3)-
CON_CH_OLD(3),0))+ [0,0,0,1,0,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(4)-CON_CH_OLD(4)>0, APPLIENCES_PC(4)-
CON_CH_OLD(4),0))+ [0,0,0,0,1,0,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(5)-CON_CH_OLD(5)>0, APPLIENCES_PC(5)-
CON_CH_OLD(5),0))+ [0,0,0,0,0,1,0,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(6)-CON_CH_OLD(6)>0, APPLIENCES_PC(6)-
CON_CH_OLD(6),0))+ [0,0,0,0,0,0,1,0,0,0,0,0,0,0]*(IF(APPLIENCES_PC(7)-CON_CH_OLD(7)>0, APPLIENCES_PC(7)-
CON_CH_OLD(7),0))+ [0,0,0,0,0,0,0,1,0,0,0,0,0,0]*(IF(APPLIENCES_PC(8)-CON_CH_OLD(8)>0, APPLIENCES_PC(8)-
CON_CH_OLD(8),0))+ [0,0,0,0,0,0,0,0,1,0,0,0,0,0]*(IF(APPLIENCES_PC(9)-CON_CH_OLD(9)>0, APPLIENCES_PC(9)-
CON_CH_OLD(9),0))+ [0,0,0,0,0,0,0,0,0,1,0,0,0,0]*(IF(APPLIENCES_PC(10)-CON_CH_OLD(10)>0, APPLIENCES_PC(10)-
CON_CH_OLD(10),0))+ [0,0,0,0,0,0,0,0,0,0,1,0,0,0]*(IF(APPLIENCES_PC(11)-CON_CH_OLD(11)>0, APPLIENCES_PC(11)-
CON_CH_OLD(11),0))+ [0,0,0,0,0,0,0,0,0,0,0,1,0,0]*(IF(APPLIENCES_PC(12)-CON_CH_OLD(12)>0, APPLIENCES_PC(12)-
CON_CH_OLD(12),0))+ [0,0,0,0,0,0,0,0,0,0,0,0,1,0]*(IF(APPLIENCES_PC(13)-CON_CH_OLD(13)>0, APPLIENCES_PC(13)-
CON_CH_OLD(13),0)) + [0,0,0,0,0,0,0,0,0,0,0,0,0,1]*0
aux     GAMMA = GRAPH(LIGHTING_MKTS(1),0,0.1,[0.81,0.81,0.8,0.81,0.82,0.82,0.82,0.82,0.82,0.83,0.83"Min:0;Max:2"])
dim     GAMMA_C = (1..3)
aux     GAMMA_C = [1,0,0]*GRAPH(MKTS_C(1),0,0.1,[2,2,2,2,2,2,2,2,2,2,2"Min:0;Max:2"])+
[0,1,0]*GRAPH(MKTS_C(3),0,0.1,[2,2,2,2,2,2,2,2,2,2,2"Min:0;Max:2"])+
[0,0,1]*GRAPH(MKTS_C(5),0,0.1,[2,2,2,2,2,2,2,2,2,2,2"Min:0;Max:2"])
dim     GAMMA_G = (1..2)
aux     GAMMA_G = [1,0]*GRAPH(MKTS_G(1),0,0.1,[2,2,2,2,2,2,2,2,2,2,2"Min:0;Max:2"])+
[0,1]*GRAPH(MKTS_G(3),0,0.1,[2,2,2,2,2,2,2,2,2,2,2"Min:0;Max:2"])
aux     GAS_DISP_NUEV_AD = MAX(GN_DISPONIBLE-ARRSUM(GAS_UTILIZADO), 0)
dim     GAS_UTILIZADO = (VAPPLIANCES)
aux     GAS_UTILIZADO = [0,0,1,0,0,0,1,0,0,0,0,0,0]*TOT_APPLIANCES*CONSUM_PER_APPL
aux     GN_DISPONIBLE =
30*(GRAPH(TIME,1993,1,[130000,190000,230000,280000,320000,350000,410000,510000,570000,640000,680000,710000,740
000,750000,780000,790000,810000,820000"Min:0;Max:1000000;Zoom"]))
aux     GNPXCAPITA = GNP/POPULATION
aux     GOV_ELEC_USE = (PRO_ELEC_COMM_G-TOTAL_COMM_NP_G+TOTAL_COMMP_G)*1000
doc     GOV_ELEC_USE = Mwh/year
aux     INCOME = GNPXCAPITA
aux     INDUST_ELEC_USE = (ELECTRD_IND-LIGHTING_INDNP+LIGHTING_INDP)*1000
doc     INDUST_ELEC_USE = unidades Mwh/year
aux     INVESTMENT_INCENTIVE = IF(ELEC_EXHAUSTION<0.3,1,0)
aux     LIGHTING_INDNP = ELECTRD_IND*LIGHTING_CONPCI
