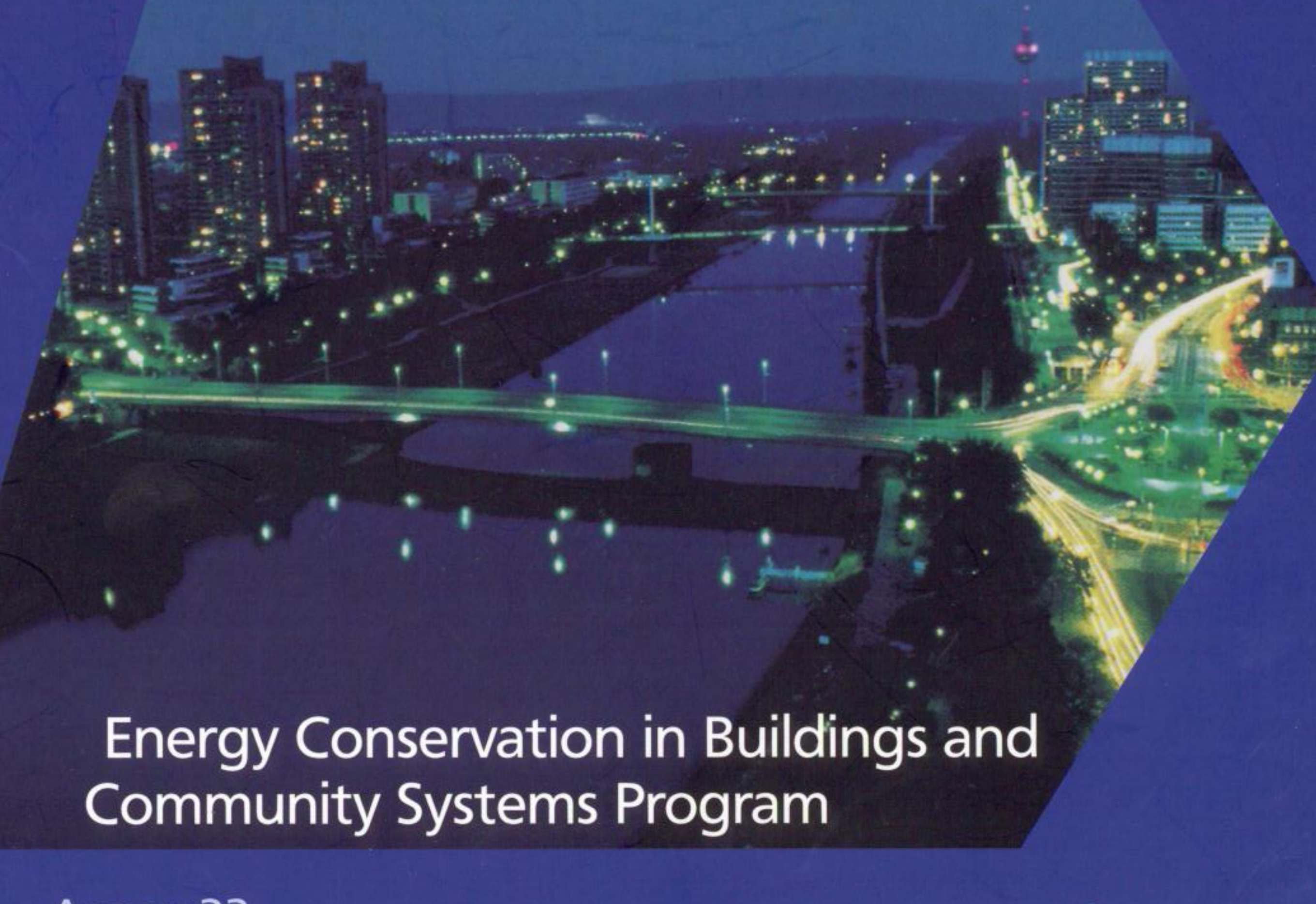
International Energy Agency



Energy Conservation in Buildings and Community Systems Program

Annex 33
Advanced Local Energy Planning (ALEP) – a Guidebook

Participating Countries: Germany • Italy • Sweden • The Netherlands

Edited by
Reinhard Jank
Klimaschutz- und Energieagentur
Baden-Württemberg GmbH
Karlsruhe, Germany

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Main authors:

Thomas Steidle Christoph Schlenzig	IER - Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart, Germany
Vincenzo Cuomo Maria Macchiato	IMAAA-CNR - Institute of Advanced Methodologies for Environmental Analysis, Basilicata, Italy INFM – National Institute for Physics of Matter, Italy
Evasio Lavagno	LAME - Energy Department, Politecnico di Torino, Italy
Bo Rydèn	Profu AB, Mölndal, Sweden
Sander Willemsen Wilbert Grevers	G3 Advies, Beusichem, The Netherlands
Reinhard Jank (Editor)	Klimaschutz- und Energieagentur Baden-Württemberg GmbH, Karlsruhe, Germany

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Fachinstitut Gebäude Klima e.V.(FGK)
Danziger Str. 30
D-74321 Bietigheim-Bissingen, Germany
(fgk-ev@t-online.de)

Preface

The International Energy Agency's Implementing Agreement for a Programme of Research and Development on Energy Conservation in Buildings and Community Systems was established in Paris on March 16, 1977, to conduct cooperative research, development, demonstrations and information exchange towards achieving the objective of a sustainable energy supply system. This IEA-work is realized by undertaking a series of "Annexes", which are established to coalesce the knowledge gained through research and development performed by participating countries on a particular topic.

Since 1977, more than 40 Annexes have been started by all, or a subset of the 18 countries which have undersigned that Implementing Agreement. Almost all of these Annexes are devoted to the first part of the agreement's title, Energy Conservation in Buildings. Much progress there has been made in this field since 1977, which is also documented in many of the final reports of these Annexes. In contrast to this „microscopic" view of the municipality, the municipal energy supply and demand system as a whole was hardly ever the subject of R&D – with some exceptions. Whereas the analysis of the energy demand of buildings requires research in buildings physics, as well as methodological research, such as the development of dynamic simulation models or data bases for life-cycle analyses, „community systems" analysis requires the consideration of the „macroscopic" aspects of a municipality, including the municipal energy supply infrastructure, along with waste incineration. Thus, the „systems" aspect is much more important in this case.

Energy supply of communities and the potential to improve energy efficiencies to tap into new energy resources and to reduce energy demands has gained increasing interest from municipal administrations in recent years. Environmental issues shifted more into the center of interest during the eighties, and this was later enforced by increased concern about the effects of green house gases on the atmosphere. Due to these developments, major efforts have been undertaken in some countries to develop and apply the instrument of *Local Energy Planning* (LEP) as a tool to make integrated planning of entire community systems possible. In fact, LEP was in recent years increasingly considered as a kind of "meta-planning" instrument, which integrates the knowledge and experiences of various planning disciplines to enable the urban administration to simultaneously optimize the entire municipal organisation under a variety of given goals.

The potential of LEP to improve the urban environmental situation is by far not exhausted. The reduction potentials of municipal energy consumption and the actual reductions attained still diverge widely (in most cases). Often this is caused by insufficient application of LEP or the absence of LEP at all, such as when the responsibilty for energy conservation is left to the owners of individual buildings and the local utility. Moreover, due to quite different legal requirements/regulations, major differences in the development and application of LEP in different IEA-countries have been observed, as reported in Annex 22, *Energy Efficient Communities*, which was carried out between 1991 and 1993 in six IEA countries (Belgium, France, Germany, Italy, Sweden, Turkey).

One result of this Annex 22 was that continous application of LEP in countries like Sweden or Germany gave planners in municipal administrations, utilities and private consultants an overall familiarity with the means and tools of LEP. With increasing use of personal computers, planners began to use a growing number of special tools for economic or environmental calculations, geographical or customer information systems and data bases. Many of these were described in Annex 22. However, one important conclusion of Annex 22 was that almost no use of *systems optimization models*, developed and available in the field of systems analysis, were found in the application of LEP, with the exception of applications at Chalmers University of Göteborg and in Denmark. The reason for this was the absence of any information on the existence of such models amongst planners. In the final report of Annex 22 it was stated that „whereas partial solutions and tools have been developed and documented quite broadly in the past ten or fifteen years of LEP-applications, still a long way has to be gone to provide fully consistent and scientifically supported instruments for the supply of professional LEP-solutions."

Recognizing this gap between the availability of scientific solutions and their use in practice, four countries decided to carry out practical applications of the Linear Programming Optimization Model *MARKAL* with concrete case studies, to exchange experiences on the use of the model and its outcome, and to provide a „Guidebook on Advanced Local Energy Planning" (ALEP). The four countries (Germany, Italy, Sweden and The Netherlands) then began Annex 33 *„Advanced Local Energy Planning"*, focusing both on the application of MARKAL in LEP case studies, as well as on the evaluation of modern methods of „process management" in LEP projects, which are usually used in complex decision-making processes. One product of this Annex is the „Guidebook on Advanced Local Energy Planning", which is presented here.

Many colleagues have contributed to this work, which is the product of a continous co-operation throughout the course of Annex 33. The four participating countries established a guidebook working group to discuss all material. The main authors of the specific chapters are:

R. Jank	Chapter 1	
Th. Steidle	Chapter 2 and 3	
B. Rydèn, H. Sköldberg and S. Rath-Nagel	Chapter 4	
	Chapter 5	Case Study Managers: 5.1 – V. Cuomo and M. Macchiato 5.2 – E. Lavagno and D. Scaramuccia 5.3 – E. Lavagno 5.4 – B. Rydèn and H. Sköldberg 5.5 – R. Jank and Th. Kilthau 5.6 – W. Grevers
V. Cuomo, M. Salvia and Ch. Schlenzig	Appendix A.1	
V. Cuomo and M. Macchiato	Appendix A.2	
M. Macchiato and C. Cosmi	Appendix A.3	

I gratefully acknowledge the cooperation of these individuals. In addition, I want to emphasize the helpful cooperation of all participating countries, represented by Prof. Vincenzo Cuomo, Prof. Maria Macchiato, Monica Salvia, Lucia Mangiamele and Carmelina Cosmi, from INFM – National Institute for Physics of Matter; IMAAA-CNR – Institute of Advanced Methodologies for Environmental Analysis – National Research Council of Italy; DIFA – Department of Environmental Engineering and Physics, University of Basilicata; Prof. Evasio Lavagno, Chiara Cordegone, D. Scaramuccia, Angelo Venezia and Giuliano Zoppo, from LAME – Energy Department, Politecnico di Torino; Bo Rydèn and Håkan Sköld-berg from Profu AB, Mölndal; Daniel Stridsman and David Weiner from Chalmers University, Dept. for Energy Systems Technology, Göteborg; Robert van Driel, Sander Willemsen, Frank Spruit and Wilbert Grevers, G3 Advies BV, Beusichem, The Netherlands; Thomas Kilthau, Mannheimer Energie AG; Wolf-gang Krüger, Thomas Wilde and Stephan Rath-Nagel, IC Consult, Aachen; and Thomas Steidle and Christoph Schlenzig, University of Stuttgart, Institute for Energy Economics and Rational Utilization of Energy, who have carried out the different tasks of Annex 33 and contributed to the edition of this guidebook. I also appreciate our discussions with the ETSAP group, in particular with Tom Kram from ECN Policy Studies Group in Petten, The Netherlands and Gary Goldstein (ERG, Washington). Our text was revised by Karl Stellrecht, Saratoga, California, who polished our English and managed to provide a „readable" publication.

I do hope that our results will enhance further interest and developments in community systems planning, which in my opinion will be of enormous importance if the objectives of a future sustainable world are to be achieved in an efficient way.

Karlsruhe, June 2000

Reinhard Jank
Klimaschutz- und Energieagentur Baden-Württemberg
(Operating Agent, Annex 33)

INTERNATIONAL ENERGY AGENCY

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Programme was formulated among a number of industrialised countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Cooperation and Development (OEDC) to administer that agreement. Twenty-two countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Programme, the Participants undertake cooperative activities in energy research, development and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRO), assisted by a small Secretariat staff, coordinates the energy research, development and demonstration programme.

Energy Conservation in Buildings and Community Systems

As one element of the Energy Programme, the IEA encourages research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is encouraging various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programmes, building monitoring, comparison of calculation methods, as well as air quality and inhabitant behaviour studies.

The Executive Committee

Overall control of the R&D programme "Energy Conservation in Buildings and Community Systems" is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures all projects fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication.

Chairman

Mr. R. Karney, Department of Energy, Building Systems and Materials Division

1000 Independence Ave, SW,
Washington DC 20585, USA

Tel. + 1 202 586 9445
Fax + 1 202 586 1628
e-mail: richard.karney@ee.doe.gov

Vice Chairman

Mr. Jørn Brunsell, Norwegian Building Research Institute

PO Box 123 Blindern,
N-0314 Oslo, Norway

Tel. + 47 22 96 55 46
Fax + 47 22 96 57 25
e-mail: jorn.brunsell@byggforsk.no

IEA Secretariat Liaison

Mr. Mel Kliman, Office of Energy Efficiency and Technology

9 rue de la Fédération,
F-75739 Paris Cedex 15, France

Tel. + 33 1 4057 6875
Fax + 33 1 4057 6859
e-mail: kliman@iea.org

National representatives:

AUSTRALIA	Mr. John Murray	Prof. J. Ballinger
BELGIUM	Prof. J. Lebrun	Mrs. L. Meuleman
CANADA	Mr. M. R. Atif	
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UNITED KINGDOM	Dr. E. Perera	Dr. M. Liddament Mr. B. Austin
USA	Mr. R. Karney	

ALEP - Advanced Local Energy Planning
- a Guidebook -

Chapter 1 Introduction

1.1 Sustainable Development

During the last decade of this century, industrialized countries have increasingly recognized that their societies must develop a *„culture of sustainability"*, if they do not want to irresponsibly and irreversibly damage the ability of future generations to satisfy their own needs. This issue was the subject of a number of recent UN conferences, culminating in the signing of „Agenda 21" during the UN Conference on Environment and Development (Rio de Janeiro, 1992).

This agreement is the most concrete international declaration so far on the necessity of change towards a sustainable development. According to chapter 28 of Agenda 21, „communities within the signing countries shall develop a guideline for a sustainable development within their area of competence accompanied by a consultation process with their citizens" (***„Local Agenda 21"***). Since the quantity and patterns of energy consumption are one of the most important reasons for a „lack of sustainability", and since a large portion of overall energy consumption takes place within the local community, the responsibility to develop local energy systems that are increasingly "sustainable" rests to a large extent with local decision makers – amongst them, primarily, the local administration.

1.2 Local Energy Planning (LEP)

„Sustainability" has many different facettes, such as ecologic and economic development, reduction of greenhouse gases, responsible use of natural resources, social equity or the so called „north-south-compensation". At the *urban level,* however, the consumption of energy is, along with traffic and land use, the most important issue in this context. The decisive instrument for urban energy policy is *„Local Energy Planning"* (LEP), an approach to support the development of a local energy strategy by means of rational planning and management principles.

LEP is based on methods and experiences developed after the first energy crisis in 1973, with the purpose of influencing the local energy system according to the specific goals of (local) energy policy. The prevailing objectives were then focused on the reduction of oil consumption, improved energy efficiency by the use of, for example, cogeneration technologies, and, during the eighties, reduction of pollutant emissions. Today we are observing a shift to local sustainability and a strategic optimization of the energy system under deregulated market conditions. Thus, LEP is for many reasons an important task for both the municipal administration and the local utilities.

In the process of carrying out LEP projects in some countries like Sweden or Germany during the last two decades, it was recognized that partial solutions for individual projects and a long-term strategy for the whole municipality have to be optimized *simultaneously,* and that a variety of different decision-makers and interest groups have to be involved in the decision making and implementation process. Therefore, LEP is a long-term iterative process, rather than a short-term planning task. However, only in recent years have features of a „consistent methodology" emerged in response to the requirements of such an „integrated" or „holistic" approach. Consistent system optimization is a prerequisite for achieving the goal of sustainability at the urban level, since it allows for adequate consideration of the many interactions between the different components of the local energy system.

As a consequence, LEP is quite different from the traditional engineering approach. Although it makes use of methods and tools of traditional technical planning (from an engineers viewpoint), it also has to deal with a more „societal" approach by including aspects of motivation and communication, group dynamics, conflict resolution and project management. In addition, the aspect of „institutional learning" as a means of developing consensual solutions is of special importance for the successful implementation of the LEP results.

The term *„integrated solutions"* means that a combination of different measures shall be developed to realize a strategy that will achieve the given goals in the best possible way. Besides the traditional planning of individual measures, it is necessary to consider the municipal energy system as a whole, including possible interactions and interdependencies of its components: a comprehensive view of the overall „complex" system and its long-term behavior under different assumptions and influences.

With this requirement we enter the field of systems analysis, which so far has not generally been applied in the context of LEP, despite its already long scientific tradition in other disciplines. In the final report of IEA-Annex 22, „Energy Efficient Communities" (FZ Jülich, 1992), it was stated that this was a major weakness of LEP, since the potential of systems analysis and operations research could provide a significant advance in the design process of complex technical systems. Today, there are a number of „Energy System Models" available which have been developed for the planning of large energy systems on national or regional levels. In Sweden and a few other countries there have been initial attempts to apply such models within LEP-projects at the municipal level. These experiences have proven the potential benefits, but also the necessity of further development and propagation of the existing knowledge of the systems analysis approach among traditional planners.

In addition, technological data bases, such as the German IKARUS data base, have been recently developed. Such data bases would realize their full benefit in combination with suitable computer models. Moreover, computer based marketing and infrastructure planning, using for example utility customer support systems or geographical information systems (GIS), is today as normal to the planner as the presentation of results by appropriate presentation tools. Therefore, the time has now come to make proper use of all these tools to improve and accelerate the planning process, and create a sound basis for LEP by using the comprehensive and detailed energy models which are provided today by modern systems analysis.

1.3 Advanced Local Energy Planning (ALEP)

The application of methods and models of systems analysis enables the planner to simulate and optimize the behaviour of systems as a whole, rather than only optimizing its individual components. As a much better understanding of the results of specific planning decisions is attained, this facilitates the involvement of affected local decision makers. At the same time this is a prerequisite for successful implementation of the planning results.

It is this combination of the use of energy models for comprehensive and detailed energy planning, participative involvement of affected groups and modern methods of project management, which we understand as ***„Advanced Local Energy Planning"* („ALEP")**. Such an ambitious approach will generally be necessary to carry out complex projects in a complex environment, and to find consensual solutions which have a realistic chance of implementation.

ALEP is applicable to a municipality of medium or large size with a complex energy supply system (such as a combination of centralized and decentralized components, a variety of different energy carriers, cogeneration potentials at different scales, waste incineration, potential for renewable energies, and major retrofit potentials in the existing buildings stock). For such a complex system, a long term strategy for the energy supply should be developed by either the municipal administration or the local/regional utility (or both), which is even more important under deregulated market conditions. The strategy is optimised to a system of different goals that are generally a subset of the overall goal of sustainability.

ALEP, therefore, is an extension of the traditional LEP approach, as shown in fig. 1-1. It is based on tools and methods of systems analysis for the technical planning process of the (complex) local energy system to develop a consistent „comprehensive energy plan". The results serve as the basis for a group-dynamic approach to achieve consensual solutions among the different actors who are involved in the implementation of the comprehensive strategic energy plan.

To summarize, ALEP is more than the traditional LEP because it

- makes use of comprehensive models of systems analysis which are capable of simulating (and optimizing) the whole system, rather than only considering its components
- provides a long-term strategic energy plan which satisfies different sustainability goals
- involves all affected groups and decision makers to maximize the chance of realization
- employs principles of modern project management and group dynamics
- is a continuous process rather than a project with a defined end.

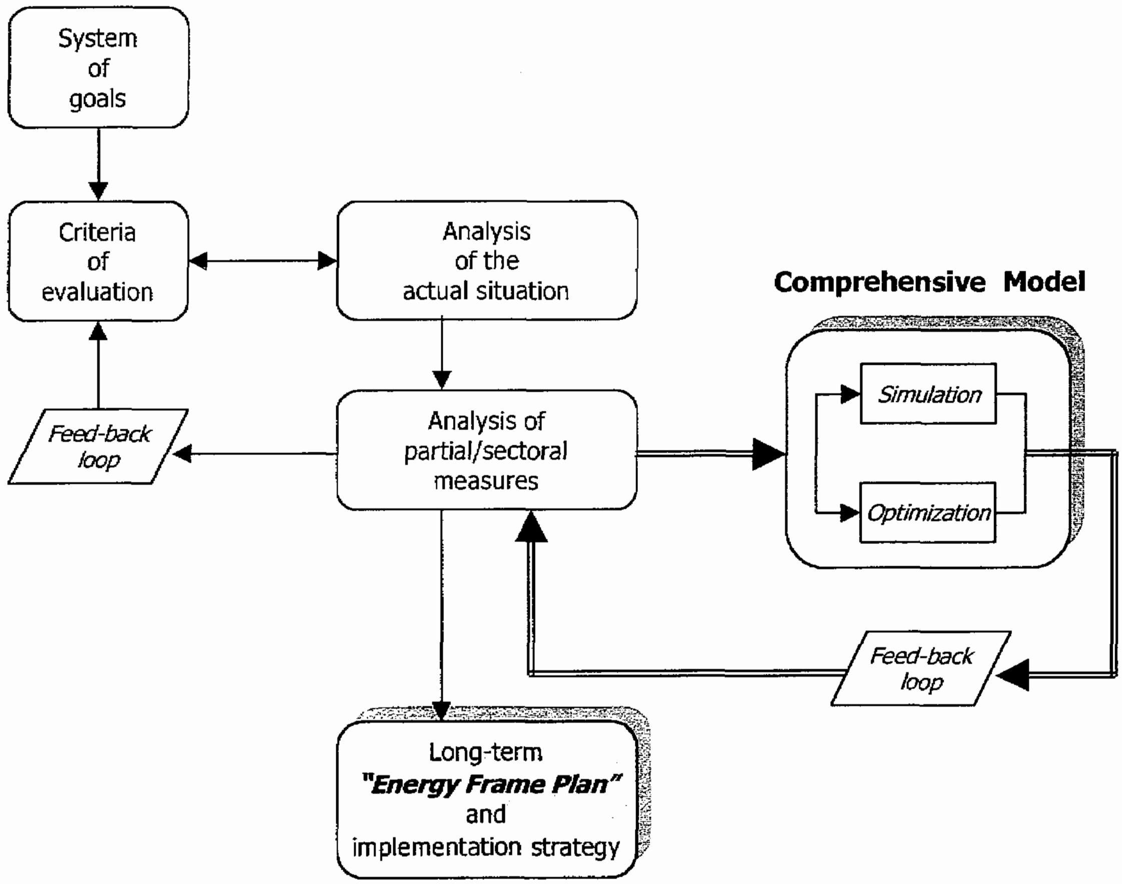


Fig. 1-1: Traditional LEP and ALEP approach (double line) using support of existing software tools and a „comprehensive model" (of the entire local energy system)

In fig. 1-1, the traditional LEP approach, as shown by the left part of the graph, is supplemented by the use of a comprehensive energy systems model capable of simulating and optimizing the entire local energy system (right part of the graph, double line). Partial or sectoral measures are still made with traditional tools, using input data from the comprehensive model in an iterative process. Once the comprehensive model for the local energy system is established, consistent model runs with different scenarios can be carried out very easily.