aux     LIGHTING_INDP =
LIGHTING_MKTS(1)*LIGHTING_INDNP*LIGHTING_EFFACI+LIGHTING_MKTS(2)*LIGHTING_INDNP
doc     LIGHTING_INDP = LIGHTING INDUSTRY WITH EFFICIENCY POLICY
dim     LIGHTING_MKTS = (1..2)
aux     LIGHTING_MKTS =
[1,0]*LIGHTING_TOT(1)/SUM(I=1..2;LIGHTING_TOT(I))+[0,1]*LIGHTING_TOT(2)/SUM(I=1..2;LIGHTING_TOT(I))
dim     MKTS_C = (1..6)
aux     MKTS_C =
[1,0,0,0,0,0]*LIGHTING_TOT_C(1)/SUM(I=1..2;LIGHTING_TOT_C(I))+[0,1,0,0,0,0]*LIGHTING_TOT_C(2)/SUM(I=1..2;LIG
HTING_TOT_C(I))+
[0,0,1,0,0,0]*LIGHTING_TOT_C(3)/SUM(I=3..4;LIGHTING_TOT_C(I))+[0,0,0,1,0,0]*LIGHTING_TOT_C(4)/SUM(I=3..4;LIG
HTING_TOT_C(I))+
[0,0,0,0,1,0]*LIGHTING_TOT_C(5)/SUM(I=5..6;LIGHTING_TOT_C(I))+[0,0,0,0,0,1]*LIGHTING_TOT_C(6)/SUM(I=5..6;LIG
HTING_TOT_C(I))
dim     MKTS_G = (1..4)
aux     MKTS_G =
[1,0,0,0]*LIGHTING_TOT_G(1)/SUM(I=1..2;LIGHTING_TOT_G(I))+[0,1,0,0]*LIGHTING_TOT_G(2)/SUM(I=1..2;LIGHTING
_TOT_G(I))+
[0,0,1,0]*LIGHTING_TOT_G(3)/SUM(I=3..4;LIGHTING_TOT_G(I))+[0,0,0,1]*LIGHTING_TOT_G(4)/SUM(I=3..4;LIGHTING
_TOT_G(I))
dim     NUM_POS_AP_GN = (1..2)
aux     NUM_POS_AP_GN = ([1,0]*((.9*GAS_DISP_NUEV_AD)/CONSUM_PER_APPL(COOKNG)))+
([0,1]*((.1*GAS_DISP_NUEV_AD)/CONSUM_PER_APPL(HEATHNG)))
dim     OBSOL = (VAPPLIANCES)
aux     OBSOL = TOT_APPLIANCES/LIFE_EXPA
dim     PRICE_APPL_SOURCE = (VAPPLIANCES)
aux     PRICE_APPL_SOURCE =
ENERGY_PRICE(ELECTRICITY)*[1,1,0,0,0,1,0,0,0,1,1,1,1,0]+ENERGY_PRICE(NATURALG)*[0,0,1,0,0,0,1,0,0,0,0,0,0,0]+EN
ERGY_PRICE(GLP)*[0,0,0,1,0,0,0,1,0,0,0,0,0,0]+ENERGY_PRICE(WOOD)*[0,0,0,0,1,0,0,0,0,0,0,0,0,0]
aux     PRICE_REDF = GRAPH(LIGHTING_MKTS(1),0,0.1,[1,0.85,0.73,0.61,0.53,0.46,0.42,0.4,0.4,0.4,0.4"Min:0;Max:1"])
dim     PRICE_REDF_C = (1..6)
aux     PRICE_REDF_C =
[1,0,0,0,0,0]*GRAPH(MKTS_C(1),0,0.1,[1,0.8,0.7,0.63,0.59,0.55,0.51,0.47,0.43,0.4,0.38"Min:0;Max:1"])+
[0,0,1,0,0,0]*GRAPH(MKTS_C(3),0,0.1,[1,0.8,0.7,0.63,0.59,0.55,0.51,0.47,0.43,0.4,0.38"Min:0;Max:1"])+
[0,0,0,0,1,0]*GRAPH(MKTS_C(5),0,0.1,[1,0.8,0.7,0.63,0.59,0.55,0.51,0.47,0.43,0.4,0.38"Min:0;Max:1"])
dim     PRICE_REDF_G = (1..4)
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aux      PRICE_REDF_G =
[1,0,0,0]*GRAPH(MKTS_G(1),0,0.1,[1,0.8,0.7,0.63,0.59,0.55,0.51,0.47,0.43,0.4,0.38"Min:0;Max:1"])+
[0,0,1,0]*GRAPH(MKTS_G(3),0,0.1,[1,0.8,0.7,0.63,0.59,0.55,0.51,0.47,0.43,0.4,0.38"Min:0;Max:1"])
aux      PRO_ELEC_COMM =
GRAPH(TIME,1993,1,[2756,2893,2969,3100,3251,3408,3533,3673,3842,4019,4203,4396,4599,4789,4987,5193,5410,5636"Min:
0;Max:6000;Zoom"])
doc      PRO_ELEC_COMM = ELECTRICITY DEMAND COMMERCE , Gwh/year, UPME.
aux      PRO_ELEC_COMM_G =
GRAPH(TIME,1993,1,[1756,1921,2115,2318,2500,2709,2741,2930,3145,3377,3629,3892,4146,4419,4703,5004,5325,5693"Min:
0;Max:6000;Zoom"])+GRAPH(TIME,1993,1,[957,965,995,1036,1081,1128,1177,1226,1275,1325,1375,1425,1475,1525,1575,162
6,1676,1727"Min:0;Max:2000;Zoom"])
doc      PRO_ELEC_COMM_G = ELECTRICITY DEMAND COMMERCE [LIGHTING,  AIR CONDITIONING] , Gwh/year,
UPME.
aux      PROJECTS_PLAN =
GRAPHSTEP(TIME,1993,1,[0,36,36,40,11,45,1,17,0,49,13,0,29,23,4,12,62,0.48"Min:0;Max:100;Zoom"])
dim      REPLACE_OBS = (VAPPLIANCES)
aux      REPLACE_OBS =
([1,0,0,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(1)*(OBSOL(COOKE)+OBSOL(COOKEE)+OBSOL(COOKNG)+OBSOL(COO
KLPG)+OBSOL(COOKW)) +
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(2)*(OBSOL(COOKE)+OBSOL(COOKEE)+OBSOL(COOKNG)+OBSOL(COO
KLPG)+OBSOL(COOKW))+
[0,0,1,0,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(3)*(OBSOL(COOKE)+OBSOL(COOKEE)+OBSOL(COOKNG)+OBSOL(COO
KLPG)+OBSOL(COOKW))+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(4)*(OBSOL(COOKE)+OBSOL(COOKEE)+OBSOL(COOKNG)+OBSOL(COO
KLPG)+OBSOL(COOKW))+
[0,0,0,0,1,0,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(5)*(OBSOL(COOKE)+OBSOL(COOKEE)+OBSOL(COOKNG)+OBSOL(COO
KLPG)+OBSOL(COOKW))+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*ACQ_DECISIONHH(6)*(OBSOL(HEATHE)+OBSOL(HEATHNG)+OBSOL(HEATHLPG)+OBSOL(
HEATHS))+
[0,0,0,0,0,0,1,0,0,0,0,0,0,0]*ACQ_DECISIONHH(7)*(OBSOL(HEATHE)+OBSOL(HEATHNG)+OBSOL(HEATHLPG)+OBSOL(
HEATHS)) +
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*ACQ_DECISIONHH(8)*(OBSOL(HEATHE)+OBSOL(HEATHNG)+OBSOL(HEATHLPG)+OBSOL(
HEATHS))+
[0,0,0,0,0,0,0,0,1,0,0,0,0,0]*ACQ_DECISIONHH(9)*(OBSOL(HEATHE)+OBSOL(HEATHNG)+OBSOL(HEATHLPG)+OBSOL(
HEATHS))+ [0,0,0,0,0,0,0,0,0,1,0,0,0,0]*ACQ_DECISIONHH(10)*(OBSOL(LIGHTE)+OBSOL(LIGHTEE))+
[0,0,0,0,0,0,0,0,0,0,1,0,0,0]*ACQ_DECISIONHH(11)*(OBSOL(LIGHTE)+OBSOL(LIGHTEE))+
[0,0,0,0,0,0,0,0,0,0,0,1,0,0]*ACQ_DECISIONHH(12)*(OBSOL(FRIDGE)+OBSOL(FRIDGEE))+
[0,0,0,0,0,0,0,0,0,0,0,0,1,0]*ACQ_DECISIONHH(13)*(OBSOL(FRIDGE)+OBSOL(FRIDGEE))+
[0,0,0,0,0,0,0,0,0,0,0,0,0,1]*ACQ_DECISIONHH(14)*OBSOL(OTHERS))
aux      RESID_ELEC_USE = SPROD(APPLIANCES_CON, ELEC_VECTOR_HH)/1000
doc      RESID_ELEC_USE = Mwh/year
dim      SUBST_ENTRY = (VAPPLIANCES)
aux      SUBST_ENTRY =
([1,0,0,0,0,0,0,0,0,0,0,0,0,0]*ADQ_DEC_OLD(1)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLI
ANCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW)) +