1.4 The ALEP-Guidebook

This guidebook is the result of the experiences compiled from the case studies of IEA Annex 33: Advanced Local Energy Planning. It is intended as a guidebook on advanced energy planning, as defined above, and is designed for readers with a background in traditional energy planning, such as the optimal economic design of a cogeneration plant or the calculation of the heating demand of a building. The guidebook focuses on those aspects of LEP, which have been characterized here with the attribute „advanced". After reading this guidebook, the reader should be able to understand the potential benefits of comprehensive systems analysis tools for strategic planning. In addition, the reader will receive an overview of the principles of „interaction management" for complex projects, in order to achieve maximum consensus among the affected groups and decision makers, which is the primary requirement for the implementation of the planning results.

The following two chapters in the guidebook describe the principles and logical sequence of individual steps in an ALEP project. In the fourth chapter, the use of „models", comprehensive and detailed, is discussed and concrete examples of their application are provided. In Chapter 5, the case studies which have been carried out within the participating countries in the course of this IEA Annex 33 project are presented in a condensed form. In particular the „advanced" aspects of ALEP within these case studies are stressed. Finally, a short description of the models and computer tools that have been used in the case studies is provided in the Appendix to present to the reader some examples of existing tools and their practical use.

Chapter 2 Basic Principles of Advanced Local Energy Planning

2.1 Introduction

The purpose of ALEP is to find a path towards an economic and ecological sustainable local energy system while also taking into account limited financial and human resources as well as incomplete insight into the future development of economic, technical and social conditions. This task falls under the responsibility of either the local/regional administration or the local utility.

The planning approach outlined in this guidebook to achieve these goals follows four basic principles:

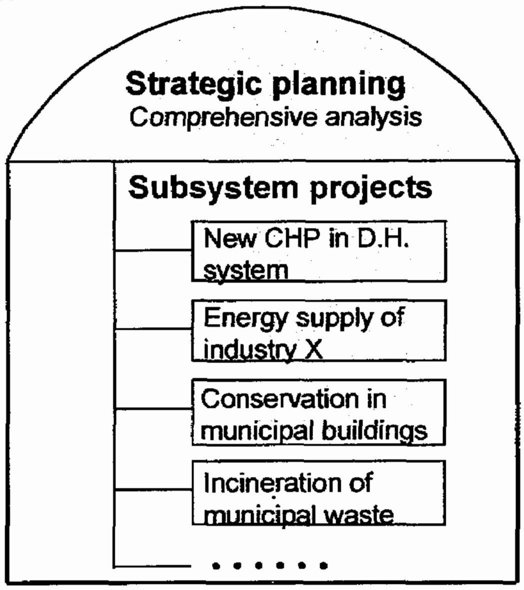
(1) Combine integrated long term strategic planning of the whole energy system (= comprehensive analysis) with detailed planning of concrete subsystem projects
(2) Utilize system analysis methods and computerized energy system models
(3) Involve all relevant interest groups in the planning process
(4) Set-up a plan for continuous improvement and monitoring.

2.2 Combining integrated long term strategic planning with detailed planning of concrete sub-system projects

Energy systems in agglomerated urban regions consist of highly interconnected subsystems. Planning of this energy system comprises two levels:

(1) Comprehensive analysis of the overall local or regional energy system for long term strategic planning.

(2) Analysis and optimization of subsystems like the heating system of individual buildings, insular district heating systems or the energy supply of production plants.



The traditional approach is to study and plan each subsystem of an energy system individually (and combine them, eventually, into an overall energy plan). In general, this will lead to a sub-optimal system, because it neglects numerous interdependencies which may exist between the system components. To understand the advantage of a systems approach and the need for long term strategic planning, it is important to recall some facts about energy systems:

- Planning and operation of the energy system is generally carried out by different actors with sometimes conflicting goals. Local interest groups may have different opinions concerning the "optimal" energy supply system.
- A local energy system consists of long-lived infrastructures (planning horizon of 10 to 30, and eventually up to 50 years), which does not lend itself to quick modification or response. Changes of the energy system generally establish long lasting facts. Thus long term developments of frame work conditions (energy prices, economic growth, socio-economic changes etc.) must be adequately considered in the planning process.

- The energy system contains many interdependent subsystems (changes to one subsystem may have effects on other subsystems).
- Measures on the supply-side compete with conservation measures on the demand side. Capital and human resources are scarce and must be directed towards the most effective measures.
- The economic success of investments must be evaluated in the context of uncertain socio-economic factors, like general economic development, energy prices, taxes and legislation.
- Energy system planning interacts with strategic planning in other fields. Planning tasks like environmental planning, urban planning or transportation system planning may affect the energy system.
- Changes in the energy system affect residents, local industries and the environment, and thus have a large impact on the urban environment.
- The exploitation of local renewable resources (biomass, wind, solar energy, hydro energy, waste heat etc.) is often expensive and needs stable, long term demand and commitment to justify the investment.

The ALEP approach comprehensively analyses the whole energy system of a region (e. g. municipality) and then explores and analyses different possible strategies. However, ALEP should not be a theoretical study, but should be oriented towards the development of specific energy projects within the community. Detailed subsystem analysis on the other hand only deals with the problems on a small scale. Here, there is a risk of losing understanding of the overall picture. Therefore, existing local energy projects like boiler retrofits, installation of co-generation plants, local district heating projects, energy conservation measures for individual buildings, planning of incineration plants, demonstration projects for renewables, etc. should be considered from a more comprehensive point of view. Ongoing activities like energy management of municipal buildings, urban planning or waste management, should also be integrated. All these individual activities should be considered simultaneously to provide a comprehensive and consistent long-term energy plan that analyses the behavior of the entire energy system.

The goal of the comprehensive analysis is to reveal the strengths and weaknesses of the present energy system and to identify needs, threats and opportunities for the future. ALEP should help to determine the most effective measures to achieve a given set of goals, while also taking long term projections of technical and socio-economic (frame conditions) into account. Individual subsystems are then planned or selected for further analysis depending on their priority and improvement potential in regard to the long term strategy.

Comprehensive and detailed subsystem analysis complement each other. As guiding principles for balancing comprehensive vs. subsystem analysis the following rules of thumb should be applied:

- Do not let the comprehensive analysis alone determine the choice of detailed projects for investigation, but also take the existing situation in the area into account.
- Prioritize among existing activities. Do not be too ambitious by creating too many new projects.
- Co-operate with those who are already engaged in specific projects. Integrate existing projects with the same planning „philosophy„. "Proper coordination is economical and efficient".

The following example shows the interaction between comprehensive and detailed studies.

The balance between energy supply and energy conservation

The balance between heating energy supply and energy conservation can be studied both in subsystem analysis for „typical„ buildings, and as one issue in the comprehensive analysis. It is valuable to exchange information between these studies. Typical information which could flow from the comprehensive to the detailed study is the future mix of energy supply alternatives for specific user sectors (single family houses, multi-family houses etc.), future energy prices (gas price, district heating price etc.), optimal energy conservation levels as a function of heating system and building type, etc.

Information could also flow in the other direction, from the detailed to the comprehensive analysis. If the detailed study of „typical„ buildings indicates that the optimal energy conservation levels are robust with respect to certain assumptions regarding important parameters, such as energy prices, it may be favorable to simply use the calculated energy conservation levels from the detailed, study and reduce the net energy demands in the comprehensive analysis accordingly. The analysis of optimized conservation levels could thereby be left out of the comprehensive analysis. This simplifies the comprehensive analysis considerably and could facilitate more detailed investigation of other aspects of the total system.

Source: Local Energy Planning in Goteborg, Sweden

2.3 Utilisation of systems analysis methods and computerized energy system models

It is quite difficult to consider all possibilities and facts and develop a long term strategy for a complex energy system. Experiences with traditional LEP have shown that a systems analysis approach to the planning process, supported by computerized energy system models, is necessary in order to describe the entire energy system adequately and find the best strategy.

An energy system model is a simplified mathematical representation of the energy flows and costs of an actual (technical) energy system. Such energy system models were first developed some 20 years ago to describe national energy systems. Today some of these models may be run on personal computers and can be applied to local or regional energy systems (refer to chapter 4.7 for an explanation of models).

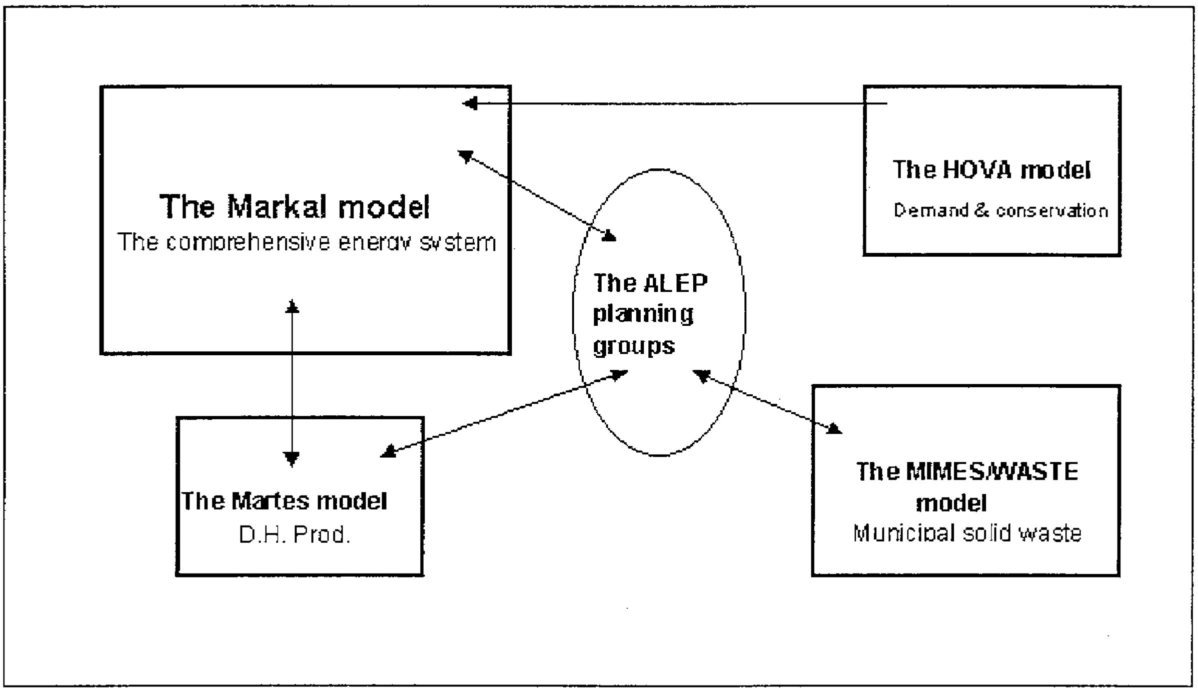
The energy system model serves several different purposes in the ALEP process:

- it provides a common structure and "language" for the discussions
- it is neutral in the sense that the methods of calculation and the input data and assumptions are transparent and accessible to all parties involved
- it is interactive and supports communication since new ideas and questions can be evaluated very quickly once the model is established
- it can manage the large amounts of data necessary for a regionally dis-aggregated and complex analysis.

The interaction between comprehensive studies and subsystem analyses must also be accompanied by the use of models (see Figure 1.2). In the ALEP case studies presented in this Guidebook (chapter 5) the energy system model MARKAL was used for the comprehensive analysis. Some of the subsystem studies, coupled with the comprehensive analysis in the case studies, also included models for the analysis of specific problems in the subsystems. Models for subsystems are familiar to planners, and are therefore well accepted by the individual actors involved in the energy system. The following example gives an overview of the models used in the Göteborg study.

Models used in the Göteborg energy planning project

- *The MARKAL model was used for the comprehensive study.*
- *MARTES is a user friendly simulation model for detailed analysis of district heating production, including total cost, marginal cost, production strategies, emissions, etc.*
- *HOVA is an Excel-based model for analysis of energy conservation potential. Based on data for individual measures and the structure (age and numbers) of buildings it is possible to calculate conservation costs and potential. Measures can also be aggregated into „packages„ to facilitate use in the following models, e.g. MARKAL.*
- *MIMES/WASTE is an optimization model for strategic analysis of waste management systems. It is designed to facilitate new solutions for future waste management systems that are both cost-effective and environmentally sound. The model includes a detailed breakdown of the waste, which makes it possible to analyze e.g. the cost of separation and energy recovery.*



2.4 Involving local interest groups in the planning process

A planning approach that considers only technical aspects and neglects social and political factors of the region is not adequate and often fails because it lacks consensus. The planning process must be embedded in an organizational scheme which includes all local interest groups. Only early involvement and motivation of these groups will ensure achievement of ambitious objectives. The institutional organization defines the roles of the actors directly or indirectly involved in the planning process. Examples of such actors include:

- political decision-makers at the local level,
- representatives from utilities,
- representatives from the municipal or regional administration,
- industrial energy consumers, chambers of commerce,
- environmental groups.

The institutional organization should be tailored to the existing decision mechanisms within the local area. These mechanisms are quite different in European countries; therefore no general recommendation for the institutional framework can be offered.

Figure 2-1 shows an example of an organizational set-up (Refer to chapter 4.3 for an explanation of the different functions of these groups):

- Steering Group: Decision-makers, stake holders of the project and key persons from different interest groups, responsible for the general goals of the ALEP project,
- Reference Group: Experts from local organizations and interest groups. The reference group may include temporary experts for specific questions.
- Working Group (Study Team): Local and external experts carrying out the study.

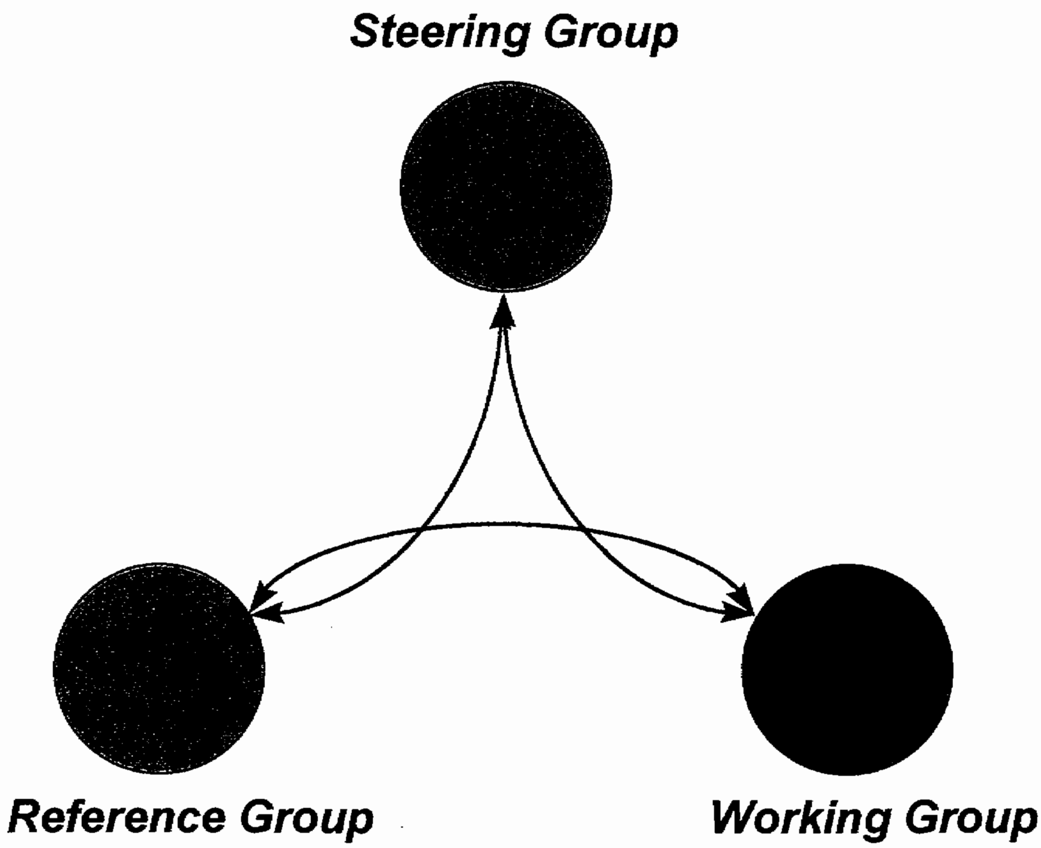


Figure 2-1: Example of an organizational set-up for an ALEP project

> *In the Swedish city of Göteborg the organisational set-up was as follows:*
> *The initiative to the new Energy Plan 2000 came from the Environment Policy Steering Group, a group of key politicians with special interest in environmental issues. They gave the task to the Göteborg Planning Commission (Steering Group), who thereby became responsible for the preparation of the energy plan.*
>
> *This plan was then developed by the "Energy Group" (Working Group), which was chaired by a city staff person, and consisted of personnel from Göteborg Energi AB (the utility), the Planning Commission, the Agency for Environmental Protection, the Agency for Traffic, and the Agency for Real Estate.*
>
> *The Energy Group established a Reference Panel (Reference Group) with experts in different fields. The reference group included members from the following institutions: Göteborg Energi AB (the utility), large industries, the county administration, the municipal building authority, the agency for real estate, the agency for Environmental Protection, Chalmers University of Technology, and occasional appearances by selected experts. Experts from this panel were invited to hearings when certain issues were discussed. This was felt to be a very effective way of getting the opinions of experts outside the Energy Group into the planning process.*

The purpose of using a comprehensive energy system model within the organizational set-up is to provide an approved method to calculate the effects and costs of policy strategies proposed by different interest groups. The impartial and reliable results from the model help to determine the different positions and find a settlement to conflicting interests.

It is important to understand that local energy planning is not a one time event, but rather an iterative process. The refinement and improvement of strategies is accomplished through continuous communication and discussion of partial results and new ideas between the groups.

ALEP fosters understanding of problems and possible conflicting goals associated with the local energy system. Thus ALEP will include a learning process concerning the various social and technical aspects of energy systems. This will improve the ability of the parties involved to take an active role in the planning process (see chapter 4.3 for more information on the learning process).

2.5 Continuous improvement and monitoring

The main result of ALEP is a ***local/regional energy plan***. The implementation steps of this energy plan must be checked and improved, when frame work conditions change or new experiences are gained during implementation. The actual development should be compared continuously with the planned development using suitable indicators. Through this continuous improvement process it is possible to identify areas where the actual development differs from that specified in the action plan.

After implementation of the energy plan, the ALEP planning process shifts to a monitoring phase. Monitoring and evaluation is necessary, for example, to detect changes in basic assumptions used for the energy plan or to detect problems caused by the energy system. Such findings may make it necessary to adjust some of the goals and parts of the action plan which might have been based on other assumptions. One monitoring activity could be an annual report to the decision makers.

The different steps and phases of the planning process for the ALEP project mentioned throughout chapter 2 are explained in more detail in chapter 3.

Chapter 3 The Phases of the Planning Process

3.1 General overview of the planning process

An ALEP project will in general involve many people with different backgrounds and sometimes competing agendas. It is a large-scale project packed with complex technical details. Most importantly, the objectives are not well defined at the beginning of the ALEP project but are rather themselves part of the analysis. Therefore ALEP must be supported by a well structured planning approach. In addition to using computer based models from systems analysis, as mentioned above, the „structured planning process" as described in this chapter is a decisive characteristic of an ALEP project.

The planning process can be divided into six phases:
1. Preparation phase to begin the ALEP process.
2. Orientation phase to formulate goals and set up the ALEP project.
3. Main study phase with comprehensive strategic analyses and subsystem analyses to examine different strategies.
4. Evaluation and decision phase to define a final energy plan and climate protection strategy.
5. Implementation phase to implement the energy plan in individual projects.
6. Supervision & monitoring phase to detect erroneous projects and deviations from the energy plan.

Each successive phase goes into more detail and improves the understanding of the energy system. Iteration loops are necessary to include important new findings. Figure 3-1 shows the phases of the planning process.

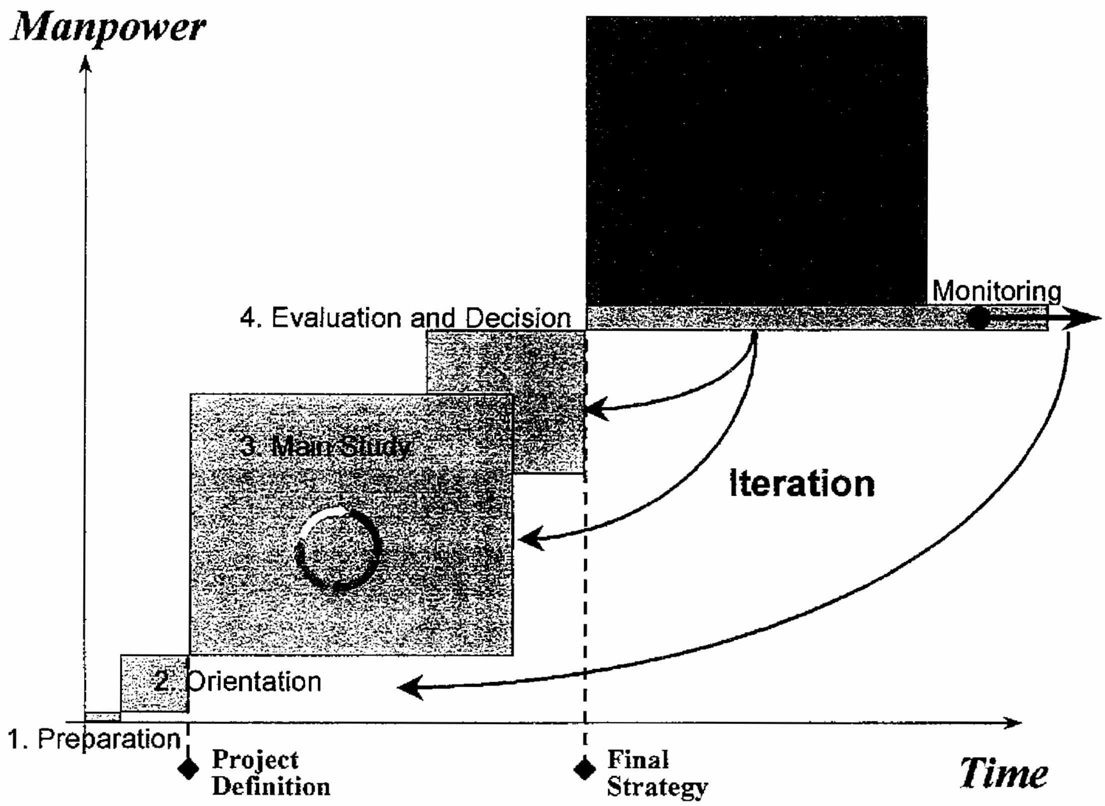


Figure 3-1: Phases of the planning process

The x-axis is the time frame for the project. The y-axis stands for the manpower needed for the different phases. Both axis have a purely qualitative scale, indicating also that the different phases build upon each other, while main study phase and evaluation and decision phase need a certain overlap. Thus the area of a phase indicates the human resources allocated to it in a qualitative manner. The sizes of the areas shown in Figure 3-1 should be seen as a rule of thumb. The implementation phase in particular may need considerable more time and resources than the main study. The monitoring phase on the other hand could be a very small annual effort.

The preparation phase serves to start the ALEP process by collecting basic information on local problems connected to the existing energy system, and by identifying and inviting local interest groups who may participate in the project. The orientation phase is decisive for the project. Here the objectives and scope of the study are defined based on a first assessment of the present situation of the energy system. After completion of this phase the tasks and scope of the project should be well defined. In the main study phase, the objectives serve as guiding principles for the development of the energy system model and the necessary data acquisition (see chapter 4.2 for a definition of the term model). With the help of the model, different options for competing measures and strategies will be analyzed. The results of the main study are discussed during the evaluation and decision phase. Normally, some iteration loops within the main study phase and during the evaluation phase are necessary to find an optimal solution, e. g. a solution that best meets the different goals of all interest groups. This iteration procedure is made much easier by the use of a model. With the finalized strategy described in the final report, ALEP has reached its most important milestone, the Local Energy Plan. The ALEP process continues with two additional tasks, however: the implementation phase and the supervision and monitoring phase. Implementation means realization of the energy plan through individual projects. A supervision phase should then be used to check the success of the implemented projects. Unfavorable developments detected during the supervision phase may lead to new iterations in the planning process and even a re-evaluation of the energy plan.