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*ADQ_DEC_OLD(2)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,1,0,0,0,0,0,0,0,0,0,0,0]*ADQ_DEC_OLD(3)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*ADQ_DEC_OLD(4)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,0,0,1,0,0,0,0,0,0,0,0,0]*ADQ_DEC_OLD(5)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*ADQ_DEC_OLD(6)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APP
LIANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS))+
[0,0,0,0,0,0,1,0,0,0,0,0,0,0]*ADQ_DEC_OLD(7)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APP
LIANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS)) +
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*ADQ_DEC_OLD(8)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APP
LIANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS))+
[0,0,0,0,0,0,0,0,1,0,0,0,0,0]*ADQ_DEC_OLD(9)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APP
LIANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS))+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*ADQ_DEC_OLD(10)*(TOT_APPLIANCES(LIGHTE)+TOT_APPLIANCES(LIGHTEE))+
[0,0,0,0,0,0,0,0,0,0,1,0,0,0]*ADQ_DEC_OLD(11)*(TOT_APPLIANCES(LIGHTE)+TOT_APPLIANCES(LIGHTEE))+
[0,0,0,0,0,0,0,0,0,0,0,1,0,0]*ADQ_DEC_OLD(12)*(TOT_APPLIANCES(FRIDGE)+TOT_APPLIANCES(FRIDGEE))+
[0,0,0,0,0,0,0,0,0,0,0,0,1,0]*ADQ_DEC_OLD(13)*(TOT_APPLIANCES(FRIDGE)+TOT_APPLIANCES(FRIDGEE))+
[0,0,0,0,0,0,0,0,0,0,0,0,0,1]*ADQ_DEC_OLD(14)*TOT_APPLIANCES(OTHERS))*(-1)
dim      SUBST_EXIT = (VAPPLIANCES)
aux      SUBST_EXIT =
[1,0,0,0,0,0,0,0,0,0,0,0,0,0]*ELI_DEC_OLD(1)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW)) +
[0,1,0,0,0,0,0,0,0,0,0,0,0,0]*ELI_DEC_OLD(2)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,1,0,0,0,0,0,0,0,0,0,0,0]*ELI_DEC_OLD(3)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,0,1,0,0,0,0,0,0,0,0,0,0]*ELI_DEC_OLD(4)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
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[0,0,0,0,1,0,0,0,0,0,0,0,0,0]*ELI_DEC_OLD(5)*(TOT_APPLIANCES(COOKE)+TOT_APPLIANCES(COOKEE)+TOT_APPLIA
NCES(COOKNG)+TOT_APPLIANCES(COOKLPG)+TOT_APPLIANCES(COOKW))+
[0,0,0,0,0,1,0,0,0,0,0,0,0,0]*ELI_DEC_OLD(6)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APPL
IANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS))+
[0,0,0,0,0,0,1,0,0,0,0,0,0,0]*ELI_DEC_OLD(7)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APPL
IANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS)) +
[0,0,0,0,0,0,0,1,0,0,0,0,0,0]*ELI_DEC_OLD(8)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APPL
IANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS))+
[0,0,0,0,0,0,0,0,1,0,0,0,0,0]*ELI_DEC_OLD(9)*(TOT_APPLIANCES(HEATHE)+TOT_APPLIANCES(HEATHNG)+TOT_APPL
IANCES(HEATHLPG)+TOT_APPLIANCES(HEATHS))+
[0,0,0,0,0,0,0,0,0,1,0,0,0,0]*ELI_DEC_OLD(10)*(TOT_APPLIANCES(LIGHTE)+TOT_APPLIANCES(LIGHTEE))+
[0,0,0,0,0,0,0,0,0,0,1,0,0,0]*ELI_DEC_OLD(11)*(TOT_APPLIANCES(LIGHTE)+TOT_APPLIANCES(LIGHTEE))+
[0,0,0,0,0,0,0,0,0,0,0,1,0,0]*ELI_DEC_OLD(12)*(TOT_APPLIANCES(FRIDGE)+TOT_APPLIANCES(FRIDGEE))+
[0,0,0,0,0,0,0,0,0,0,0,0,1,0]*ELI_DEC_OLD(13)*(TOT_APPLIANCES(FRIDGE)+TOT_APPLIANCES(FRIDGEE))+
[0,0,0,0,0,0,0,0,0,0,0,0,0,1]*ELI_DEC_OLD(14)*TOT_APPLIANCES(OTHERS)
aux     TOT_GEN_CAP = ARRSUM(GENERION_CAP)
aux     TOT_GEN_CAP_P = ARRSUM(GENERION_CAP_P)
aux     TOTAL_COMM_NP_G = ARRSUM(COMMC_NP_G)
aux     TOTAL_COMMNP_C = ARRSUM(COMMC_NP)
aux     TOTAL_COMMP_C =
MKTS_C(1)*EF_FACC(1)*COMMC_NP(1)+MKTS_C(3)*EF_FACC(2)*COMMC_NP(2)+MKTS_C(5)*EF_FACC(3)*COMMC_
NP(3)+MKTS_C(2)*COMMC_NP(1)+MKTS_C(4)*COMMC_NP(2)+MKTS_C(6)*COMMC_NP(3)
doc     TOTAL_COMMP_C = LIGHTING INDUSTRY WITH EFFICIENCY POLICY
aux     TOTAL_COMMP_G =
MKTS_G(1)*EF_FACC_G(1)*COMMC_NP_G(1)+MKTS_G(3)*EF_FACC_G(2)*COMMC_NP_G(2)+MKTS_G(2)*COMMC_N
P_G(1)+MKTS_G(4)*COMMC_NP_G(2)
doc     TOTAL_COMMP_G = LIGHTING INDUSTRY WITH EFFICIENCY POLICY
aux     TOTAL_ELECTRICITY_USED =
(INDUST_ELEC_USE+RESID_ELEC_USE+COMM_ELEC_USE+GOV_ELEC_USE+OTH_ELEC_USE)*(1+NOT_TECH_LOS
SES+TECH_LOSSES)+SPROD(GENERION_CAP, [.003,.064,.064])
doc     TOTAL_ELECTRICITY_USED = Unidades Mwh/año.
aux     VRATE_GNP_GROWTH =
GRAPH(TIME,1993,1,[0.045,0.056,0.06,0.051,0.054,0.063,0.043,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05,0.05"Min:0;Ma
x:0.15;Zoom"])
doc     VRATE_GNP_GROWTH = UPME-E011/95
aux     VRATE_POP_GROWTH =
GRAPH(TIME,1993,1,[0.019,0.01825,0.01754,0.01712,0.0166,0.01618,0.01589,0.01544,0.01509,0.01488,0.01463,0.01439,0.014
21,0.0141,0.01389,0.01372,0.01358,0.01358"Min:0.012;Max:0.02;Zoom"])
dim     ACQ_DELAY_G = (1..4)
const   ACQ_DELAY_G = [0.5,0.1,0.1,0.1]
dim     APPL_CON_PH = (VAPPLIANCES)
const   APPL_CON_PH = [0.43,0,0.1,0.17,0.29,0.98,0.0067,0.0067,0.0067,1,0,1,0,1]
doc     APPL_CON_PH = % APPLIANCES PER HOUSEHOLD. 1 TO 5 COOKING. 6 TO 9 HEATING. 10 TO 11
LIGHTING. 12 TO 13 FRIDGES. 14 OTHERS. EACH GROUP SHOULD ADD TO 1.