After implementation, the performance of the system should be monitored regularly over several years. This helps to detect situations where a re-orientation or a completely new ALEP process should be started. During the supervision and monitoring phase the energy system model is very helpful. The report formats developed during the ALEP project can be used to analyze and document the performance of the system using actual measured data. When a new ALEP planning cycle starts, the database will be up to date, and only minor changes to the model and minimal data acquisition will be necessary to update the model. This reduces the cost and time for the revision of the ALEP project enormously.

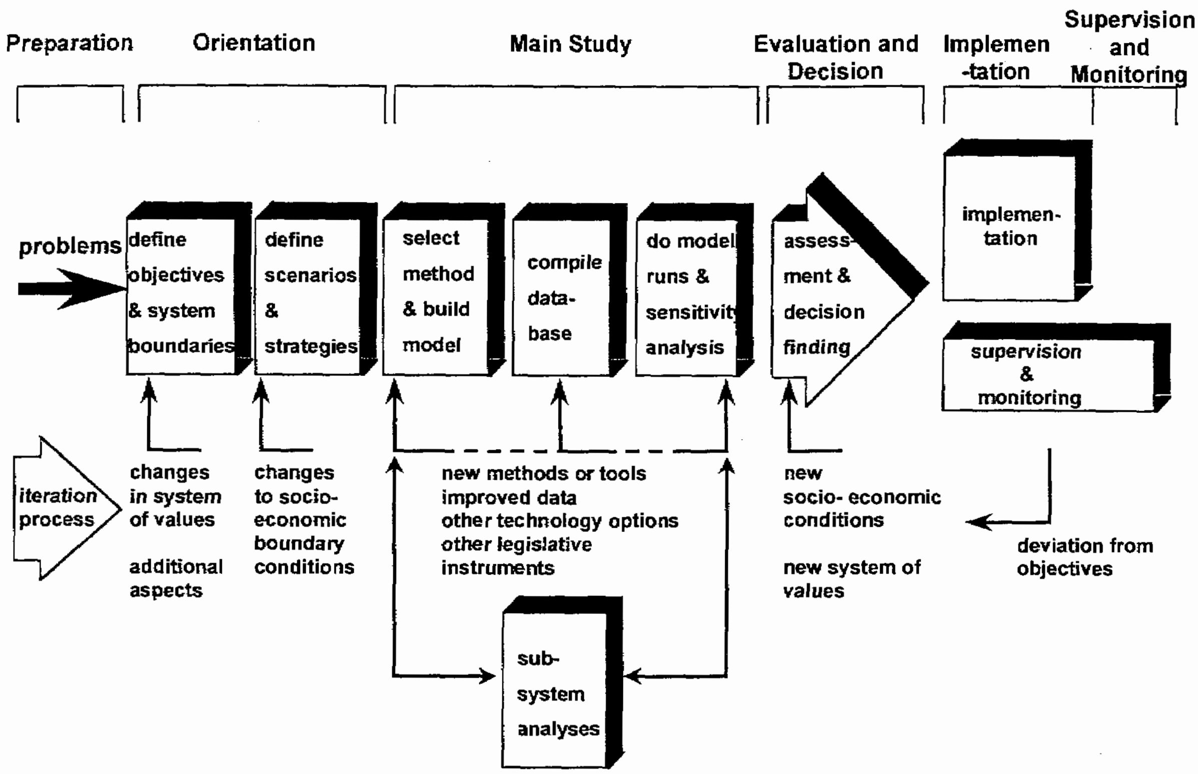


Figure 3-2: Phases and Tasks of the ALEP process

Figure 3-2 shows the phases and tasks of the ALEP planning approach. The tasks are linked together by an iterative process. Reasons for iterations are indicated. Findings and results in later phases may lead to new considerations which must be fed back into the process, leading to a refinement of the model and the associated energy plan. Some findings may be more fundamental to the plan, such as a shift in the system of values. They may require changes of the objectives, or a new decision phase. Detailed information for each phase is described in chapters 3.2 to 3.7.

An equally important part of the project, besides the technical analysis, is the involvement of interest groups in communication and decision making (refer to chapter 4.3 for more information on project organization and "institutional learning process").

The project structure and working plan of an ALEP project should be based on the ideal approach described above. To which extent the different phases and steps are actually executed and how much time is devoted to them depends on how the concrete planning tasks are defined, and on the priorities of the planning team. Therefore no general rules for the budgets of the different phases can be given.

Since it is not possible to calculate the budget for the main study before the scope of the work has been defined, it would be advisable to split the ALEP project into two consecutive parts. The first part should cover the orientation phase, including assessment of the present situation and definition of the objectives. The scope, content and budget of the second part (main study and evaluation and decision phase) are defined according to the results of the orientation phase. If the organization responsible for local energy planning does not have sufficient human resources, then it may also be necessary to include the initial preparation phase into the first part.

3.2 Detailed description of the planning steps

3.2.1 The preparation phase

When the need for local energy planning emerges in a region, the responsible organization or actor assigns a specific person, organization or an especially selected team to launch the planning process (the initial group most likely consists of representatives from the city and/or utility and perhaps external experts). In general a meeting or workshop is organized to initiate the planning process. A workshop is best suited for this purpose because it enables active participation, rather than passive receiving of information. The main objective of the workshop is to define the general tasks, the organizational set-up and the financial framework. The workshop should be attended by all local actors that will be affected by the ALEP project.

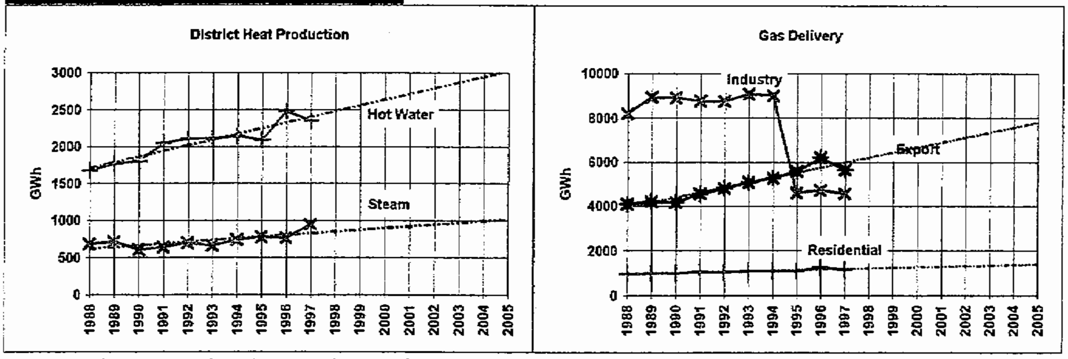
During the preparation of this workshop the initial working group collects basic information and a „rich picture„ of the present situation. Prior to the workshop, the driving actor in this phase of the project provides this background material to the other actors and interested groups. This information material may also include suggestions about project organization, choice of methods, budget, time frame etc.. However, at this point of the project, most of the information is not very detailed or of preliminary character. The following check list can help to characterize the present local situation (see also chapter 4.1 for examples of background information):

- What are the most urgent energy problems in the community?
- Which long-term objectives for energy supply may be suggested?
- Is there an actual demand for concrete decisions which may affect the energy system?
- Who are the important actors and decision makers. What are their responsibilities and relationships?
- What are reasonable system boundaries for analyzing the local energy system?
- Which areas can be influenced and which technical solutions could be considered?
- Are there already pertinent ongoing activities and information materials, or results from existing studies?
- What was the "historic" development of local energy planning in the community?
- What are the potential benefits of a long-term energy plan?
- What possibilities exist to finance the work necessary to develop the energy plan?

If all these questions can be answered, the „rich picture" mentioned above will be apparent to the working group.

The following figures show a very simple example of background information for the case study Mannheim:

Learning from existing trends



District heat production and gas delivery from recent years show a constant increase indicated by linear extrapolation. Almost 81% of the customers in the heat market are connected to gas (33%), district heat (44%) and electricity (4%) with a massive substitution of oil since 10 years from 37% to 19% currently. This development was the result of the old energy plan from 1984. A key aim of the Mannheim study was to verify this old energy plan and to determine the optimal balance between district heat and gas expansion in different areas. The gas delivery to industry is characterized by a sharp decline due to one major customer who changed suppliers and a substantial increase in exports to a neighboring city. An important question for the future liberalized energy market is the consequences of such losses in production cost of gas and especially district heating.

An agenda for the work-shop where these questions should be addressed could be:
- description of the present situation,
- identification of existing and expected problems,
- possible objectives for developing the local energy system,
- presentation of possible system (boundaries), scenarios, strategies,
- outline of planning approach and choice of methods,
- position statements and objectives of the different participating organizations.

The following results should be achieved during the workshop (examples in chapter 4.1):
- list of problems and questions that need more detailed analyses,
- outline of problem identification and agreement on main objectives,
- approximate definition of system boundaries and scope of planning approach,
- overall budget limits and time frame,
- definition of preliminary organizational set-up and general framework,
- choice of general planning approach and methods,
- preparation of ALEP action plan, time schedule and assignment of subsequent tasks.

The preparation phase will clarify the main problems and objectives. For the next step, a work plan for the project must be prepared. If external consultants assist in the planning process, this work plan should be used to prepare the material for a bid proposal for the ALEP project.

3.2.2 The orientation phase

The orientation phase is devoted to the detailed description of
(1) problems
(2) objectives
(3) system boundaries
(4) scenarios and measures.

The identification of problems and the definition of scenarios and measures requires more detailed information about the energy system than is normally available after the initiating phase. Thus the orientation phase begins with an assessment of the local energy system, including input from all actors to attain a more detailed picture of the present situation and actual problems. Examples for this data collection and analysis are given in chapter 4.1.

The most important activity in the orientation phase is the clear formulation of the problems and a detailed definition of the planning objectives:

- Objectives are needed as guiding principles for all other phases of the study. They affect the selection of system boundaries, the definition of scenarios and strategies, and the development of the energy system model. This does not imply that objectives can not be changed during the planning process, but rather that changes must be discussed and documented in the steering and reference group.
- A major task during the subsequent main study phase is the preparation of a database. Thus, the orientation phase helps to direct and limit data collection to specific topics to avoid unnecessary work.
- Lack of transparency or unresolved issues in this phase can later threaten the implementation of the energy plan, since an interest group may not accept the results of the study and may prevent or delay the implementation process.

The objectives should be accepted by all groups, and a formal agreement should be reached. Sufficient amount of time should be allocated to achieve this.

The next step, which is strongly influenced by the established objectives, is the definition of the system boundaries and the socio-economic framework of the study. When defining the scope of the study, the goal is to focus the work on the most important issues and to exclude those parts and questions of minor interest. In this way the geographical boundaries are drawn and the complexity of the actual technical energy system is reduced to a structure which is the object of further analysis. A very appropriate method, which should be used for the description of the structure of the energy system, is the "***Reference Energy System***" (RES) method (see chapter 4.2 for an explanation and examples of the RES).

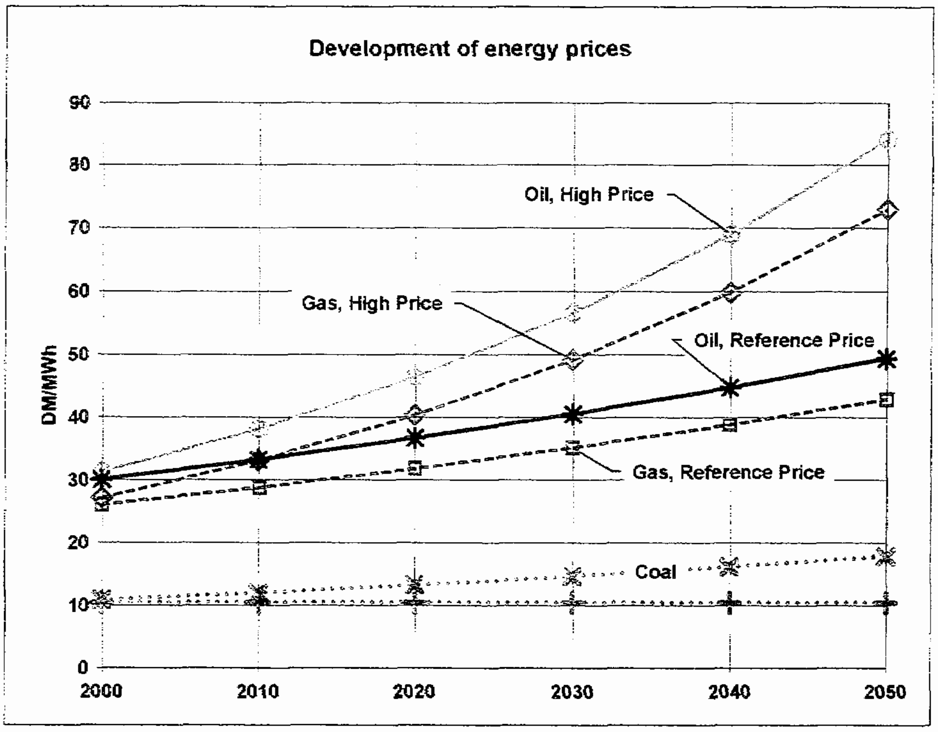
Within the system boundaries we describe the socio-economic framework. One should make clear which developments of the energy system are assumed to be exogeneous (e.g. can not be influenced by the local planners), and which parts of the energy system can and should be influenced by the planners:

- Developments of population, energy prices, discount rate and technologies or decisions of national politics can not be influenced by the planner or decision makers at the local or municipal level. Specific assumptions for the development of these parameters are called scenarios. Scenarios set the socio-economic stage for the development of the energy system.
- Three principal types of actions to be taken by the decision makers can be distinguished:
  (1) control system parameters such as (local) taxes restrictions or subsidies,
  (2) behave as an actor on a market, and
  (3) communication.

Example: introduction of new technologies or fuels, demand-side management programs, information campaigns, emission restrictions, subsidy programs, or the construction of new power plants. (Combinations of measures are called strategies. In this sense we use the term strategies already at this stage of the planning process. During the main study, different strategies are evaluated to identify a dynamic strategy or energy plan (see chapter 4.6 for examples of scenarios and strategies)).

The following graph shows the development of energy prices as an example for a typical exogeneous parameter:

Definition of energy prices as a scenario parameter



The development of prices shown is a synthesis of different and in some cases more detailed projections by different authors. Resources of coal are abundant and the price should stay low. An increase of 1% per annum is assumed in the high price scenario. The demand for gas in Europe is expected to grow considerably which will put some stress on the available transport capacities and resources. World market prices for oil are expected to increase mainly due to growing demand and price control by OPEC. Therefore a 1% per annum increase is assumed for the reference scenario, and a 2% per annum increase for the high price scenario. The oil and gas prices shown in the graph are wholesale prices. Since the development of these assumptions, crude oil prices on the world market have increased much faster due to OPEC agreements. The wholesale gas prices in Germany also dropped considerably due to regulatory interventions of the government. A projection cannot include these effects, especially if the forecast period is too long.

At this point the planners have to make some important decisions. The planning approach, the energy system models and the computer software for the comprehensive study must be selected now, before data collection and model building is started (refer to chapter 4.3 and 4.4 for a discussion on how to make such a choice).

- The first question concerns the role of the comprehensive study. The planners can place the main emphasis and effort on the comprehensive study and the development of an optimized overall strategy ("comprehensive approach"). In contrast, the planners can instead base the work on ongoing projects and studies, and try to co-ordinate them with a comprehensive study ("project oriented approach"). In the latter case, the comprehensive study is rather small, and less extensive. This approach might be adequate for smaller communities (30.000 to 50.000 inhabitants) or a project with a limited scope.
- Other choices concern whether or not to use software tools for the comprehensive study and the subsystem or component analysis. These software tools employ different methods, such as simulation or optimization, and the planner has to select an appropriate tool for his purpose (see chapter 4.4 for more information on energy system models and the role of simulation and optimization).

The final organizational set-up adopted according to the questions and problems of the project must be established during the orientation phase. This will define the role and responsibilities of each participant as well the communication patterns. The organizational set-up, as described in chapters 2 and 4.3, serves to integrate public opinion and different interest groups into the process. It helps to find consensual solutions and to prepare the basis for decisions. In the orientation phase the reference group has a very active part. Members of the reference group must bring in the specific requirements of the different interest groups and build a common system of goals and a vision for the future. The task of the steering group is to negotiate compromises between the parties at the political level.

The orientation phase ends with a report which includes:

- a description of the present situation of the energy system,
- the planning task in detail (e.g. problems, objectives, system boundaries),
- scenarios and strategies which should be investigated,
- a draft version of the structure of the energy system model (for example as RES representation of the technical energy system),
- the institutional set-up and its responsibilities,
- existing or ongoing studies and projects related to local energy planning,
- the work plan with a time schedule and budget for the subsequent phases,
- additional information about the general framework,
- planning approach, modeling method and energy system models to be used.

The items of this report are subject to continual improvements during the project. The document defines the core of the project and should be accessible to all participants.

3.2.3 The main study phase

The main study integrates a comprehensive analysis for long term strategic planning with several detailed analyses of important subsystems or questions of specific interest. The information exchange between these two planning levels produces the necessary amount of detail that is required for the decision making process.

During the orientation phase it will already be decided whether the „comprehensive„ or the „project oriented„ approach will be used. This guidebook will concentrate on the comprehensive study. Therefore, in the following sections, we will describe the steps required to develop a detailed energy system model, which is the main task of the comprehensive study. The combination of the comprehensive model and detailed subsystem analyses will also be discussed, but we will not go into detail about modeling subsystems and using special purpose tools.

We strongly recommend to begin with a small (pilot) model containing only the most important components at the outset in order to obtain initial results, and then to refine this model during the course of the work. The simple preliminary model points to the strengths and weaknesses of the existing system, and to the dangers and opportunities of future developments. During the discussion of the preliminary results, questions about the accuracy will arise which will help the planners to gain new insight and to improve the model in these specific areas. This iterative ALEP planning process supports the successive refinement of the energy system model. The integration of all stake holders including those parties questioning this approach, will help to improve the acceptance of the model as a tool for ALEP.

Studies of subsystems which run in parallel to the comprehensive study, should use the same basic data in addition to their individual more specific data. Results from these analyses will contribute additional detailed information to the comprehensive study.

Since it takes a substantial amount of time to get optimization models running, a simulation approach could help in the beginning to become familiar with the modeling technique and to produce initial results. Simulations use an explorative approach for modeling. As opposed to optimization models, which calculate the optimal mix of technologies and energy carriers for a given cost structure and a given set of constraints, simulation models calculate the impacts of a clearly defined strategy path, i. e. a given technology and fuel mix.

The description of the different steps of the main study phase below distinguishes between building the structure of the model (e. g. the RES) and entering data. However, these two steps are often not clearly separated in the user-interface of the models.

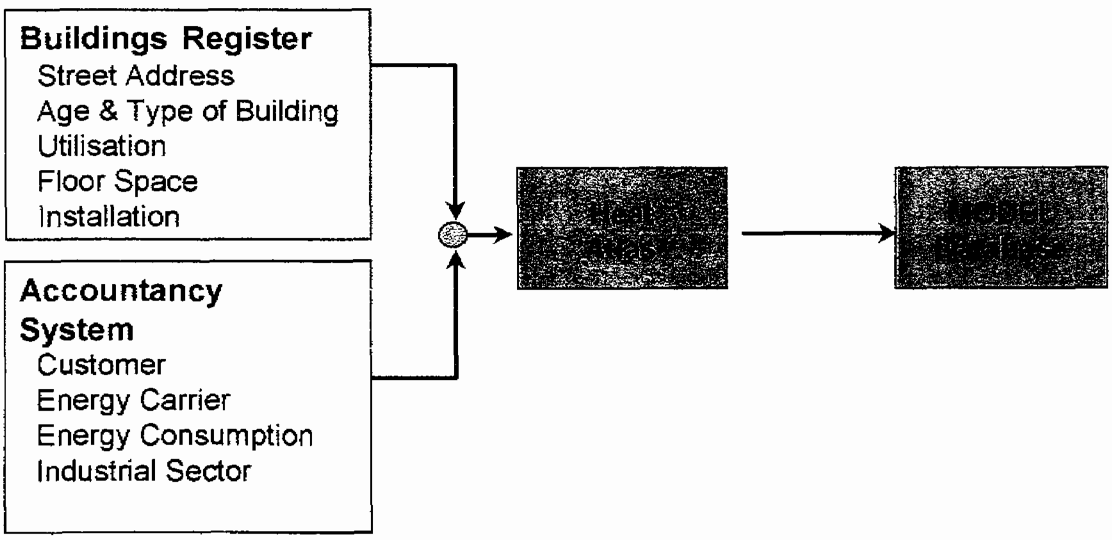
Step 1: Define the structure of the comprehensive model using the RES
The first step of the main study phase is to use the available information from the preceding phases to develop the RES, a simplified representation of the structure of the energy system. Since the RES is very illustrative and helps to communicate planning issues, developments of the RES could already be started in the orientation phase. The information contained in the RES is then transferred to the energy system model. Different software tools use individual specific methods and user interfaces to support this step. Refer to chapter 4.2 and the case studies in chapter 5 for RES examples.

Step 2: Compilation of a model database
A major task of the main study is to establish a reliable database with validated data (for example, energy demand, characteristics of supply systems, etc.). Data mining in databases of utilities, municipalities, statistical offices or other sources can be very helpful. Refer to chapter 4.5 for more information on data acquisition and databases. Some examples of data sources are:

- Business and customer information systems of utilities
- Statistical data from administrations or business organizations
- Geographical information systems (GIS)
- other similar modeling case studies

The following example shows the utilization of business databases as sources for the energy model in Mannheim.

Utilisation of business information systems for data acquisition



The MVV heat atlas was designed as a marketing instrument. Typical data of every building in Mannheim is located in the buildings register. This file is updated periodically from a database maintained by the city of Mannheim. The accountancy system of MVV contains important data for every customer (e.g. energy consumption). The combination of selected data from both systems through the street address constitutes the database of the heat atlas. Consumption data maintained in the accountancy system is loaded into the heat atlas during night time to keep the records up to date. The heat atlas could then be used to aggregate consumption data, floor space etc. for specific building types within regions as input data for the energy model.

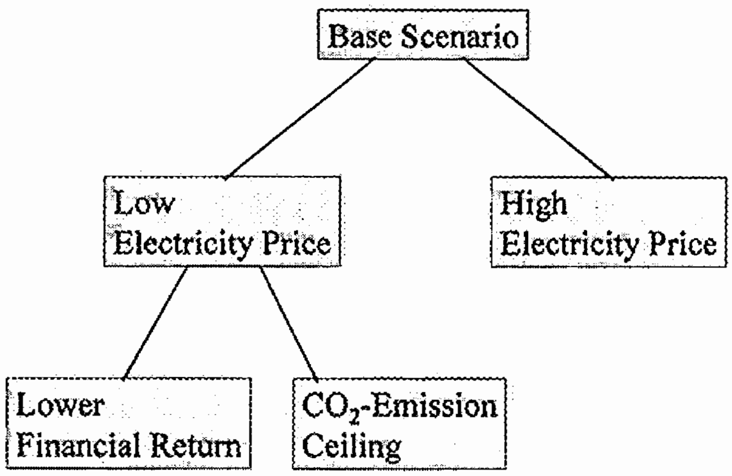
Building a valid database is not only important for computer based models, but also has value for the conventional planning approach and the communication between the planners and the interest groups, since everybody has access to the numbers and the assumptions used for the calculations. The database management system should have a good user-interface, so that the data can be easily stored and retrieved in a multi-user environment, and the validated database can be used as a common source for inputs to all models and calculations. One common database is advantageous. However, if data must be stored in different models, it is important to be very cautious with the update of the data in order to avoid inconsistencies between the models.