const   AVERAGE_DELAY = .4
const   BUILDING_TIME = 1.75
dim     COMSUMPTION_PA = (1..6)
const   COMSUMPTION_PA = [3300,5000,2000,2500,2000,2500]
doc     COMSUMPTION_PA = ELECTRICITY CONSUMPTION PER LAMP PER YEAR [EFFICIENT LAMP, NOT
EFFICIENT LAMP, EFFICIENT FRIDGES, NOT EFFICIENT FRIDGES, EFFICIENT AA, NOT EFFICIENT AA]
dim     COMSUMPTION_PA_G = (1..4)
const   COMSUMPTION_PA_G = [3300,5000,2000,2500]
doc     COMSUMPTION_PA_G = ELECTRICITY CONSUMPTION PER LAMP PER YEAR [EFFICIENT LAMP, NOT
EFFICIENT LAMP, EFFICIENT FRIDGES, NOT EFFICIENT FRIDGES, EFFICIENT AA, NOT EFFICIENT AA]
dim     Constant_42 = (1..6)
const   Constant_42 = [20000,5000,200000,100000,200000,100000]
dim     Constant_43 = (1..4)
const   Constant_43 = [20000,5000,200000,100000]
const   CONSTR_FACTOR = 0.33
dim     CONSUM_PER_APPL = (VAPPLIANCES)
const   CONSUM_PER_APPL = [5000,3000,3600,3600,10000,7250,5400,5400,0,3000,4000,2250,2250,1000]    {KWh
EQUIVALENT IN A YEAR}
dim     EF_FACC = (1..3)
const   EF_FACC = [.8, .8, .8]
doc     EF_FACC = [LIGHTING, FRIDGES, AA] EFFICIENCY FACTOR IN COMMERCE
dim     EF_FACC_G = (1..2)
const   EF_FACC_G = [.8, .8]
doc     EF_FACC_G = [LIGHTING, AA] EFFICIENCY FACTOR IN PUBLIC SECTOR
dim     ELEC_VECTOR_HH = (VAPPLIANCES)
const   ELEC_VECTOR_HH = [1,1,0,0,0,1,0,0,0,1,1,1,1,0]
dim     ELECTR_LAMPCI = (1..2)
const   ELECTR_LAMPCI = [3300,5000]
doc     ELECTR_LAMPCI = ELECTRICITY CONSUMPTION PER LAMP PER YEAR [EFFICIENT LAMP, NOT
EFFICIENT LAMP]
const   FAMILY_SIZE = 5
dim     FINAL_ACQ_DEC = (1..2)
```

```
const    FINAL_ACQ_DEC = [0.5,0.1]
dim      FINAL_ACQ_DEC_C = (1..6)
const    FINAL_ACQ_DEC_C = [0.5,0.1,0.1,0.1,.1,.1]
const    GAMMA_R = -.8
const    HOUSES_FACT = 1.05
doc      HOUSES_FACT = AVERAGE HOUSES PER FAMILY.
dim      INVEST_CAPACITY = (ELECGT)
const    INVEST_CAPACITY = [1,1,1]
dim      LIFE_EXPA = (VAPPLIANCES)
const    LIFE_EXPA = [15,15,12,12,20,10,15,15,30,1,3,20,20,5]
dim      LIFE_EXPEI = (1..2)
const    LIFE_EXPEI = [1,0.2]
dim      LIFE_EXPEI_C = (1..6)
const    LIFE_EXPEI_C = [3,1,20,20,20,20]
dim      LIFE_EXPEI_G = (1..4)
const    LIFE_EXPEI_G = [3,1,20,20]
const    LIGHTING_CONPCI = .06
const    LIGHTING_EFFACI = .8
dim      MAINTENENCE = (VAPPLIANCES)
const    MAINTENENCE = [0,0,0,30000,100000,2000,2000,20000,8000,0,0,0,0,0]
const    NOT_TECH_LOSSES = .12
dim      OBSOL_CONSTANT = (ELECGT)
const    OBSOL_CONSTANT = [0.02,0.04,0.033]
dim      OBSOL_CONSTANT_1 = (1..3)
const    OBSOL_CONSTANT_1 = [0.02,0.04,0.033]
const    OTH_ELEC_USE = 0
doc      OTH_ELEC_USE = Mwh/year
dim      PORTION_CON_PC_C = (1..3)
const    PORTION_CON_PC_C = [.143,.266,.208]
doc      PORTION_CON_PC_C = [LIGHTING, FRIDGES, AA] PORTION OF ELECTRICITY CONSUMPTION IN THE
COMMERCE SECTOR
dim      PORTION_CON_PC_G = (1..2)
const    PORTION_CON_PC_G = [.334,.167]
doc      PORTION_CON_PC_G = [LIGHTING,  AA] PORTION OF ELECTRICITY CONSUMPTION IN THE PUBLIC
SECTOR
const    RATE_INCR = 0.01
const    TECH_LOSSES = .12
dim      TIME_DELAY = (ELECGT)
const    TIME_DELAY = [9,3,7]
```

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