The RES representation and technical input data need not be generated from scratch. Results of existing studies from other cities or specially prepared example databases can be used as starting points. They provide sources for technological and economic data for the adequate representation of specific features of the energy system. These examples should then be adapted to the local situation.

Step 3: Calculation of scenarios and strategies
When the model database contains all the necessary structural, technical, economic and other data (such as discount rate and modeling period), the first model runs can be performed. First, the model is calibrated to the base year with historic data. Further model runs are devoted to investigating the development of the unaltered system. These runs are made for the base scenario, which is in general the most likely representation of the existing system along with the expectations of its future development. Finally, the behavior of the system is examined when new technologies or other measures according to the proposed strategies are introduced.

The following figure shows the scenarios for the Delfland case study (see chapter 5.6):

Definition of scenarios for Delfland



The scenarios in the case study, which focuses on the heat supply for greenhouses in a small area, are characterized by parameters which were derived from the following factors:

- *Electricity price: The cost effectiveness of heat production in co-generation plants is sensitive to the electricity price level. Low and high electricity price scenarios (for imported electricity) will reveal the optimal supply structure.*
- *Internal rate of interest: A lower requirement for financial return makes investments in new capacities more competitive with electricity import in the low electricity price scenario.*
- *CO_2- emission restriction: This scenario will show how a CO_2-emission ceiling influences the choice of technologies.*

The results of these model runs are analyzed very thoroughly, in order to fully understand them and to judge if they are realistic for the actual energy system. In reality, changes to the structure of the energy system occur over long time periods. Results of model runs suggesting unsteady or discontinuous behavior of energy carrier utilization, phasing out of technologies, build plausible in the model, indicate errors or inaccurate representations of reality. The improvement process continues until all results are well understood and validated.

One should always bear in mind that the results are only as good and accurate as the input data. The results from optimization model runs define the optimal strategies to achieve certain goals (e. g. minimal cost) under the restrictions defined in the scenarios. Therefore, the „optimal„ solution is an outcome of the assumptions and boundary conditions used in the set-up of the model. However they do consider all interdependencies of subsystems and future developments (dynamic models). Consequently models allow for much improved insight into the behavior of the system and its responsiveness to changes.

Working out measures and scenarios, and finding the necessary data is an iterative process. When the main study is finished and some results have been worked out, the robustness of these results will be checked under different scenarios with sensitivity analysis (see step 5).

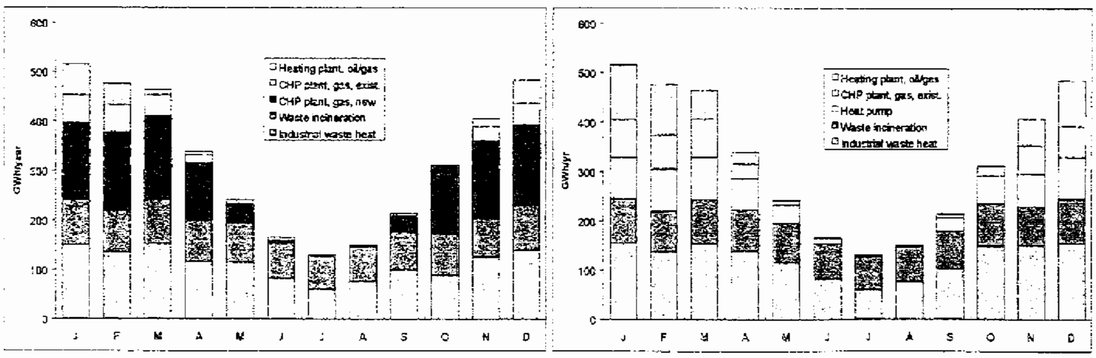
Step 4: Integrating subsystem analyses

Due to some necessary simplifications, a comprehensive model is often not adequately detailed to allow for a single clear decision between two competing technologies or solutions for subsystems. Simplifications may concern the structural representation of the technical system, time resolution of energy demand or modeling of grid connected energy carriers. Problems also arise from uncertainties in data derived and adopted from statistical material, rather than from specific surveys of the subsystem.

At certain points of the planning process, it will therefore be necessary to carry out a detailed subsystem optimization or feasibility study of a subsystem to find a detailed optimized solution for a specific part of the energy system. On the other hand, results from detailed studies should be fed back into the analysis to improve the comprehensive study. Combining comprehensive models for overall optimization and subsystem models for detailed studies in iterative steps is generally advisable (see Fig. 1-1). For the linkage of comprehensive energy system models and subsystem models it would be useful to set up the models in such a way that data can be exchanged and interpreted without difficulty (e.g. using same units, parameters, aggregation levels, etc.).

The following example from a subsystem analysis with a detailed simulation model for district heating systems is derived from the Göteborg case study (see chapter 5.4 for more details):

<u>Integration of subsystem analyses</u>



District heat production, base scenario *Low electricity price scenario*

Since MARKAL lacks in detail analysis with respect to the description of production plants, load curve, etc. it was natural to make alternative calculations using another tool. The results from a detailed simulation model concern the year 2005. If these results are compared to the results from the MARKAL model, the major trends are similar. A CHP plant of the same magnitude is introduced in the base scenario, while a heat pump is still used in the low electricity price scenario. The use of industrial waste heat is also greater in the low electricity price scenario. However, the results from the detailed subsystem model are more realistic, because it considers a *ever, the results from the detailed subsystem model are more realistic, because it considers a detailed load curve and production of the different plants month by month. After analysis of results from MARKAL and the detailed simulation model, it was possible to understand differences and make adjustments to both models.*

Step 5: Sensitivity analysis
The objective of a sensitivity analysis is to validate the stability of the model results. Robust strategies have two characteristics:
(1) Small changes in scenario conditions do not result in big changes to the effectiveness of the strategy,
(2) A strategy will prove to be optimal or satisfactory under different scenarios.

An example of a robust strategy would be energy conservation in buildings, which is economical under a wide range of price scenarios in any case. Such robust measures can be included in the energy plan.

Results from the sensitivity analysis must also be discussed thoroughly. One should try to understand the changes in the solution due to variations in the input data. Un-plausible results indicate remaining problems with the model formulation. The model must be improved until the results are well understood and stable.

During the main study phase the working group does the hands-on work to construct the model, to input the necessary data, to complete the model runs and to prepare reports summarizing the results. Experts from the reference group assist the working group in developing solutions for specific problems and to provide necessary data and know-how. The working group and reference group discuss the model results and plan new developments (scenarios, strategies, technical options) for the model. The steering group must be informed when far reaching decisions for the development of the model are necessary which require political guidance. This may concern, for example, the definition of new scenarios, the analysis of additional technologies or the allocation of additional resources within the model development.

3.2.4 The evaluation and decision phase

The purpose of this phase is to adopt a strategy for implementation. The different options elaborated during the main study will be assessed and prioritized by all groups involved in the project. The result of this phase is an agreement on the strategy, an action plan and a priority list for the implementation of measures thus providing the core of the local energy plan.

The results of the main study, for example the robust strategies, are presented to the steering group. Since the steering group may not have very deep understanding of the modeling technique, the working team has to prepare the results in easily understandable terms. The material (input data, results and derived indicators) is presented in the form of data sheets, graphs and a summary report. The inclusion of historic data in graphs is often very helpful, because one can judge how realistic the development of an indicator is. The following information should be prepared for the assessment and decision finding process:

- RES representation of the technical energy system,
- energy balance and emission balance,
- development and market shares of energy carriers,
- substitution of energy carriers,
- cost and effectiveness of proposed strategies,
- introduction and market penetration of new technologies,
- development of cost and emissions in different sectors,
- development of specific values and indicators (energy consumption per housing area, per capita consumption, consumption per household, energy use per GDP, specific energy consumption of industry, specific costs, etc.).

The documentation of the input data is of equal importance as the results. The following information could be included in the report (see also chapter 4.7):

- development of demand and development perspectives in different sectors.
- development of energy prices and taxes,
- development of population and housing markets,
- expected growth in commerce and industry,
- expected improvements of energy technologies.

The next task for the reference group and the steering group is to discuss the different options and proposed strategies, and to asses the advantages and disadvantages in relation to the goals specified at the beginning of the project. This can lead to a need for more information or the recalculation of scenarios and strategies to find more acceptable solutions, which triggers a new iterative loop in the main study. It is an important advantage of computer assisted models that this can be realized quite quickly and easily at this stage of the work. Finally, all groups should agree on a common strategy, an action plan and priority list for implementation. The final report is then presented to the decision makers, e. g. the City Council, the management of the utility and others, including the public.

At this point all „sins„ committed during the orientation phase in defining objectives and involving all relevant groups may result in strong objections against the project results. Clear communication of objectives and a consensual work program within the organizational set-up of the ALEP process will pay back at this point.

The end of this phase is the milestone for the ALEP project. The actual work on the project and the development of the energy plan ends here. However, it is very important to initiate a supervision and monitoring phase to accompany implementation, and to check the success of the implemented projects against the defined objectives.

3.2.5 The implementation phase

The action plan and priority list completed during the assessment and decision phase, concerning the energy sector and the emissions reduction strategy, must now be transformed into reality. The different measures specified by the action plan must be planned in detail. These activities are subject to ordinary project planning and management practices, and will not be covered in this guidebook. It is not necessary to continue the original organizational ALEP set-up during this phase. We suggest assigning of supervision of implementation to a new group (e. g. part of the working group) to ensure that the measures are implemented in an effective manner.

3.2.6 The monitoring phase

A good practice is to set up a continuous monitoring process over several years to compare the success of the action plan and implemented projects against the original objectives. Ineffective projects can be detected and reorganized. The monitoring phase does not only prove the success of the action plan, but also shows starting points for an iterative improvement of the energy system model, which may initiate a new ALEP process. The monitoring requires that a data collection and reporting process be organized. This can be achieved by an energy information system for the management of the data and the preparation of regular (e.g. annual) energy balances and reports. The content and format of the reports can be derived from the tables and graphs used in the evaluation phase. The monitoring process can be a part time activity for the organization responsible for energy planning, generally either the municipal administration or the local energy utility.

3.3 Interfaces with other planning activities

Energy planning (or environmental planning related to the energy system; e.g. emissions) is not the only activity within a region. There are other activities which influence the energy system, and changes to the energy system also have an influence on other areas. An important aspect is that urban planning (planning of new dwelling areas or industrial zones, renewal of districts, retrofit of the building stock, infrastructure maintenance) can be combined with improvements in the energy system. For example, the cost for insulation of houses can be financed through the funding for a district renovation scheme, or the cost for installation of a district heating system can be lowered by integrating it with the development of a new dwelling area or industrial zone.

Although traffic accounts for a large (and increasing) share of energy consumption (approximately 35% in Germany), it is very difficult to influence this sector with local energy planning. Individual mobility is very much dependent on personal preferences and life style. Technical improvements occur outside the local reach. Changes of street layout, parking restrictions, fees etc. have little effect on mobility patterns. However, promoting public transportation has a direct effect on energy consumption. To attain a complete picture of energy consumption and emissions, it is useful to include a very simple description of the transportation sector in the model.

Another link exists with waste management. On the one hand power plants produce waste which must be deposed of, and on the other hand incineration plants make use of different kinds of waste (refer to the Basilicata study in chapter 5 for discussion of waste management). A similar connection exists with the use of bio-mass as fuel. Here, the relationship between production, consumption and price is important. If desired, the production and consumption of bio-mass could be included in a simplified way in the energy system model.

The consideration of energy issues in urban planning, environmental planning, waste management or traffic planning can contribute to decision-making in these areas. Information concerning energy balances and the operational energy cost of these projects can help to sort out unfavorable alternatives. The examples presented for urban planning suggest a very close relationship between these planning areas.

Chapter 4 Steps and Tools in the Technical Analysis

In this chapter we will give a more detailed description of certain steps in the energy planning process, which was presented in chapter 3. We will also discuss a number of tools (computerised and other) which could be used in the different planning stages. Appendix A1 includes a presentation of different available computer models.

The text of this chapter is supported by examples, which to a large extent are based on the Göteborg case study (see chapter 5.4). A few simplifications and additions have been made to this case study in order to make the examples clearer and to facilitate the reader's understanding. (It is assumed that local energy planning is characterized by a continuous participation of different local groups and decision makers and by the common goal to find a consensual solution, as it is usually the case in Swedish LEP-projects)

Here follows a short introduction to the Göteborg case study:

Göteborg's energy demand and supply have undergone dramatic changes over the last twenty years. The use of oil has been drastically reduced, replaced by a new natural gas system and an expanded district heating system. The district heating system makes use of industrial waste heat, heat generated from waste incineration, and a large electric heat pump plant that recovers the heat energy from the city's sewage treatment plant discharge.

This has resulted in a drastic reduction in air pollutants from stationary sources, and a more reliable energy delivery system. These changes were brought about as a result of a planning process implemented almost two decades ago. Between 1987 and 1995 several basic conditions changed, requiring a change in the "Energy Plan for Göteborg". Energy tax structures and levels were changed, charges for pollution emissions increased, and the relative price level between fuels and other energy sources changed. Furthermore, the impending deregulation of the electric energy market was expected to result in electricity prices driven by market forces different from the current regulatory framework. All these conditions made it necessary to update the "Energy Plan for Göteborg".

The objective of the "Energy Plan 2000" is to provide a long-term strategy for Göteborg's energy policy. The plan is used as an instrument to co-ordinate the community's joint efforts. Furthermore, it is used to develop a process that will lead to improved utilisation of resources and better prepare Göteborg for its energy future. Energy efficiency is promoted along with reliable and sufficient energy supplies. The purpose of the energy plan is to attain a sustainable development for the future.

4.1 Description of the present situation

Every ALEP must contain a description of the present situation. This is the basis for the analysis of the development of the energy system. The description of the present situation is, for most planners, merely an overall picture of the base year for local energy planning. It consists of facts about energy production, energy use and emissions. A more advanced description of the present situation also includes an evaluation section. An experienced energy planner may draw certain conclusions based on the description of the present situation. Presented together with a simple analysis section, the description of the present situation thus constitutes an important first step in the comprehensive analysis within ALEP; both for the actors taking part in the planning process and later for the reader of the ALEP report. The evaluation section could also help the planner find issues that require more detailed studies.

Purposes of the description of the present situation:

- Derive starting points for the comprehensive analysis and for the subsystem studies.
- Make up the basis for the analysis of the future development. (Examples of questions to be answered are: What is the present trend of energy supply? What are the technical options to achieve the goals?)
- Evaluate the present supply and demand systems.
- Recommend possible strategies and measures.

- Help find important issues suitable for the detailed studies.
- Give background information for determining the focus of the ALEP study (e.g. concerning which emissions should be considered).

Activities included in the description of the present situation:
- Collecting and presenting data for the energy systems and emissions.
- Making a list of important questions.
- Making a list of subsystem studies.
- Compare with existing goals, e.g. "we are far away from the goal which we formulated and decided on 10 years ago, stating that 30 % of the energy supply to the community should be based on renewable energy". (The derivation of "new" objectives, i.e. the objectives of the advanced local energy plan which are to be worked out in this project, are discussed in chapter 4.3 below.)
- Making a description of actual development *trends* (e.g. "the district heating system has expanded by 10% per year for the last five years") and the status of *knowledge* (e.g. "we know that our district heating production system has a very small share of CHP production, compared to other systems in similar cities").
- Evaluation of strengths and weaknesses in the present energy system.

4.1.1The collection and presentation of data for the energy systems and the emissions

The data collection and processing of statistics are a central activity within the description of the present situation, and are done in a traditional manner. In chapter 4.5 below, the data requirements and provision are described in more detail. However, it should already be stressed at this stage that :
1. you should not invest too much resources into these elements, and
2. you must allow for a certain amount of "approximation" in some of the data.

As long as you are aware of the approximations in certain data, throughout the analysis, and take note of them in the discussion of results, then the quality of the analysis should not be significantly affected. Example: If the emissions from the transportation sector are merely used as a level for comparison in the study, with which the emissions of the energy sector are compared, and no development plan for the transportation sector is to be developed by ALEP, then the emission data can be fairly approximate.

The *methods* for collecting data and processing statistics are well-known. A detailed presentation and discussion of methods is therefore unnecessary here. We restrict ourselves by focusing on a couple of items:
- A description of the present situation should be developed, both for the comprehensive analysis and for the detailed analysis (subsystem studies) which shall be considered by ALEP. The description of the present situation should have the same system boundaries and the same degree of detail as the ALEP analyses.
- However, the "official" description of the present situation in the final reports and in oral presentations will be more illustrative if it is given on a more aggregated level. Below, the total supply and demand of energy for the entire community of Göteborg, and the total emissions of sulphur, NOx and CO2, are given as an illustrative example of an "official" description of the present energy balance and emissions for a comprehensive study. (In the "official" final report for the Göteborg Energy Plan, this description is supplemented with a RES for the complete community energy balance, together with a description of the present situation for the detailed analyses, e.g. the district heating system.)
- The description of the present situation should also include the emissions caused by the energy system. If it is possible to show the emissions from other sectors within the system boundary at the same time, this will form a good foundation for comparisons. This is important for the analysis of results (see chapter 4.7 below).
- The description of the present situation, which forms the basis for the detailed subsystem studies, can be of a very different format and content. We therefore do not find it very

helpful, in a guidebook of this type, to present examples. Instead we refer to chapter 5: "Case studies". We would, however, like to offer two recommendations:

- The descriptions should show the *complete* picture within the specific system boundary.
- A GIS map can be very illustrative and helps to complete the description of the present situation (see examples in chapter 4.3 below)

What type of data is needed at this stage? The following is a list of data and presentations which are useful for this purpose:

- Energy balances for the studied systems. (This can be given in the RES form, see chapter 4.2 below.)
- Emissions from the energy system, preferably in relation to emissions from other sectors within the system boundary.
- Useful energy demand: total, and divided by sector and/or demand group, for:
  - space heating, water heating and air-conditioning
  - lighting, ventilation, cooking, etc.
  - industrial processes, heating and cooling, etc.
- End use technologies used within sectors/groups:
  - e.g. different types of boilers for space heating
  - efficiences
- Distribution systems:
  - total distributed energy
  - geographical distribution
- Technology for the production of district heat and electricity:
  - e.g. power plants, heating plants and co-generation plants
- Primary energy supply: total and individual energy carriers:
  - e.g. oil, natural gas, coal, biomass...

A more detailed description of the different aspects of the use of data and different forms of presentation can be found in other chapters in this guidebook. In chapter 4.5 a more complete list of data is presented, together with possible sources of data. chapter 4.2 contains descriptions of the Reference Energy System, the load curve and Geographical Information Systems.

Data is stored in databases and tables. In order to privide for a better understanding for those taking part in the planning process, the *data* should be presented in diagrams. The following examples show how the data could be presented:

Description of the present situation in Göteborg.

Electricity, oil and refinery gas are the three dominate types of energy supply, each with a share of 25%. The use of energy is divided into a number of sectors, with refineries making up the largest sector. (The refinery and transportation sectors are not included in the energy plan. They are, however, included in this energy balance to show their order of magnitude and for comparison with other sectors.)

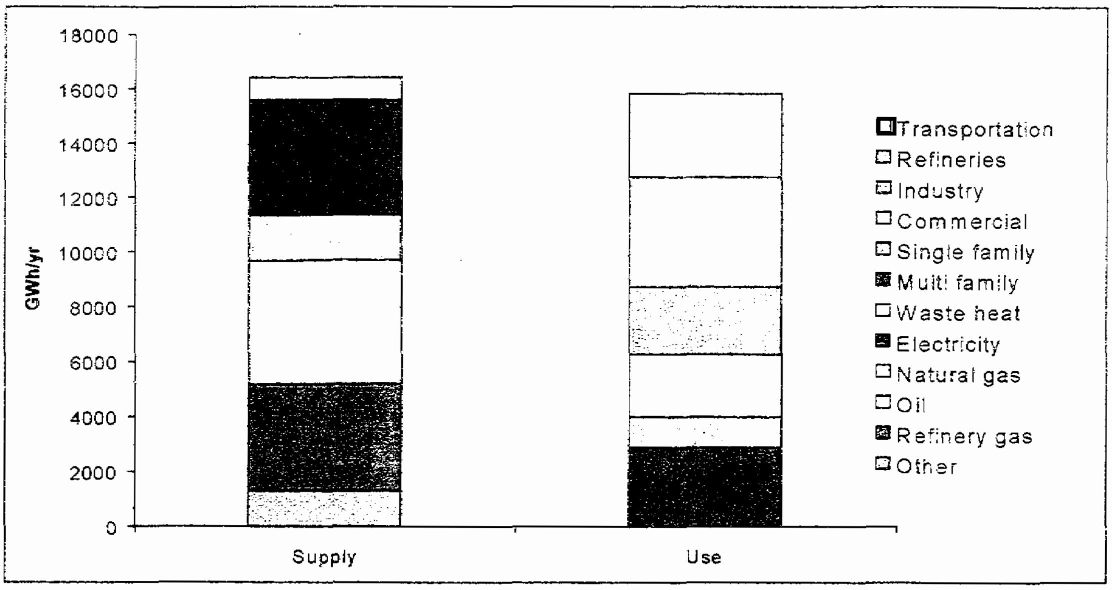


Figure 4-1: Primary energy supply and final energy demand in Göteborg 1993 [GWh].

The emissions from energy conversion in Göteborg mainly originate from refineries and transportation. Energy used for space heating, industrial processes outside the refineries and use of electricity in appliances, etc (i.e. the part of the energy system which can be found within the system boundary of the energy plan) only account for about a quarter of the CO_2 emissions in Göteborg.

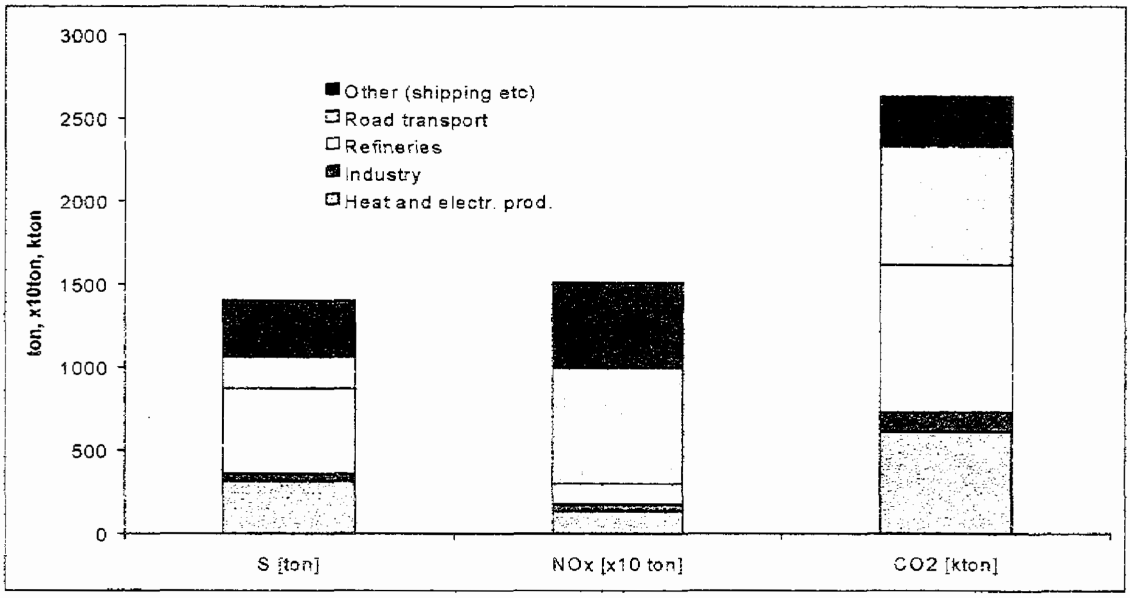


Figure 4-2: Emissions of sulphur (1400 tons), nitrogen oxides (15000 tons) and carbon dioxide (2600 ktons).

District heating is the main source of heating in Göteborg. The base load production comes from waste incineration and industrial waste heat (from the refineries). Heat pumps, natural gas fired CHP plants and oil- and gasfired heating plants make for the rest of the production. The share of heat from CHP plants is very small compared to most district heating systems of this size.

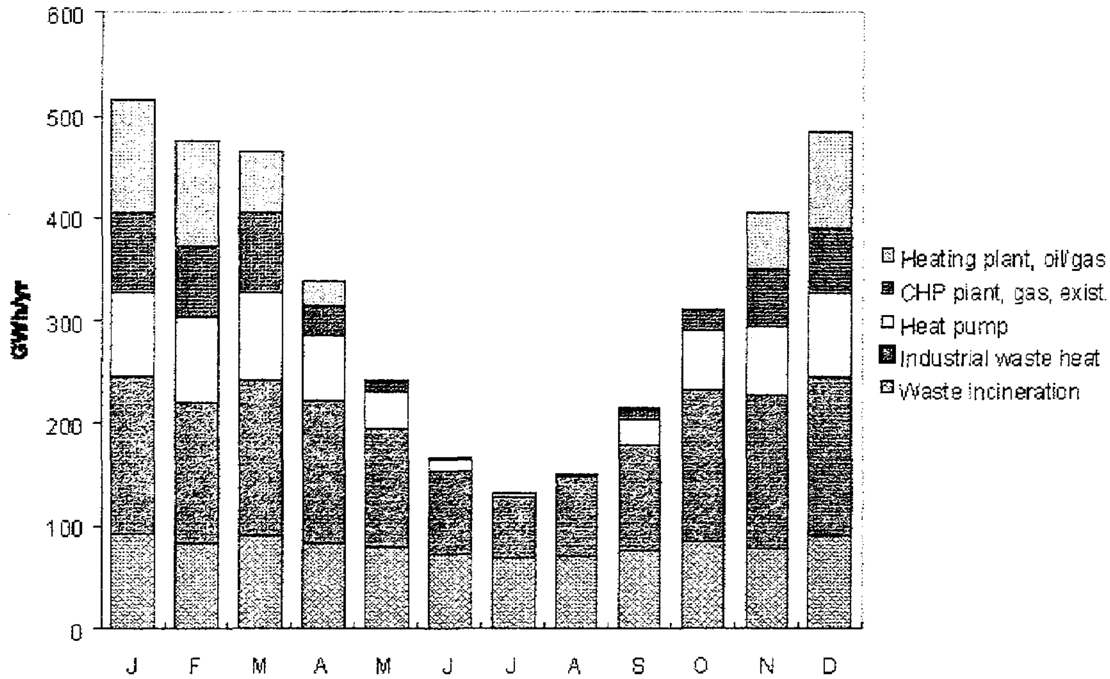


Figure 4-3: District heating production [GWh/month]

Diagrams are easy to understand. Therefore we recommend the frequent use of diagrams in reports and oral presentations. However, they will never give the complete, detailed description of the present situation which is needed for the subsequent analysis, e.g. the model work. Tables and databases are needed to give the correct degree of precision for the calculations.

Table 4.1: District heating production as presented in figure 4-3 [GWh/month]

	J	***F***	***M***	***A***	***M***	***J***	***J***	***A***	***S***	***O***	***N***	***D***	*Year*
Heating plant, oil/gas	*110*	*103*	*59*	*23*	*1*	*0*	*0*	*0*	*1*	*1*	*55*	*93*	*446*
CHP plant, gas, exist.	*77*	*70*	*78*	*30*	*9*	*1*	*0*	*1*	*9*	*19*	*57*	*63*	*413*
Heat pump	*82*	*83*	*85*	*62*	*37*	*11*	*2*	*1*	*25*	*57*	*67*	*83*	*595*
Ind. waste heat	*154*	*137*	*153*	*139*	*116*	*83*	*61*	*78*	*103*	*149*	*150*	*154*	*1475*
Waste incineration	*92*	*83*	*90*	*83*	*80*	*72*	*68*	*71*	*77*	*85*	*78*	*91*	*969*
Total (GWh)	***515***	***476***	***464***	***339***	***242***	***166***	***131***	***150***	***215***	***312***	***406***	***484***	*3900*

4.1.2 Objectives of the plan, important questions, subsystem analysis

At this stage of the planning process it may be too early to decide on the objectives of the plan. It is, however, advisable to check which goals exist among the stakeholders of the project and compare them to the present situation. This is a good basis for the development of "new" objectives for the local energy planning task. Objectives of advanced local energy planning are discussed in chapter 4.3.2.

Typical objectives in an ALEP could be:

- Reduction of emissions
- Increased use of renewable energy sources
- Increased energy savings.

It is also valuable to collect the actual strategic questions and other important questions discussed by the different actors within the local energy system. The list of important questions in Göteborg provides a good example.

Here are some of the important questions which were identified at the beginning of the energy planning project in Göteborg:

- *What role will natural gas play in the energy system? Is it wise to prepare for storage of gas? What is the environmental value of the gas?*
- *What fuels are possible to use in district heating production in the next 30 years? Will natural gas be a dominate fuel in the near future? Will the share of solid fuels change? Is biomass a realistic alternative for Göteborg?*
- *Should Göteborg commit resources to an expansion of electricity production from CHP plants, and if so, to what extent?*
- *Will there be a conversion away from electrical heating in single family houses, and if so how fast and what will be the alternative? Is it possible to influence this process, and if so how?*
- *How large is the potential of technical fixes in reducing of the use of electricity?*
- *Which influences and what effects can be expected from different advising strategies for energy conservation?*
- *How will the future use of electricity develop? Prognosis?*
- *How will restrictions on emissions of sulphur, nitrogen oxides and carbon dioxide influence the development of the energy sector? What will happen in other sectors? Should Göteborg formulate separate municipal goals?*

Although not all subsystem studies can be formulated (or be identified) already at this stage, the list which has been defined will become an important part of the "rich picture" that the description of the present situation gives. The list of detailed studies in Göteborg is as follows:

At the very beginning of the planning process existing initiatives were identified in order to find relevant issues for subsystem analysis. Examples of such issues are:

- *Large scale introduction of natural gas fired combined heat and power production, CHP, in the district heating system.*
- *Seasonal heat storage in existing rock stores, previously used for oil storage.*
- *Waste incineration; expansion and increased electricity production.*
- *The potential for energy conservation in residential and commercial buildings.*
- *The competition between district heating, natural gas and other alternatives for heating of single family houses.*
- *Alternative fuels for vehicles, e.g. electricity and natural gas*

4.1.3 System boundaries

Local energy planning can be limited in practise by, for example, a city or community border line. Other systems boundaries can also be applied. In the case studies within Annex 33 we had the following boundaries:

- Mannheim: Municipal border, transport sector excluded.
- Delfland: Industrial zone.
- Basilicata: Province border, transport and waste management included.
- Göteborg: The community border has in principle been used as the system boundary, but the transport sector and the two refineries located within the community border have been excluded. The delivery of industrial waste heat from these refineries to the district heating system is, included within the systems boundary, free from emissions. Emissions from the production of electricity outside the system border were however included in the emission budget for Göteborg. A method for this "crediting of emissions" is given in the example of system boundary and the emissions of the imported electricity below.

System boundary and emissions related to electricity import

A classic dilemma in local energy planning is how to treat electricity "import" from the international grid, from an emissions point of view. In the Göteborg energy planning project it was assumed that all electricity imported to the municipality was resulted in emissions typical of fossil fueled condensing plants. These emissions are relatively large. They can be reduced both through decreased electricity use in Göteborg and through increased CHP production of electricity, which is a much more efficient technology for electricity generation.

The fossil fueled condensing plants are assumed to cause emissions typical for an efficient oil fired plant. This is a reasonable assumption since the existing condensing plants in Sweden are oil fired. It is also reasonable since the emission data for oil fired condensing plants is calculated as an average of old coal fired plants and modern gas fired plants.

The following emission coefficients have been assigned to imported electricity:

- Sulphur:	*25 mg/MJ fuel*	*(90 mg/MWh)*
- Nitrogen oxides:	*100 mg/MJ fuel*	*(360 mg/MWh)*
- Carbon dioxide:	*78 g/MJ fuel*	*(280 g/MWh).*

An assumed plant efficiency of 45 % results in the following emissions per MWh electricity:

- Sulphur:	*90 / 0,45 = 0,2 kg/MWh*
- Nitrogen oxides:	*360 / 0,45 = 0,8 kg/MWh*
- Carbon dioxide:	*280 / 0,45 = 620 kg/MWh.*

4.1.4 Evaluation of the present situation

There may be reasons to include an evaluation section in the description of the present situation. It can be useful for the description of the present situation, especially if the resources for the comprehensive analysis are limited. This evaluation is only of simple character, and can not replace the analysis in the main study.

One useful method is the "trend/knowledge-analysis", which is based on:

1. historical trends, e.g. the development of energy demand during the past decade
2. present knowledge, e.g. the market share of district heating in different sectors.

The results from the "trend/knowledge-analysis" could either be insights on the future development of parts of the energy system or more general insights about the characteristics of the energy system.

The two examples below illustrate how the "trend/knowledge-analysis" could be applied in ALEP. The first example offers general insights and the second offers insights into a part of the energy system.

The presentation of NOx emission data (figure 4-2 is a part of that presentation) was supplemented in the description of the present situation by the following:

"Trend": NO_x emissions from the energy sector (here=heat and electricity production + industry) had decreased by approximately 3% per year during the period 1990-1995. The energy sector's share of total NO_x emissions had decreased from 20% to 10% during the same period, while the transportation sector had increased its share from 65% to 80%.

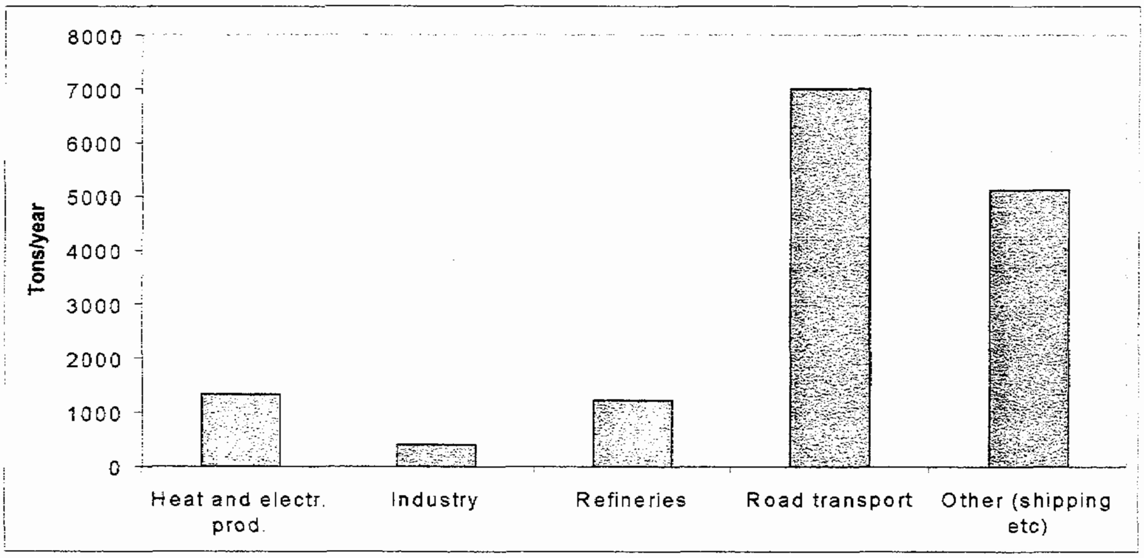


Figure 4-4: The total CO_2 - emissions of different sectors in Göteborg. The transportation sectors are included for comparison

"Knowledge": Most of the available cost effective measures for reduction of NO_x emissions in the energy sector had already been implemented. The relative emission level from the energy sector was significantly lower than from the energy sectors of comparable communities. There are also cost effective measures available in the transportation sector.

Analysis and conclusion: A simple "trend/knowledge-analysis" of the emission pictures above led to a decision to refrain from including analysis of NO_x emissions in the ALEP. This analysis was left to transportation planning, since the size of the emissions from transportation was many times larger than from the energy sector. There should be recognized that the most cost effective measures in the energy sector have already been implemented.

The other example deals with the historical development of the efficiency of typical household appliances in comparison with the development of the total use of electricity for appliances in households. This comparison of efficiency and demand resulted in the conclusion that more efficient equipment does not necessarily lead to lower electricity consumption.

There is a common view that more efficient appliances will automatically lead to reduced electricity use in this sector. An analysis of historical data, however, showed a different picture. The figure below contains two different types of information in the same table:

1. *The average energy consumption in typical household appliances (refrigerator, freezer, washing machine, dish washer, stove, and tumbler dryer) - lower curve.*
2. *The total use of electricity for appliances per person - upper curve.*

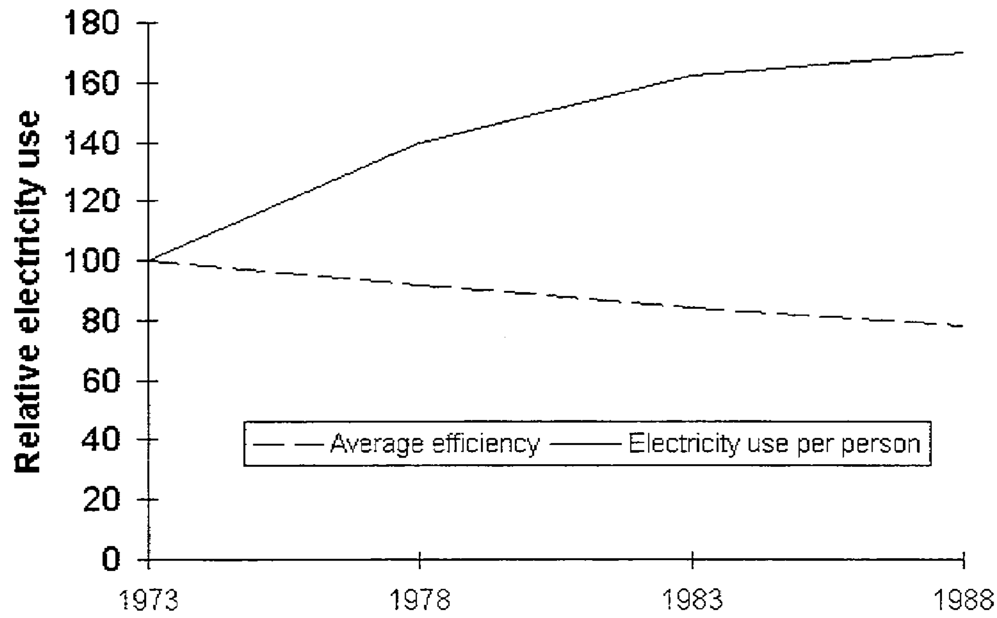


Figure 4-5: Comparison of average efficiency of typical appliances and total use of electricity for appliances per person. Relative data. 1973=100

Figure 4-5 shows that although appliances have become more efficient, the total use of electricity for appliances has increased. We can speculate on the reason for this: less people per household, more appliances per household, new types of appliances, etc. The important conclusion is that more efficient equipment does not necessarily lead to lower electricity consumption. This is important to be aware of when making prognoses for the future.

4.2. Ways of representing the local energy system

In this guidebook we will focus on three useful tools of representing the local energy system: *the Reference Energy System (RES), the Load Curve and the Geographical Information System (GIS).* These three representations are not alternatives, but rather complement each other. They are often required in order to analyse available information and produce the needed results for the different analysis' in ALEP.

4.2.1 The Reference Energy System (RES)

The Reference Energy System (RES) is a scheme which "models" the structure of a local energy system. The RES describes the flow of energy from the sources to the final use. It shows all flows of energy from the primary energy supply, large scale and small scale energy conversion, different distribution forms and the final use of energy in different sectors. Additionally the RES usually contains useful information on energy demand and even energy services (see figure 4-6). The RES, however, is *not* a geographical representation of the local energy system.

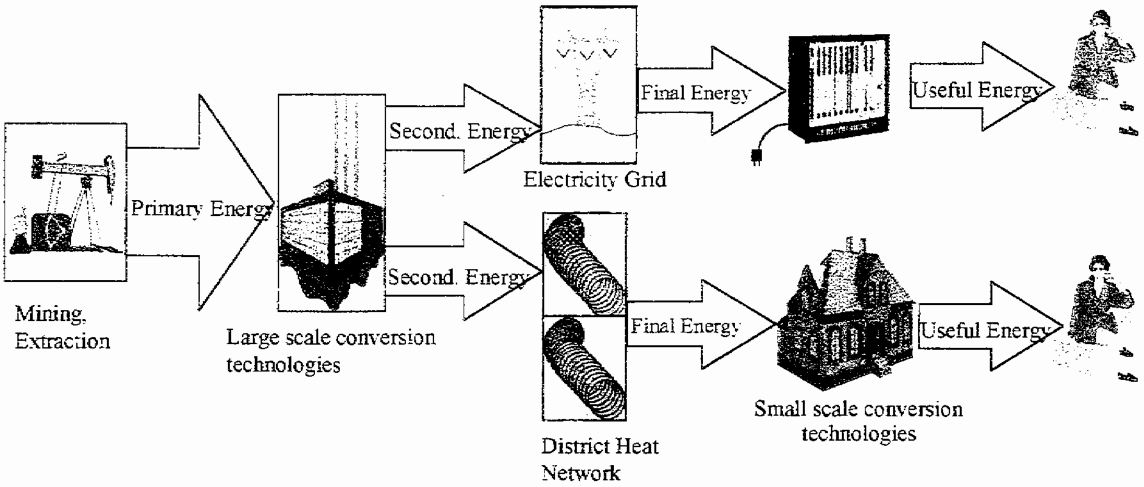


Figure 4-6: A "physical representation" of the Reference Energy System.

Using the Reference Energy System (RES) it is possible to see how energy flows and how energy conversion technologies influence the fuel-technology chains in an energy system. This means, that the benefit of coupled production can be estimated according to its contribution to both the district heating subsystem and the electrical subsystem. The roles of these subsystems can be evaluated from the perspective of the entire energy system and the requirements on this system. This overall perspective is particularly important when one evaluates demand side energy conservation technologies, i.e., the balance between supply and conservation measures, or the cost-efficiency of a proposed investment to control emissions.

A slightly more detailed RES than the one above illustrates the influence between energy flows and technologies.

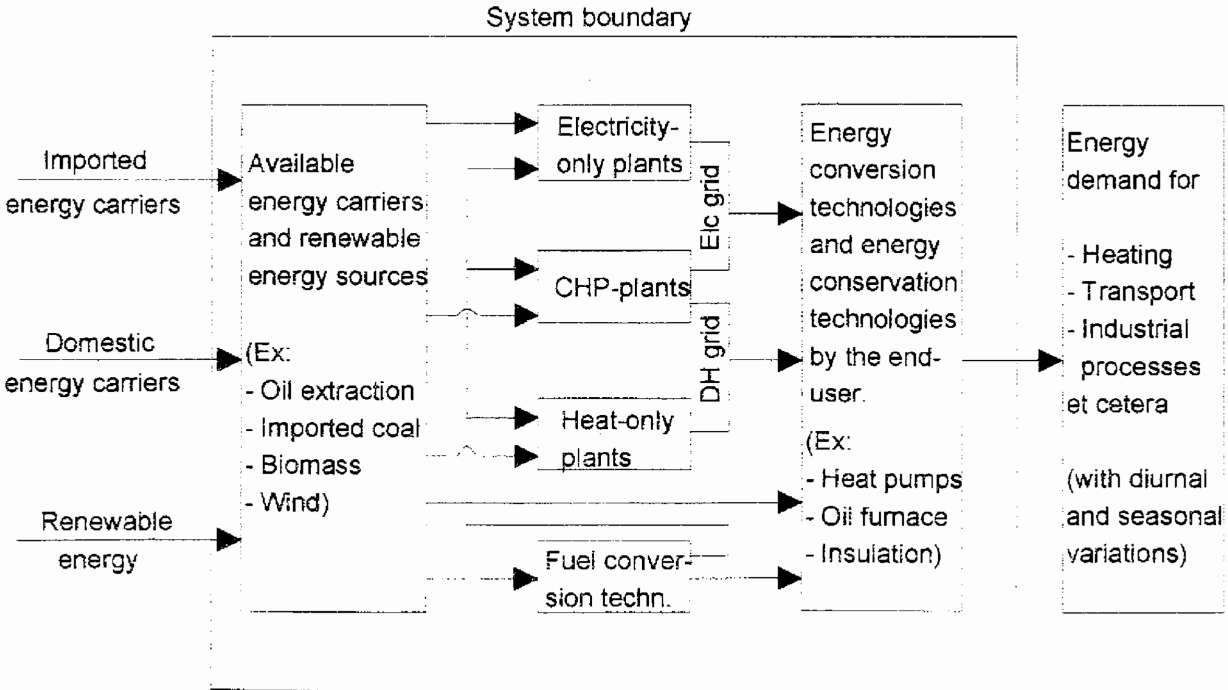


Figure 4-7: Principal representation of a Reference Energy System (RES) for an ALEP study at an aggregated level

While the RES is a graph of all relevant energy flows within the energy system, an energy balance contains the values of all energy flows. Those can be included in the graph or be presented in separate tables. (The RES may contain more conversion levels like distribution, end use technologies and useful energy demands, which are normally not included in an energy balance.)

The RES is preferably built-up according to certain practical recommendations:

- Sources and primary energy supply: The RES begins at the far left of the diagram with the input flows of energy, e.g. oil, natural gas, coal, petrol and imported electricity.
- Processes: Next follows the processes which modify the fuels, e.g. oil refining and preparation of pellets from biomass. For ALEP it is in general not necessary to include all processes within the system boundary. In many cases it is more natural to describe e.g. refined oil or biomass pellets as the primary energy supply (or available energy carriers), since processing may have taken place outside of the studied community and had no noticable influence on its energy system.
- Conversion technologies: Next the flow of energy enters the large energy conversion technologies, e.g. electricity production plants, district heating plants and combined heat and power plants (CHP).
- Distribution systems: Large scale conversion is followed by distribution systems for different energy forms, e.g. electricity, district heating and natural gas.
- End use technologies: The next step is the small scale energy conversion technologies, e.g. oil fired boilers for multi-family houses, solar heating systems for single family houses, electrical appliances, petrol fueled cars and small scale combined heat and power plants. All these technologies are supplied by "final energy" sources.
- Useful energy demand is the energy which is needed for different kinds of applications, e.g. space heating, lighting and cooking. Conservation measures reduce the need for certain energy services.

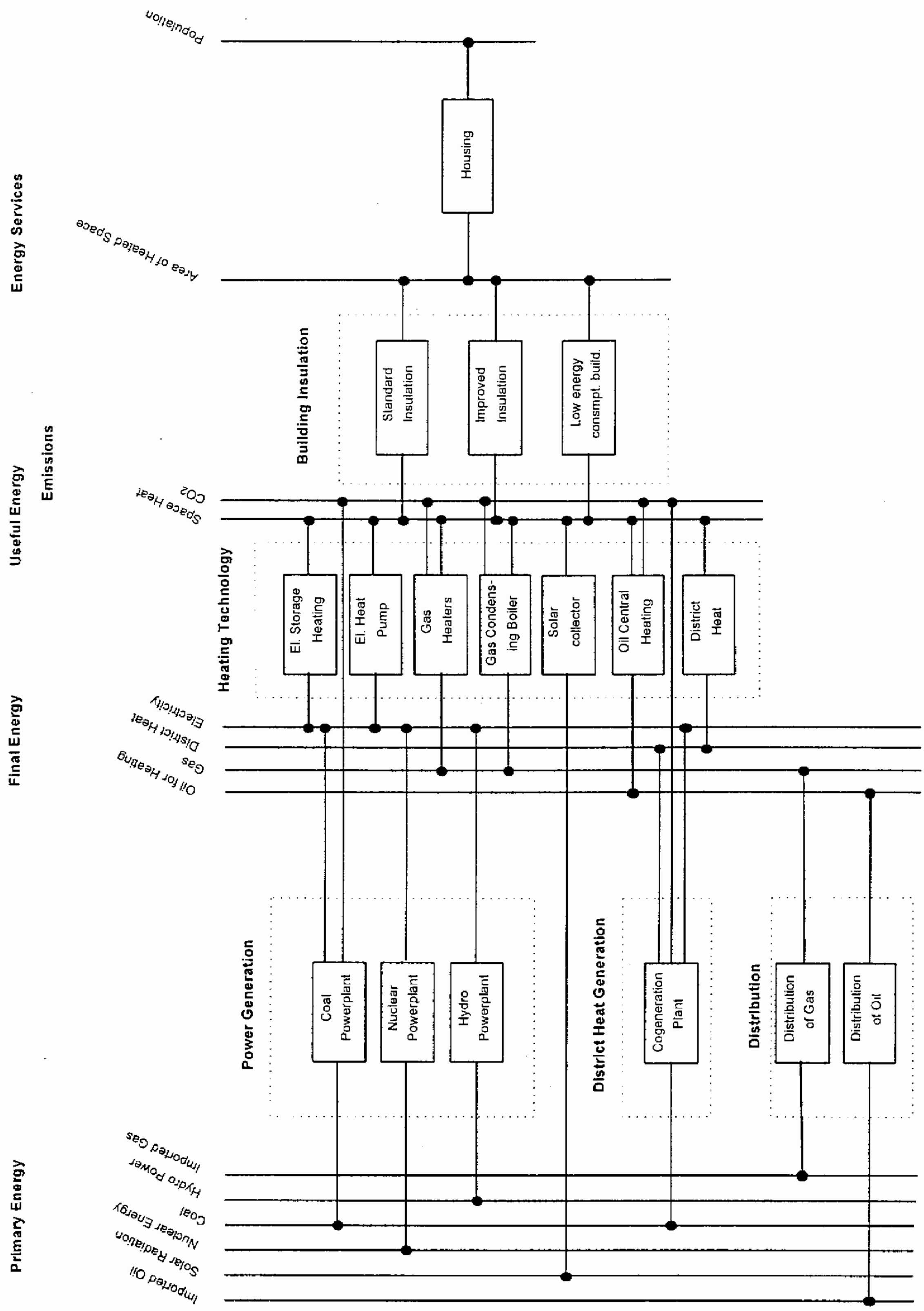


Figure 4-8: Example of part of the RES representation of a local energy system

In addition to the conventional energy balance and the RES, there is another representation tool which is used frequently: the Sankey diagram. In the Sankey diagram the flow of energy from input of energy to final use is illustrated by lines of different width, where the width is proportional to the size of the energy flow. This gives an immediate feeling of the relative importance of the energy flows. The energy system must often be more simplified than the RES, in order to fit all flows into one diagram.

From the Göteborg study we present the overall RES and a more detailed RES for the household sector in Göteborg. It is common to provide different levels of detail in RES. By working with different levels of detail, you avoid on RES that is too complex.

In ALEP studies, the RES representation will generally be the basis for all further analyses. For presentation purposes, it could very well be supplemented by energy balances or Sankey diagrams.

The Reference Energy System (RES) can be used to show different aspects of the energy system. It can cover the total energy system. In order to make it possible to include the total energy system, the RES must be somewhat simplified. Otherwise it will be too large and complicated for practical use. Below, an overall RES for Göteborg is shown.

Here we present the Göteborg RES as an example of how to use this principle for representing the local energy system. The specific Göteborg details are discussed in the Göteborg case study in chapter 5.

The complete picture can be presented if the RES is complemented by more detailed Reference Energy Systems for different parts of the system. In the figure below a detailed RES is presented for the household sector (upper right section of the overall RES). The total energy demand for the household sector was divided into four (more or less) homogenous groups of houses.

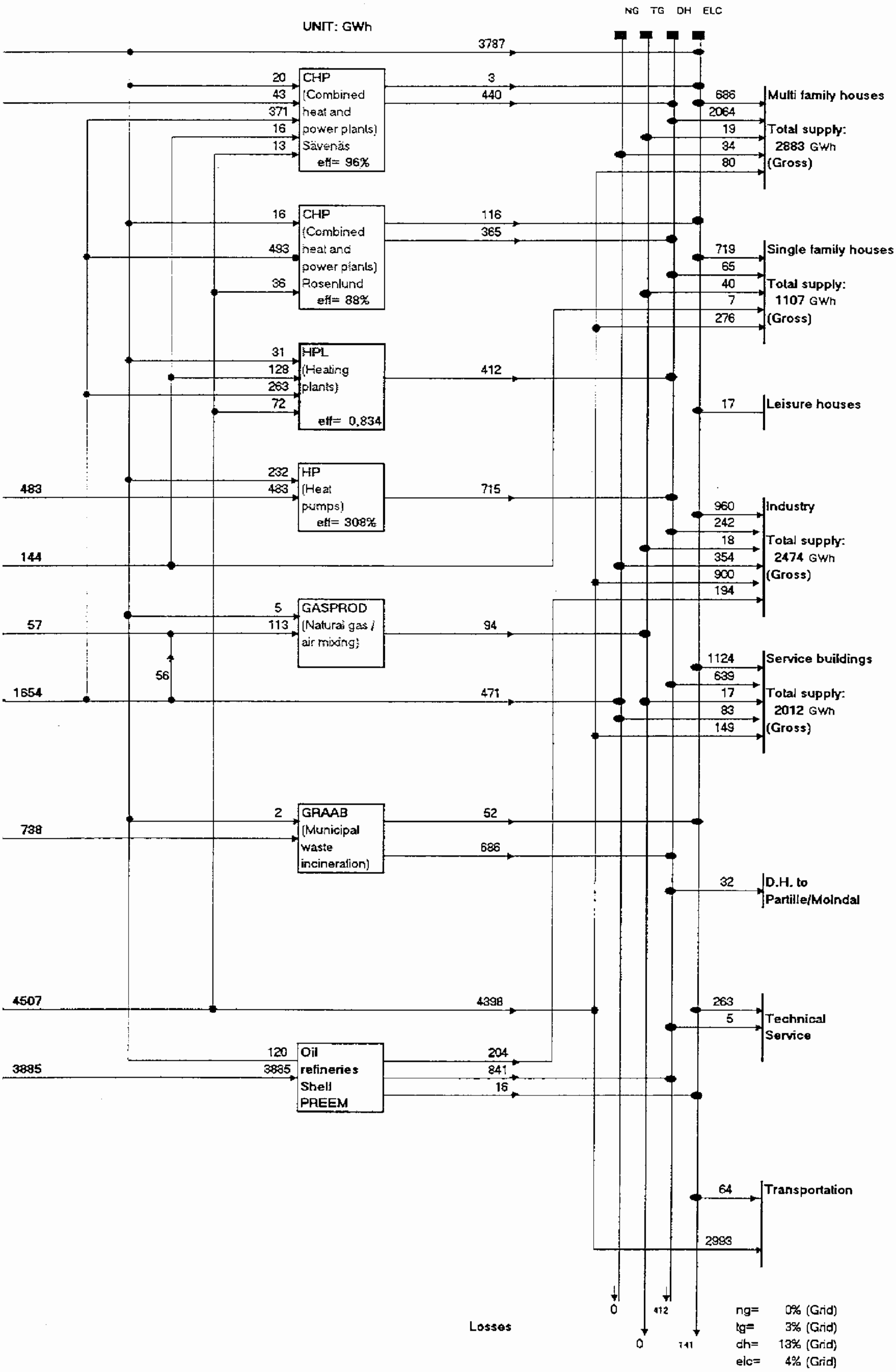


Figure 4-9: RES covering the total energy system of Göteborg, 1993, [GWh]

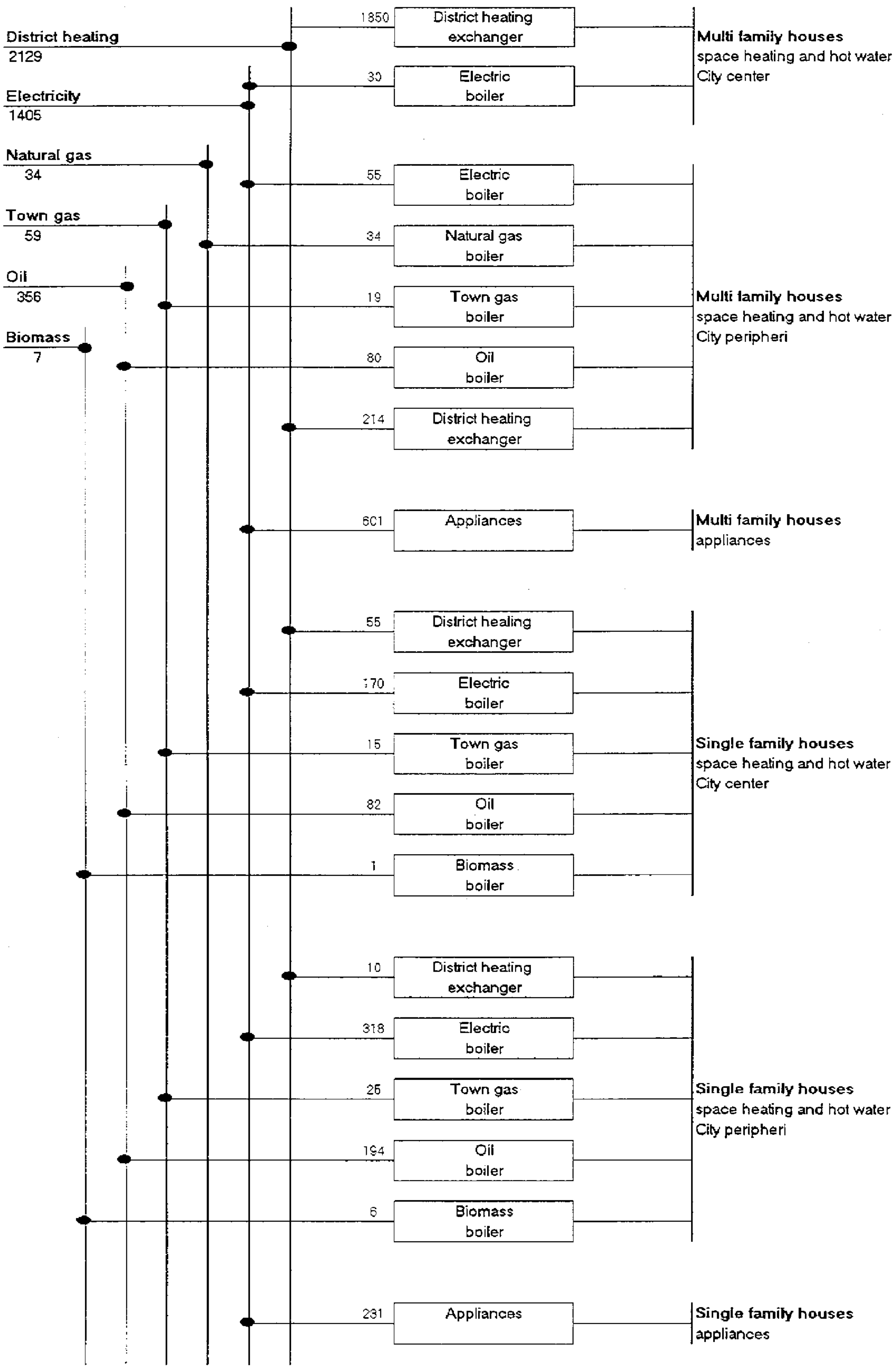


Figure 4-10: Reference Energy System for the household sector in the city of Göteborg, 1993 [GWh]

4.2.2 The Load Curve

The load curve is an illustration of how the demand for a certain energy form (electricity, heat or cooling) in a certain application varies over time.

One example is the changing district heating production in Göteborg during a typical year, as shown in figure 4-11. The diagram starts on 1 January and ends on 31 December. This load curve is made up of daily averages. The diagram shows the typical pattern of high energy production during the winter and the small energy production during the summer. (During the summer there is no need for space heating, but the need for water heating remains.)

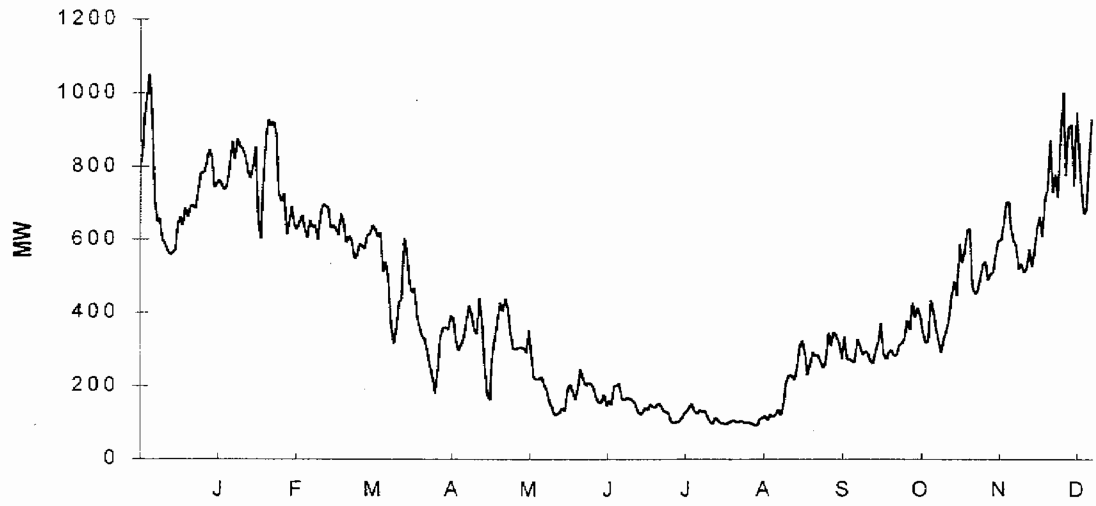


Figure 4-11: Detailed load curve for Göteborg district heating production

The energy demand variation is an indication of the heating power demand, i.e. the load curve contains information on both power and energy demand.

The load curve is often shown in a simplified form with load levels presented as monthly averages, figure 4-12. This makes the figure easier to read and it also makes calculations based on the load curve more practical to perform. However, a lot of information can be lost, e.g. about peak load.

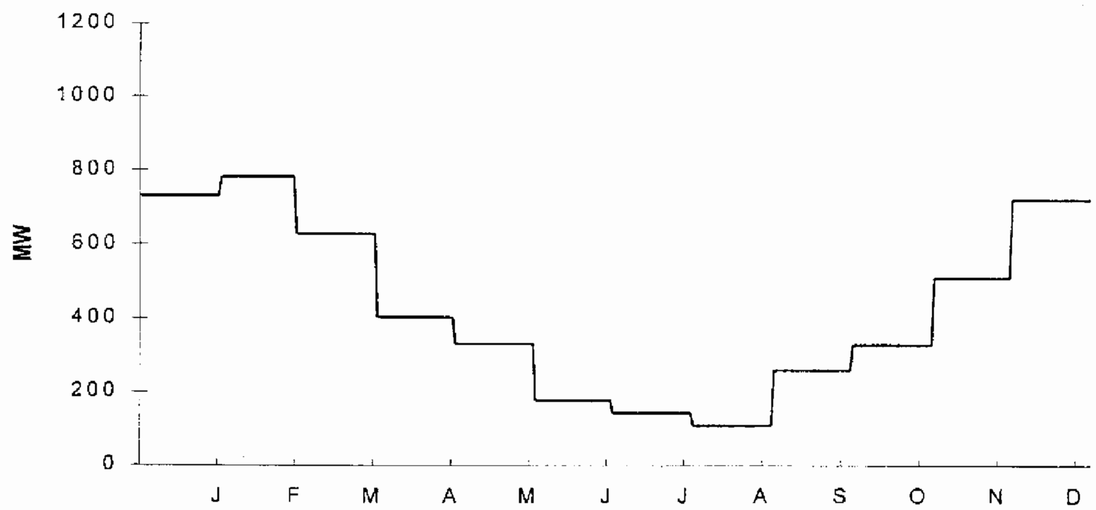


Figure 4-12: Monthly average load curve for the Göteborg district heating production

Another way of representing the changing demand for energy is the duration curve. A duration curve for the production of district heating in Göteborg is shown in figure 4-13 below. This diagram is made up of the data from the detailed load curve above. The duration curve starts with the day having the highest energy production and ends with the day having the lowest energy production. In the duration curve it is possible to see how many days during the year the energy production was higher than 600 MW. The more detailed the data used for the development of the duration curve, the better and "smoother" the curve will be. It is therefore not a good idea to simplify the duration curve with monthly average load data, since this would result in a less useful duration curve.

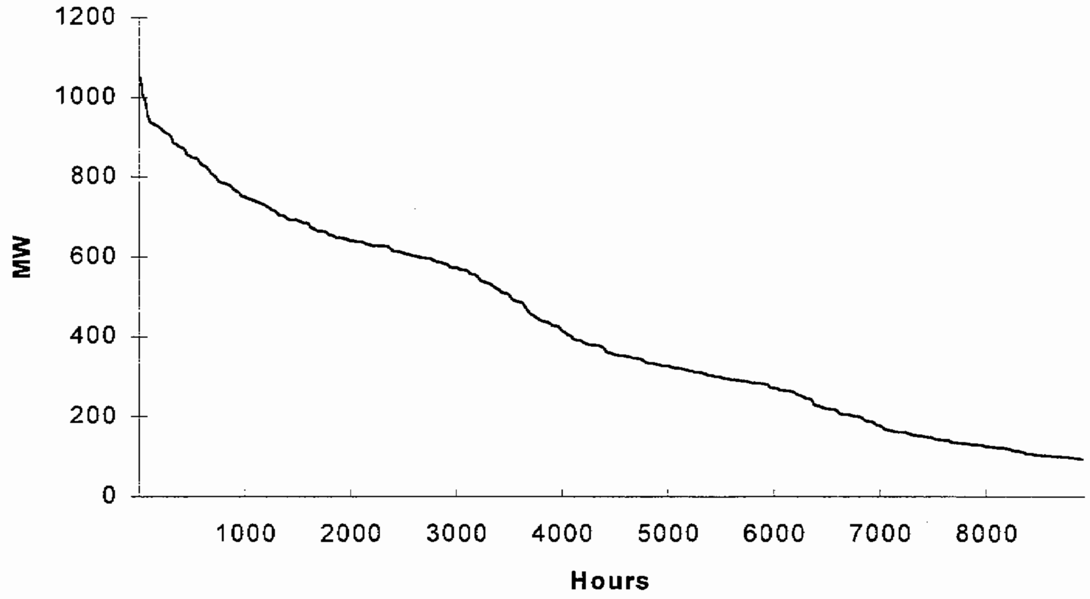


Figure 4-13: Duration curve for district heating production in Göteborg

The load curve includes more information than the duration curve, since it contains the information regarding <u>at what point</u> during the year a specific load level occurs. This information is lost when the load curve is transformed into a duration curve. If, for example, both heating and cooling demands in an analysed energy system are known, and if they are in some way interconnected, then the load curve will show that the peak level of heating occurs in January, whereas the peak load of cooling occurs in July, i.e. never peaking during the same season. Such information is impossible to extract from a duration curve.

The *load curve* is typically used in order to calculate which production plants should be <u>operatingto</u> cover the district heating load, day by day. The *duration curve* is suitable for more principle consideration of base load / peak load plants. The calculation of the total yearly energy production from each type of plant given their <u>capacities</u>. The duration curve is typically used in ordinary LEP, but is generally replaced in ALEP by calculation models which use the real load curve instead of the duration curve.

An analysis based on the load curve is only appropriate for a district heating system without coupled production, for a building where only the heat demand is considered. The investment decision should be quite well defined, e.g. finding a substitute for a retired heat plant. But if the value of the installation is influenced by choices outside the single-output or single-demand system, or if there is more than one output or more than one demand in the system, then the single load-curve representation may not be adequate for a meaningful analysis.

Computer models used in ALEP are generally RES-based, but also include load curves. They use seasonal and diurnal variations in demands (externally given as inputs), as well as load curves - internally constructed in the models - for the electric and district heating subsystems, and if necessary also for the gas subsystem. The load curves will not be as detailed as the load curve models discussed above in order to reduce the size of the mathematical problem and the calculation time for the model.

4.2.3 Geographical Information System (GIS).

GIS stands for Geographical Information System which are computer programs for presentation and handling of information connected to geographical locations through maps. There are several Windows based PC programs which can produce maps with position based information (dots, lines, areas) through symbols, colours, diagrams, etc. To be able to present information through maps it is necessary to have geographically defined data available. Today, this is not always the case, but currently digitized maps with all the existing infrastructure are generally available.

Different layers of information can be presented together or separately. There are a number of interesting GIS applications which are useful when working with energy planning. One example is the "heat map" presented below. It shows the location of heating plants in one layer, and heat density in another layer. A base map with roads and streets, lakes and rivers and the municipality border constitute the background.

"Heat map" - a GIS tool including several levels of information for ALEP

In a "heat map" you can combine information of different types on a GIS map:

- The existing demand devices per demand sector, and
- The heat density: The heat density is the total useful energy demand in a certain settlement zone, divided by the area of this zone. The unit could be GWh/km^2, kWh/m^2 or MW/km^2.

By combining these on the same map, you can e.g. get an idea of the possibilities to expand the district heating system.

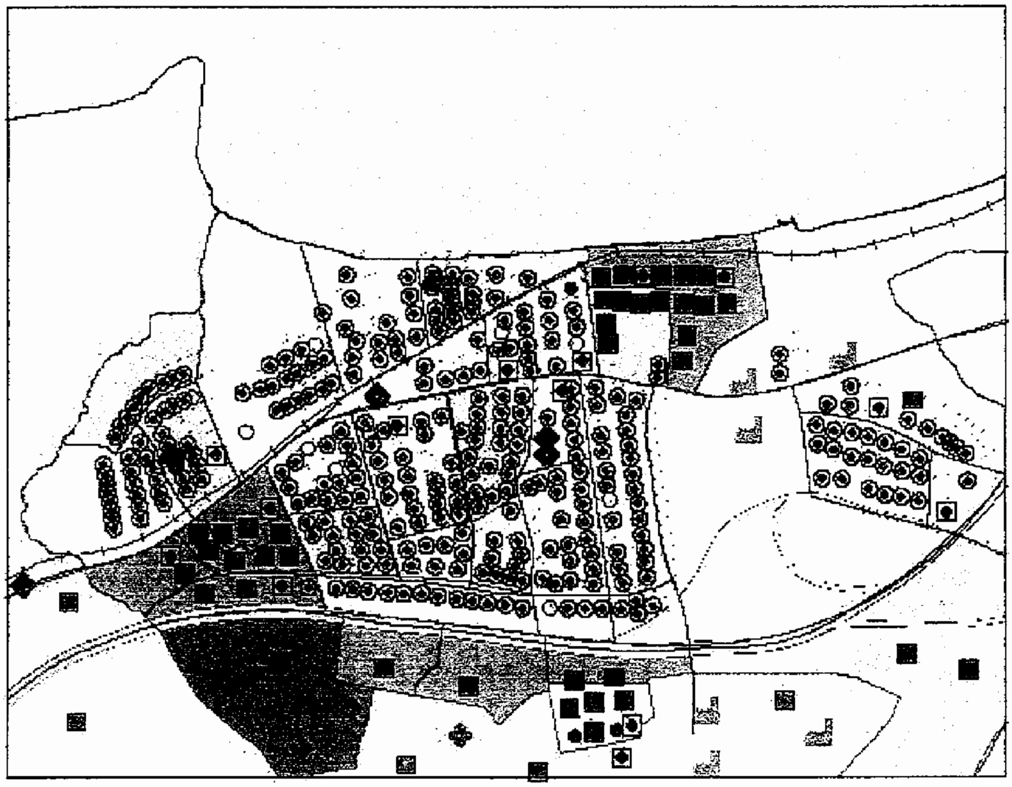


Figure 4-14: A computer-based "heat map"

Explanation of fig. 4-14: The dark brown areas have the highest heat density and the light yellow the lowest. Demand devices in single family houses are given as circles; e.g. a single family house using an oil boiler is shown as a circle with a spot in the centre. Rectangles are used for multi family houses; e.g. a red *rectangle illustrates a multi-family house connected to the district heating grid. Commercial buildings are symbolized by rhomboids.*

4.3 The comprehensive analysis

The purpose of the comprehensive analysis is to give a foundation for the choice of development for the local energy system as a whole. It goes without saying that those who design a local energy plan cannot control the development, but their task is never the less to derive the development they consider best, based on available objectives and constraints, and then convince the relevant decision-makers to implement it. The comprehensive analysis serves as a basis for decisions on the future local energy strategy.

Such a strategy, however, cannot be based on a comprehensive analysis alone. Detailed analyses also have to be carried out. Depending on the chosen approach, strategic or project oriented, the comprehensive analysis will have different contents and importance for the ALEP project. This chapter describes how the comprehensive analysis can be realised, based on a number of good examples.

The comprehensive analysis is also important for the learning process. During the process of the comprehensive analysis all participating parties meet and deal with many of the central issues in the project. It is of particular importance that there is ongoing dialogue between the participating project groups and the working group responsible for the comprehensive analysis during the whole process, in order to establish continuous information exchange between them.

A full description of the different stages of the comprehensive analysis can be found in chapter 3. The different activities are briefly listed here. The planner, and the planning groups, will (as described at length in chapter 3):

- base the comprehensive analysis on the description of the present situation (see chapter 4.1 and chapter 3.2 and 3.3);
- find suitable ways of representing the local energy system (see chapter 4.2);
- decide upon the objectives for the study (see chapter 4.3.2)
- establish a RES (see chapter 4.2);
- select a computerised energy system model (see appendix A.1);
- develop a validated database (see chapter 4.5);
- construct one base scenario and several alternative scenarios from a reasonable set of assumptions about future development (see chapter 4.6), and run the model;
- analyse the model runs and present the results (see chapter 4.7)
- use an iterative process involving the comprehensive study and the subsystem and component studies within the ALEP project (see chapter 4.4).

4.3.1 Description of the present situation

The basis for the comprehensive analysis is the description of the present situation, but it is recommended that the planner already begin the comprehensive analysis in the preparation phase. Then the description of the present situation can be designed to fit the demands of the comprehensive analysis. This "iterative process" in the beginning of the ALEP is the least time consuming, and is described in detail in chapter 3.2 and 3.3 above.

The comprehensive analysis is often closely connected to the use of a certain computer model. It is however, not wise to let the capabilities of a computer model shape the structure of the comprehensive study. It is better to develop the principal design of the comprehensive study first, then choose which model to use, and finally find the necessary balance between what you would like to do and what the model can actually achieve. (An overview over available computer models is provided in Appendix A.1.)

An evaluation of the description of the present situation should include a summary of the important questions to be treated by the ALEP -study, an overview of existing studies, a definition of the "local energy system" and its system boundaries etc. (see chapter 4.1).

4.3.2 Objectives

The process in which the objectives of the study will be decided should be started in the preparation phase as well. This process however, takes time, because it must be based on a broad discussion. The final determination of the objectives is not always made before the main study is started. It is instead most often one of the phases of the comprehensive analysis.

In an ALEP study, objectives of two principally different types are used:
a) National restrictions, which can be treated as "fixed objectives" that the local government and decision-makers cannot influence.
b) Objectives originating from local needs, which are formulated locally

Typical objectives, of both types, formulated by decision makers for local energy planning deal with:
(1) Reduction of emissions
(2) Increased use of renewable energy sources
(3) Increased energy conservation

We suggest four criterias that objectives should fulfill in order to be useful for ALEP. The objectives should be:
- hierarchical,
- quantitative (magnitude and time),
- consistent and
- realistic.

These four criteria are useful to bear in mind when developing objectives for the energy plan.

During the analysis the objectives (e.g. objectives 1-3 above) must be operationalized. Only through this process can the objectives become useful for the comprehensive analysis. The following is illustrative, and shows one way of developing the three objectives listed above. Here the aspect *quantitative* has been defined much better, making it possible to measure whether or not the objectives have been reached.

1) *Emission targets for the energy sector in the municipality:*
   Carbon dioxide *emissions from combustion of fossil fuels should be reduced by 8 % during the period 1990-2010, in accordance with the agreement signed by the European Union at the UN-conference in Kyoto, Japan, 1997.*
   Sulphur *emissions should decrease by 25 % by the year 2010, calculated from the 1995 level. Sulphur content in fuel oil must not exceed 0,1 %.*
   Nitrogen oxide *emissions should decrease.*
   Hydrocarbon *emissions should decrease through a high degree of substitution of old wood fired boilers by new boilers with accumulator.*

2) *The use of* ***renewable energy*** *sources should increase. By the year 2000 renewable energy should make up for at least 50 % of the heat production which takes place in municipal energy production plants. This share should increase to 75 % by the year 2010.*

3) *Efforts for* ***increased energy efficiency and energy conservation*** *should be intensified. The objective is a 2% reduction of the useful energy demand for space heating per year, until 2010, and a 1% reduction of the demand for electricity for appliances in residential and commercial buildings per year during the same period.*

The municipality should set a good example *in its own administration and companies, as well as through the introduction of measures which contribute to the fulfillment of the above mentioned goals.*

Another criterion for useful objectives is consistency:
(1) internal consistency (between different local objectives), and
(2) external consistency (between local and regional or national objectives)
The forms of consistency are exemplified below.

The goals of the energy plan above are in accordance with the municipality's goals in the physical plan and in the Local Agenda 21 plan (first form of consistency). The goals should strive for consistency with the national and regional goals in the energy and environmental fields (second form of consistency). However, in three cases some important deviations from the regional goals were made:

I) The regional goal to reduce the total use of energy was excluded, since it was in conflict with the municipal goal to encourage large industrial expansion. The specific energy use (energy use per useful unit) should, however, decrease through more efficient use of energy. This is an important goal (goal 3 above).

II) The regional goal to reduce the total emissions of carbon dioxide from the energy and transportation sectors by 10 % between 1990 and 2000 was also not adopted. It was practically impossible to achieve this goal, both regionally and locally, since the 1997 level exceeds the 1990 level, and only a few years remain until 2000. The goal of the energy plan is instead formulated in accordance with the agreement for the European Union at the UN-conference in Kyoto, Japan, 1997, i.e. a reduction by 8 % from 1990 to 2010. The goal is also limited to the energy sector (including industry), since the municipality has few possibilities to influence the transportation sector.

III) The reduction targets for nitrogen oxides and hydrocarbons have not been quantified. It was only specified that the emissions from the energy sector should decrease. The regional goals were a reduction of nitrogen oxides by 30 % and a reduction of hydrocarbons by 50 % by the year 2000. None of these goals will be achieved in the region. Emissions of both substances originate to a large extent from the transportation sector and can therefore be only affected marginally by local measures.

For those who formulate and decide on local objectives it is important to be aware of the limitations to influence the development. It is not advisable to have goals which are unrealistic or deal with issues beyond their control.

4.3.3 Scope of the analysis

The scope of the ALEP analysis is to a large extent determined by the objectives. This is true for different dimensions of the planning:

- The choice of geographical area to be studied – system boundary (see chapter 4.1.4)
- The size of the analysis resources allocated to different parts of the energy system
- Which analysis models are being used for the comprehensive and subsystem studies

When you formulate and decide on the objectives it is important to be aware of the limitations of the local decision-makers influence.

4.3.4 The choice of approach

Different approaches for the comprehensive analysis can be chosen. If the comprehensive analysis dominates the ALEP, a s*trategic approach* has been chosen. In a *project oriented approach* the main work is concentrated around the subsystem and component studies, and the comprehensive analysis helps the planner to co-ordinate the different projects.

The choice of approach is of strategic importance for the ALEP project. It helps to attain a good result in the most efficient manner, both in the comprehensive analysis and in the ALEP project as a whole. It also helps to drive (or accelerate) the learning process. Before starting the comprehensive analysis, we strongly recommend making a decision on ther intended approach.

The strategic approach is focused around the comprehensive study. Around two thirds of the analysis work is allocated to the comprehensive study. It is the main work of the ALEP project. The comprehensive energy system model has an extensive system boundary. It models interdependencies between subsystems and long term developments, but uses simplified descriptions of subsystems. The comprehensive analysis generates information exceeding that of individual subsystem projects. Thus the comprehensive analysis will be strategic for the selection and orientation of detailed studies. Detailed projects on the other hand have the advantage of increasing the degree of detail and credibility of the comprehensive study. Comprehensive analysis and detailed studies can be realised in parallel. Information flows in an iterative process between the two levels. All analyses and models use a common, and validated, database. One should be prepared to commit sufficient resources, and to firmly guide the project through a political steering group or the like.

In the project oriented approach LEP is started with subsystem studies. On the basis of existing subsystem projects, the planner aims to co-ordinate the projects through a comprehensive study. The content and scope of the comprehensive study is thus guided by the focus of the detailed projects, but the study is designed broadly enough to describe the entire energy system. Besides the detailed projects, the comprehensive energy system model contains only a small number of additional subsystems (using simplified descriptions of subsystems) but also includes long term aspects and interdependencies between subsystems. As a result of the comprehensive analysis one may come to the conclusion that some subsystem projects should be enlarged or that additional projects should be started. The results from the ALEP project are nevertheless based mainly on the detailed studies. The comprehensive analysis is built on the data and inputs of the subsystem studies and should at least include the description of the present situation and one or two scenarios. The subsystem projects require the major part of the budget.

4.3.5 A pilot study

If the strategic approach is chosen, a useful starting point is to run a pilot study.

In a pilot study all phases of the comprehensive analysis are run through in a short time using the comprehensive model with a simplified RES. This is possible if you use aggregated data with lower quality than used in the main study. It is often also necessary that the planner guides the work and discussions in the groups, to avoid too much focus on one of the single phases (e.g. the input data).

The main aim of the pilot study is to increase the understanding of the methods and models used, and to start the learning process coupled with the analysis of results. It is essential to reach results as soon as possible. It is the preliminary results which stimulate the discussion of the reference and working groups. They discuss the selections made in the strategy phase concerning objectives, scenarios, constraints and other inputs, before too much of the main work of the project is completed.

4.3.6 Structuring the problem

For a successful project it is important to structure the problem well before beginning the main analysis. There are a number of factors which should be taken into account. Since ALEP is more than just technical analysis, there is a need for structuring of both technical and organisational aspects.

The Technical Energy System

The Technical Energy System comprises all energy technologies in the community and all flows of energy to these technologies from outside the community, between the technologies and from the technologies to the end users. We structure, or represent, the Technical Energy System in the comprehensive analysis - and in the energy system models - by using:

- Reference Energy System (RES)
- Load and duration curves
- Geographical Information System (GIS)

These "models" for representation also help reduce the complexity of the energy system under study.

There are four factors in the environment of the Technical Energy System that influence the choice of energy technologies and energy flow paths. The factors are:

- <u>Energy sources:</u> the price and availability of energy carriers on international, national and regional energy markets, and the availability and cost of extraction of energy carriers from natural resources within the system boundaries;
- <u>Useful Energy Demand:</u> demand for energy services in different sectors and different geographical regions of the community;
- <u>Technological progress:</u> new, or improved technologies, for conversion and energy conservation, become available as new options for the system
- <u>Physical environment:</u>
    * Physical Constraints on the use of certain technologies, e.g., availability of natural heat sinks or heat sources, or the use of solar radiation.
    * Environmental Regulations, e.g., emission restrictions on individual plants, or on parts of the Technical Energy System, or on the whole system. These may also be expressed as emission fees or taxes.

Data and prognoses, for the development of these factors, are the most important input to the comprehensive analysis.

Input data

The comprehensive analysis requires input data for the present situation (see chapter 4.1 above), and the development of the four factors in the environment of the energy system.

In the comprehensive analysis input data cab be used as follows:

(1) For model work non-aggregated data will be used as inputs to the energy system models:
   - the present use of energy carriers, e.g. fuels, electricity, district heat ...
   - the present demand of heat, tap water, steam, electricity ...
   - existing capacities of energy technology, e.g. plants, boilers, network ...

(2) Outside the model aggregated data is used:
   - as the starting points when you include constraints to the model, e.g. a reduction of CO_2 emissions with x% compared to the present level.
   - as reference levels when you analyse the results from the model runs. It is, for example, useful to use the information of the present primary energy supply for the local energy system, when you analyse the results from the model runs for a certain period in the future.
   - for the presentation of input data and results.

The evaluations made in the description of the present situation can give useful information for all phases in the comprehensive analysis.

System boundary

The system boundaries for the local energy plan are important to define. It separates the Technical Energy System which will be included in the analysis from the system environment. In chapter 4.2 the system boundary is discussed further.

Time horizon

The energy planner also will have to decide on the time horizon of the analysis. Two considerations may guide the decision: On the one hand, most investments in energy systems are long-term investments with a usual planning period of 20-30 years. On the other hand, recent changes in political, economic and even technical boundary conditions indicate that even a short period of 5-10 years may be difficult to assess in regard to major determinants of change. As a recommendation we suggest choosing a shorter time horizon for the detailed studies and a longer time horizon of up to 30 years for the comprehensive study.

The system of actors/organisations in the energy system

The ALEP planning approach is focused on technical aspects of planning and the integration of social and political processes. A planning approach which neglects the political aspects of planning often fails because of lacking consensus. Therefore the planning process must be embedded in an organisational set-up which includes all interested social, political and economic interest groups. Only early involvement and motivation of these groups will ensure that ambitious objectives can be achieved. Examples of actors within the planning process are:

- political decision-makers,
- representatives from utilities,
- representatives from the municipal or regional administration,
- industrial energy consumers, chambers of commerce,
- environmental groups.

The institutional organisation defines the roles of the actors directly or indirectly involved in the project. The institutional organisation should be tailored to the existing decision mechanisms within the area of investigation. These mechanisms may be quite different in European countries; therefore no general recipe for an institutional framework can be given.

As a general rule an organisational framework should be established which contains the following functions:

- Steering function: Setting goals and strategic directives, defining the political framework, resolving conflicts, suggesting decisions, approving the final report, approving contracts for external consultants. The steering group is not identical with the decision makers (e. g. municipal council).
- Process management (affiliated with the steering function): directing, controlling and promoting the process, communicating and solving problems, contacting relevant people, moderating meetings.
- Reference function: discussing and developing scenarios and strategies, providing data and knowledge, discussing models and model results, suggesting action plans, approving of final report.
- Working function: development and operation of the energy system model, analysing results, preparing reports.
- Project management (affiliated with the working function): supervision of project time and budget, leading and co-ordinating work, guiding all phases in the sense of ALEP.

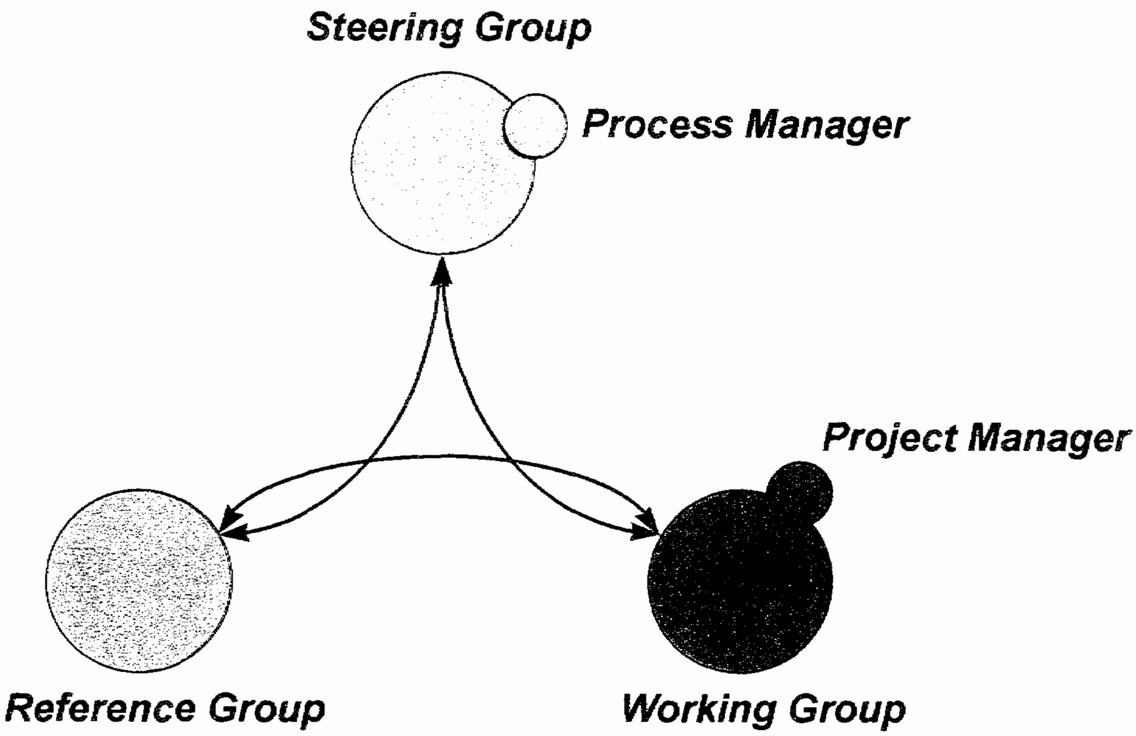


Figure 4-15: Example of an organisational set-up for ALEP

The figure above shows an example of an organisational set-up; other constellations containing for example only two groups are also possible. The steering group is not involved in the day to day business of the project. The process manager provides day to day support on behalf of the steering group. The involvement of the steering group is most important at critical points and at milestones of the project. The steering group plays a leading role, especially in the definition of goals and objectives at the beginning of the project and the decision phase at the end of the comprehensive study. The involvement of key persons from the very beginning is absolutely necessary to secure successful implementation. The reference group will be included in the project at the request of the working group as dictated by the progress of work.

Including a learning process in the ALEP

A learning process ont the various social and technical aspects is quite important for the success of ALEP, because ALEP requires the understanding of problems and possible conflicting goals associated with the local energy system by the different interest groups. The learning process improves the ability of the parties to take an active role in the planning process. However, organisations can only learn through their individual members. The learning process for the individual members of the groups has four components:

1. learning about the technical system and the options for finding adequate solutions to problems,
2. learning about the complex interdependencies of economy, energy system, environment and society,
3. learning and understanding the objectives of other groups,
4. learning and mastering communication.

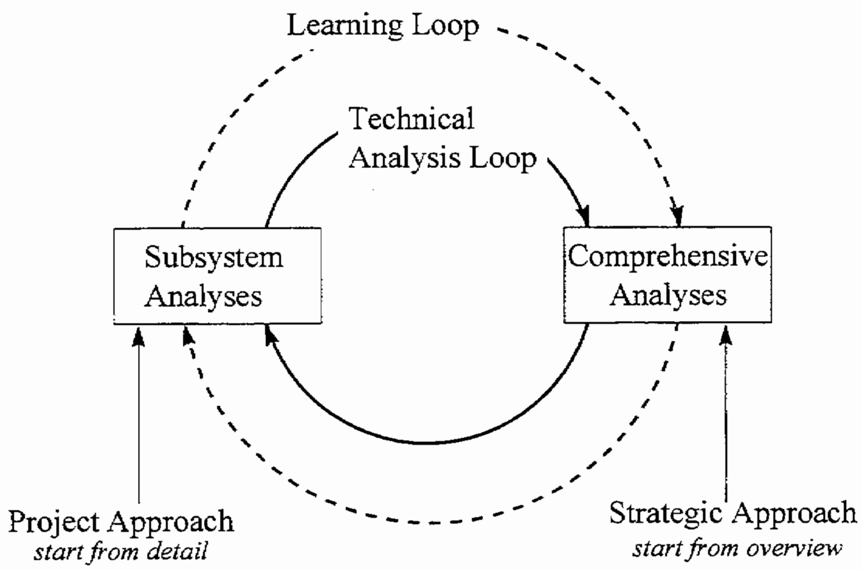


Figure 4.16: Two-fold loops of learning and technical analysis

The two-fold loop above shows the principle of the simultaneous processes of learning and technical analysis. The technical analysis loop consists of iterative considerations at different levels of detail and feed back of results (see also chapter 3.1 and 3.4). Simultaneously the learning loop improves the technical, communicative and organisational knowledge of the group members and their ability to understand and support the planning process. Two different approaches are possible (see chapter 4.3 for „strategic approach" and „project oriented approach"). The strategic approach starts with a comprehensive analysis of the energy system. Although the strategic approach seems more logical and straight-forward, in practice it is often specific individual projects that provide the starting point for local energy planning. In this case the work proceeds from project oriented subsystem analysis to overall strategic considerations. The persons responsible for ALEP must be aware of obstacles to learning and create a communicative atmosphere within and between the individual groups where the learning process can be cultivated.

4.3.7 Recommendation for the development of the local energy system

The comprehensive analysis provides the basis for a recommendation for the long-term development of the local energy system. When all work with the comprehensive analysis has been finished, choices and decisions have to be made. In the process of preparing those decisions one should ask:

1. What goals must the development achieve (see above);
2. Which measures are the best according to the targets;
3. Which are the best strategies for implementing these measures.

This means that the comprehensive analysis must result in a recommendation for concrete decisions to be made to reach the goals. In other words, it is not enough to conclude the comprehensive analysis with a set of scenarios showing different pictures of the future energy system. The challenge is to take the analysis further and make a choice regarding how the energy system <u>should</u> develop in order to meet the principle objectives.

The recommendations for the local energy system must be backed up by relevant strategies, distribution of responsibilities, etc., which are further described in chapter 4.7 below.

4.4 The interaction between the comprehensive and the subsystem studies

The interaction between the comprehensive analysis and the subsystem studies is an important part of the work in an ALEP project. The co-ordination between the two should be reciprocal.

The potential for energy conservation in Göteborg has been studied both in detailed subsystem analysis and as a component in the comprehensive analysis. It is valuable to exchange information between the studies. Typical information which could flow from the comprehensive to the detailed study is the future mix of energy production alternatives for specific user sectors, e.g. single family houses, future energy prices, e.g. district heating price, optimal energy conservation levels as a function of heating system and building type, etc. Information could also flow in the opposite direction, from the detailed to the comprehensive analysis.

If it turns out from the detailed study that, in some types of buildings, the optimal energy conservation levels are more or less robust with respect to assumptions about important parameters then it may suffice to just use the calculated energy conservation levels from the detailed study and simply reduce the net energy demands in the comprehensive analysis accordingly. The analysis of optimal conservation could then be left out of the comprehensive analysis. This grreatly simplifies the comprehensive analysis and could facilitate better descriptions of other aspects of the total system.

It is important to have an interaction of the comprehensive analysis with ongoing planning projects for subsystems and components. This is true regardless of the chosen approach for the comprehensive analysis (see chapter 4.3.3). Ongoing activities can affect the comprehensive analysis in a number of ways, and vice versa:

1. <u>Use the same objectives and prerequisites for the comprehensive analysis and the subsystem studies</u>
   It is desirable to use the same objectives and prerequisites for all parts of the ALEP. Otherwise it will be difficult to draw general conclusions from the material and to co-ordinate the comprehensive and the detailed studies. However, this is easier said than done since some of the detailed studies mayalready be in progress prior to the start of the ALEP. In this case it may suffice to interpret the results intelligently, or to make a few additional calculations, in order to facilitate co-ordination.

2. <u>How to deal with results that are contradictory</u>
   Two studies may produce different results even if the same assumptions have been used. If this happens it is important to understand the reasons and to present a clear explanation.

The example below gives an illustration of such a contradictory problem.

In the Göteborg ALEP project the district heating production was analysed using both a comprehensive computer model, MARKAL, and a detailed production simulation model, MARTES. The results from the two models were not exactly the same, e.g. regarding the suggested size of a future CHP plant. This can partly be explained by the different degree of detail in the used load curve, (see figures below). The simplified load curve of MARKAL was the basis of the determination of the size of the CHP plant, since the load level during spring and autumn is constant. However, the load level during the winter is too short to make CHP production at that power level economic. The load curve of MARTES does not affect the size of a CHP plant in the same way.

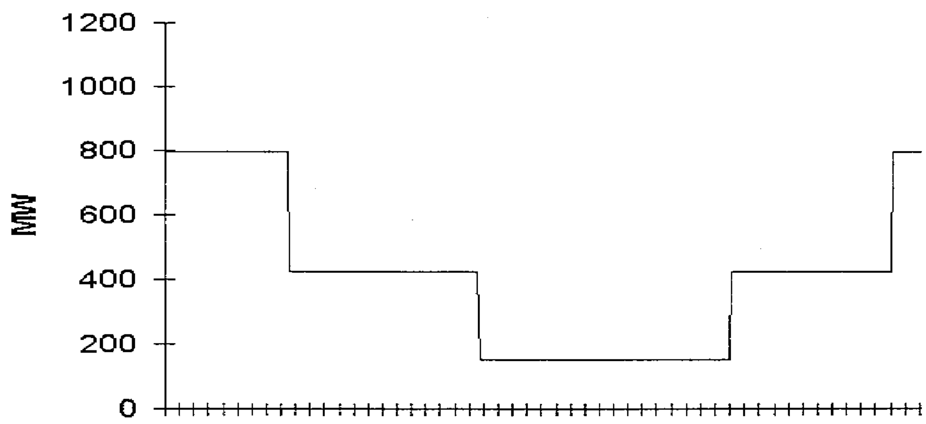


Figure 4-17: Load curve for district heating production, MARKAL

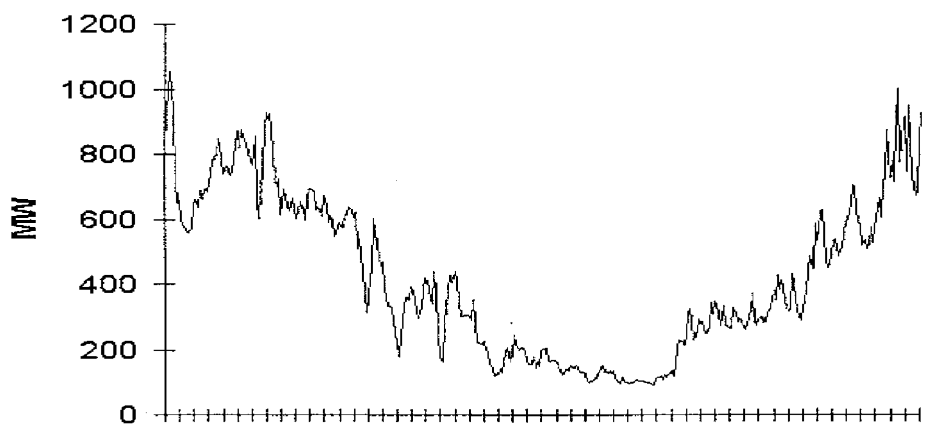


Figure 4-18: Load curve for district heating production, MARTES

The subsystem and component analyses have different purposes, for example:

(1) To give a more detailed analysis of the development of a certain part of the energy system than is given by the comprehensive study. One example is the detailed analysis of the district heating production in Göteborg above.

(2) To aggregate input data for the comprehensive analysis, and then - the reverse - to give the results from the comprehensive analysis a more detailed description.

(3) To include knowledge and expertise from the subsystems within the comprehensive analysis.

We refer to conventional text-books on LEP to discuss methods for subsystem and component analysis.

4.5 Data requirements and data provision

4.5.1 Data acquisition

Data collection and preparation is a crucial part of planning. To factually work on data acquisition a clear picture of the individual analysis steps that are to be performed is necessary. Knowing precisely the data requirements requires in-depth knowledge of the system and the needs, options, and possible constraints. It also means that the steps of analysis – or more generally, the methodology – to be applied in the planning process have been decided upon.

4.5.2 Information systems

Databases for use by component analysis tools have already been mentioned. Data organisation, i.e. features of data input, storage, selection, display and retrieval, is usually an integral part of the software. In general, the tools make use of spreadsheet, database, or other standard software packages. Tools should facilitate data-set display or printout.

One should be very cautious in building on an omniscient information system providing all pieces of information necessary for the comprehensive study. However, frequently in communities the municipal administrations and statistical offices have useful databases. Other information can be obtained from statistical, market research, or other surveys, or from studies performed for comparable areas, for the larger regions or the country as a whole. Databases that also contain geographical data would be useful for facilitating visualisation of the various system elements by means of a geographical information system (GIS).

If the databases are used in the daily work of administrations, then it can be assumed that the data is reliable and kept up-to-date, as required for the analysis. It has already been pointed out that further efforts by the planner or the Work Group is necessary to fill information gaps with additional assessments. The planner should make use of existing information systems to the farthest extent possible, but he should refrain from developing a pertinent system for use in the analyses that follow.

Sources for data acquisition in Sweden

Statistics and data for the energy sector are relatively easibly accessible in Sweden. Here we present some of the most important sources, structured according to the description of the technical energy system shown in the figure below.

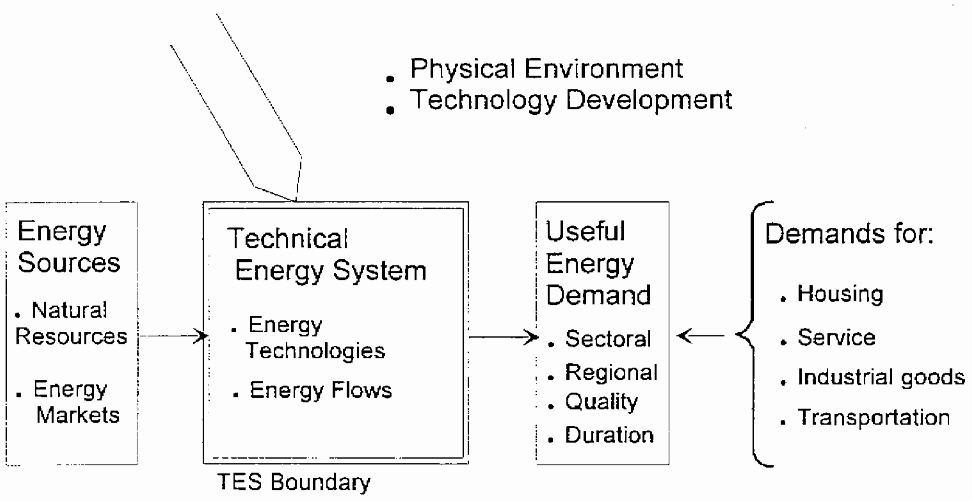


Figure 4-19: *The Technical Energy System*

Energy sources

The present prices on international, national and regional energy markets can be found in:

- *national analyses made by e.g. the Swedish National Energy Administration*
- *analyses made by different branch organisations*
- *local market surveys.*

Prognosis for the development of prices of energy carriers are presented by:

- *the Swedish National Energy Administration (often not specifically presented as a fuel price prognosis, but rather found as input for their normal investigations.)*

- *branch organisations.*

Availability and cost of utilisation of energy sources from resources within the system boundaries:

- *local sources, e.g. industries with waste heat, industries producing by-products, e.g. sawdust, municipal waste for incineration, etc.*
- *branch organisations.*

Taxes and environmental fees:

- *summaries made by the Swedish National Energy Administration*
- *summaries from the Swedish Fiscal Administration*
- *branch organisations.*

Useful energy demand

Data on the demand for energy services in different sectors and different geographical regions of the community can be found both at the national office for statistics and at local sources, such as municipal administrations/companies and energy utilities. The following is a briefing of the data sources for the different demand categories. For all sectors the goal is to find data on:

1. *the existing building stock, e.g. the number of single family houses with oil fired boilers*
2. *the use of energy, e.g. the number of MWh used in single familiy houses heated by oil*

The connection between 1) and 2) is the specific energy use, expressed in kWh/m^2.year. Sometimes both 1) and 2) are available, sometimes only one of them. In this case, general data about specific energy use can be utilised. Such data is available in certain statistical products, e.g. MASTERFILE.

The following examples deal with how data on building stock and energy use can be found for different user categories:

Single familiy and multi familiy houses – heating: The number of buildings and/or area with different means of heating are available in the Swedish National Housing Inventory (FoB), ENERGIPAK and MASTERFILE. The energy consumption for buildings heated by electrical, district heating and natural gas can be found in the utility's customer database.

Single familiy and multi familiy houses appliances, etc.: This is also available in the utility's customer database. (The use of natural gas for cooking is negligible in Sweden.)

Commercial buildings – heating and appliances, etc.: Large property owners keep data about their buildings, e.g. in facility management files and data bases. The energy companies have data about the total use of electricity, district heating or natural gas; however there is generally not seperation between heating and other uses. ENERGIPACK and MASTERFILE contain statistics about private buildings; MASTERFILE also includes estimates for publicly owned buildings.

Industry: Total use of different fuels and electricity per municipality is available from SCB's industry statistics. The energy companies have data on the total use of electricity, district heating and natural gas; however they are not divided between heating and other uses. The number and area for the majority of industries is available in MASTERFILE.

It is in general far more difficult to find data on commercial buildings and industry than on residential buildings.

Source	Single family houses	Multi family houses	Commer-cial buildings	Indus-tries	Updated
FoB	x	x			every 5th year
Energipak (SCB)	x	x	(x)	(x)	every 6th year
Masterfile	x	x	x	x	every 6th year
Energy company registers	x	x	x	x	every year
Large property owners		x	x		every year
SCB's energy statistics	x	x	x		every year (survey of 20,000 buildings)
SCB's industrial statistics				x	every year

Table 4-2: *A summary of sources for statistics regarding "the useful energy demand" in Sweden*

Information on technologies:

Existing equipment

- *Large scale energy conversion plants: Data (performance, costs etc.) is available from the owners.*
- *Distribution system: Data (performance, costc etc.) is available from the owners*
- *Small scale energy conversion plants: Market surveys etc.*
- *Energy conservation technologies: Market surveys etc.*

New equipment

- *Large scale energy conversion plants: Official sources, national investigations, technology data bases, manufacturers*
- *Small scale energy conversion plants: Market surveys, etc.*
- *Energy conservation technologies: Market surveys, etc.*

Information on environmental issues:

- *Emission statistics are available from official sources, e.g. The Swedish Environmental Protection Agency and the County Administrations. Measurements are continously being taken at large plants.*
- *Regulations for allowed emissions are available from official sources (e.g. Web-Site of environmental ministries)*

General remark:

If data is missing it may be necessary to initiate a detailed study (see chapter 4.4 above).

4.5.3 Data documentation

If the subject and the objective of the analysis is defined, a step-by-step approach to develop the database to be used for the local model must be followed. Data from a variety of sources is to be assembled in this database. A database documentation system is needed for drawing up the single data elements, quoting the referenced material, outlining the calculation steps and assumptions made, and finally presenting the data as model parameter values. Data documentation is necessary to produce information that can be discussed, put in question; improved, etc. Documentation of the input data is also a prerequisite for the model results to become acceptable and will be useful to the working group in later work phases.

4.6 Analysis and presentation of results

4.6.1 Use of scenarios

Generally, one run of the model used for a specific ALEP project makes use of one set of input data and generates one set of related output information.

However, software tools allow for parametrisation, i.e. the presentation of one or more pieces of output information as a function of varying values of one or more parameters of the input data. This feature helps - with the steps of analysis and when discussing results with the working groups - to visualize effects of an especially important or doubtful parameter value on the result. For example, the variation of the maximum allowed CO_2 emission used in the comprehensive study resulted in different patterns in the resulting primary energy mix; or, in the component analysis, by cost increments used to stepwise change the investment costs for a CHP plant, the effect on the specific heat and electricity costs could be shown.

In general, to hedge against uncertainties of far-reaching projections or otherwise doubtful input data, different paths of future development involving more complex changes to the model database may be analysed, i.e. variations of more than one model parameter value are necessary. For example, it will usually not suffice to vary the price of coal at one point in time - rather the period values throughout the time frame will have to be changed for an assessment of a "price scenario". Furthermore, taking into account the interdependency of prices of the various energy carriers, an alternative price path for coal should trigger (different) price changes for other energy carriers as well.

Consistent hypotheses of the prices of relevant energy carriers over the study time frame have to be assessed in separate model runs and the results analysed thereafter as discussed in Chapter 4.7. Each hypothesis must be based upon predicted global economic developments, as well as conditions specifically connected to the area of investigation. This is perhaps the most difficult step in scenario analyses.

It is also common practice to consider hypotheses of the development of energy demand. Different supply options for newly developed areas, of performance of local industries, and effects of overall economic development, such as the discount rate for investments, characterise the hypotheses. Furthermore, each hypothesis must be *consistent*, i.e. projections for the various demand sectors must follow the same underlying assumptions. Such hypotheses are appropriately assembled in ***„scenarios"***, each resulting in a model database and output information of a model run, and the set of scenario results allows conclusions to be drawn on uncertain future developments.

4.6.2 Elements of scenarios

The following specific technical terms have become familiar to modellers working with comprehensive models:

Scenario: A scenario is the description of a potential development of the analysed system during the time frame. We refer to the case studies in chapter 5 for scenario examples.

Context: All development underlying a scenario that are not subject to the control of local authorities are denoted as the context or the ***system environment***. Assumptions regarding four factors in the system environment in principle make up the context. This is discussed further in chapter 4.3 above.

Strategy: All developments underlying a scenario that can potentially be achieved through efforts of local authorities particularly for this scenario are denoted as the strategy, for example the intended expansion of district heating.

Context parameters:

Context parameters characterise the conditions of the existing system boundaries.

Strategy parameters:

describe the measures of the strategy.

Reference scenario:

For the reference scenario, both the context and the strategy project the trends of the past into the future. No fundamental changes are assumed to take place during the time frame chosen for the comprehensive study. The reference scenario serves as the basis for evaluating alternative scenarios.

Although the concept of scenario techniques has its origin in the area of comprehensive studies, it is considered useful for component studies as well. For both categories, this concept facilitates a top-down approach to structuring and documenting data, performing data acquisition and communicating within the project team.

4.6.3 Formal and logical plausibility checks

During the course of the ALEP project the Working Group and the Reference Group are involved in the systematic evaluation of the results of the model runs. Frequently, computation, scenario analysis, and modification of input data are repeated until useful results are obtained. This iterative process requires some time depending on the size and complexity of the model, and the experience of the working group.

The very first results of LP model runs may include so-called infeasible solutions. Infeasible solutions are generated, when conflicting boundaries are set.

In order to generate feasible solutions and to separate useful results, formal and logical plausibility checks are provided by the energy models. Formal plausibility checks trace formal input errors such as typing, unit or dimension mistakes. Logical plausibility checks eliminate logical deficits in the input elements, determined by incomplete problem definition.

A powerful instrument for plausibility checks is the information embodied in shadow prices, slack periods and reduced costs of an LP-solution (see fig. 4-21 for an example).

4.6.4 Example for building and selecting scenarios: The Göteborg case study

Five different scenarios have been analysed in this planning project. The scenarios are defined by a number of assumptions describing the context of the energy system.

The following scenarios have been calculated and analysed:

- Reference scenario (or Base scenario): This scenario is based on the assumptions considered most probable. It is assumed that the price of electricity increases by 50%, up to 320 SEK/MWh, and that the seasonal differences decrease significantly compared to the base year 1993. In 1996 additional industrial waste heat becomes available (from the Preem refinery). For the emissions calculation we assume that imported electricity is produced in coal fired condensing power plants. If gas fired CHP production is introduced by the LP model, we limit the allowed capacity to 350 MW electricity.

- "Unlimited" CHP expansion: Here the size of a possible gas fired CHP plant has a high limit. Apart from this the assumptions of this scenario are identical to those of the reference scenario.

- Low electricity price: In this scenario the electricity price is assumed to remain at the present level. Other than the price, the sme assumptions as the reference scenario are used.

- High real yield requirements: The real interest rate is used for the calculation of present values, etc. Here we assume 12 %, instead of 5 % as in the reference scenario. All other assumptions are identical to those of the base scenario.

- Limited gas supply: Most scenarios show a large expansion in the use of natural gas. This would make Göteborg very dependent on natural gas, which is presently only available from one supplier. Therefore we have designed a scenario where the supply of gas is limited to 3 TWh/yr, to illustrate a situation where dependence on natural gas is not allowed to reach the same level as some of the other scenarios.

These five scenarios have been chosen since they illustrate various development trends which differ greatly in some cases. When analysing the results it is important to observe how different parameters are influenced by the various scenario assumptions. Comparison of the scenarios indicate the robustness of different strategies.

4.6.5 „Meaningful" scenarios

In scenario analysis, useful results are filtered from those considered not useful. This evaluation requires that the working group have experience in both mathematical modelling and energy economics. After the separation of useful results from a set of scenarios has been completed, it is essential to find a suitable format for cross-scenario presentation.

It is advisable to select one of the scenarios as the reference scenario (or base case) for scenario analysis and presentation. All other scenarios are discussed in relation to the reference scenario. In most cases the reference scenario has already been selected in parallel to the scenario definition. It is however neither necessary nor important that the reference scenario be the scenario with the highest likelihood of occurrence.

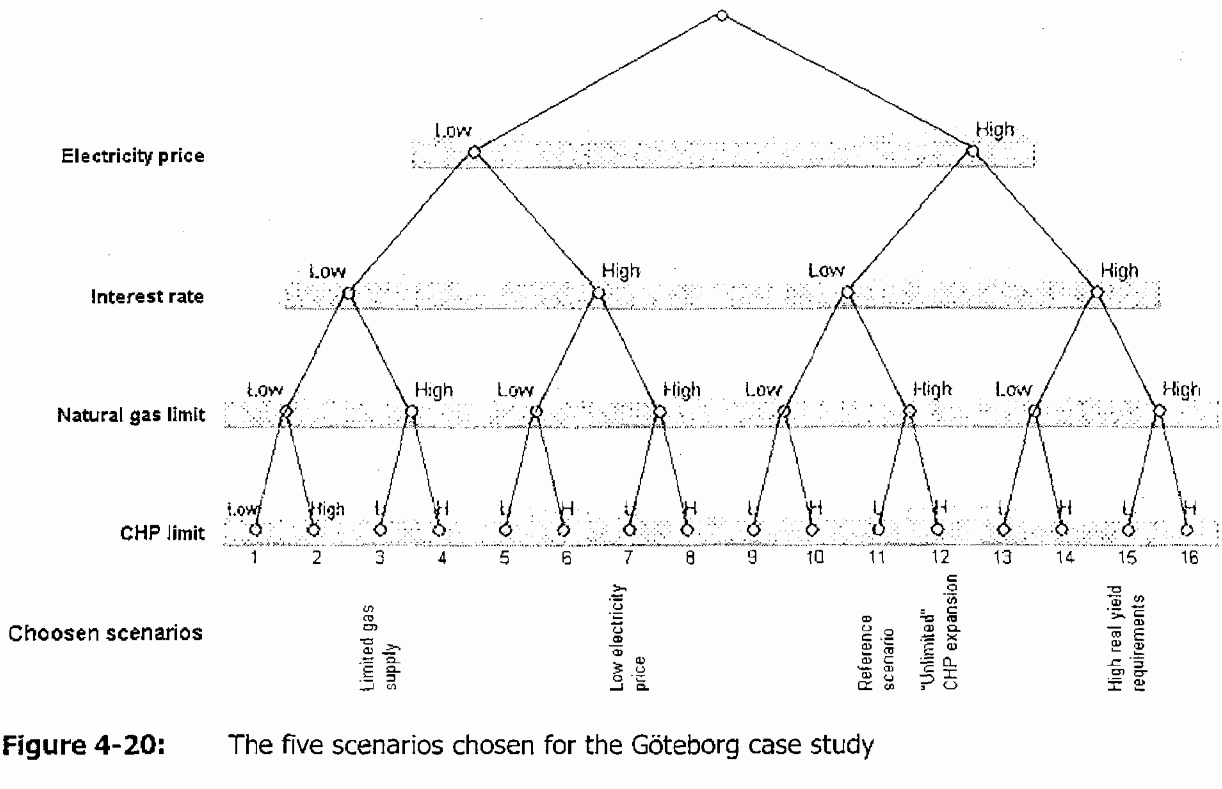


Figure 4-20: The five scenarios chosen for the Göteborg case study

Due to the normally large amount of information contained in the scenario results, it is necessary to find an adequate way to extract relevant information and a gradual access to the presented material. A very useful approach is the creation of summary tables for cross-scenario presentation showing some selected main indicators, such as primary energy consumption, total system cost, emissions for several pollutants etc., in order to provide an overview.

Those summary tables allow a quick survey of the main differences between the scenarios. For more detailed analyses, especially with respect to the technology mix, more in-depth investigations for individual scenarios are necessary (see chapter 5.4 for more information on the Göteborg case study).

Result of specific interest: Shadow prices of district heating in Göteborg

The ALEP approach often includes the use of optimised computer models such as MARKAL. Such models typically produce so called shadow prices for various energy products, e.g. district heating. The shadow price can be presented for different time intervals, e.g. winter, spring/autumn and summer. The shadow price is an indicator of the cost for the next kWh of energy that is to be supplied. This information is very useful for the understanding of the production cost by season, and for pricing strategies of the utility.

The shadow price for district heating production is a parameter which is interesting to analyse in a scenario analysis. In the Göteborg energy plan the shadow prices for district heating for a large number of scenarios were compared. Figure 4-21 shows the shadow price for each season. The scenarios are:

- Base case: No restrictions on when natural gas can be used, slightly higher electricity price than the present
- Gas contract: Winter, spring and autumn use no more than 35% above the average level, slightly higher electricity price than the present.
- High electricity price: Much higher electricity price than the present, no restrictions on the use of natural gas.
- No CHP: No new CHP plants allowed, no restrictions on the use of natural gas, slightly higher electricity price than the present.

(Natural gas is a fairly new fuel for Göteborg. During an introductory period there were no time-dependent or temperature-dependent restrictions on the use of natural gas, i.e. the seasonal profile of gas consumption was unconstrained.)

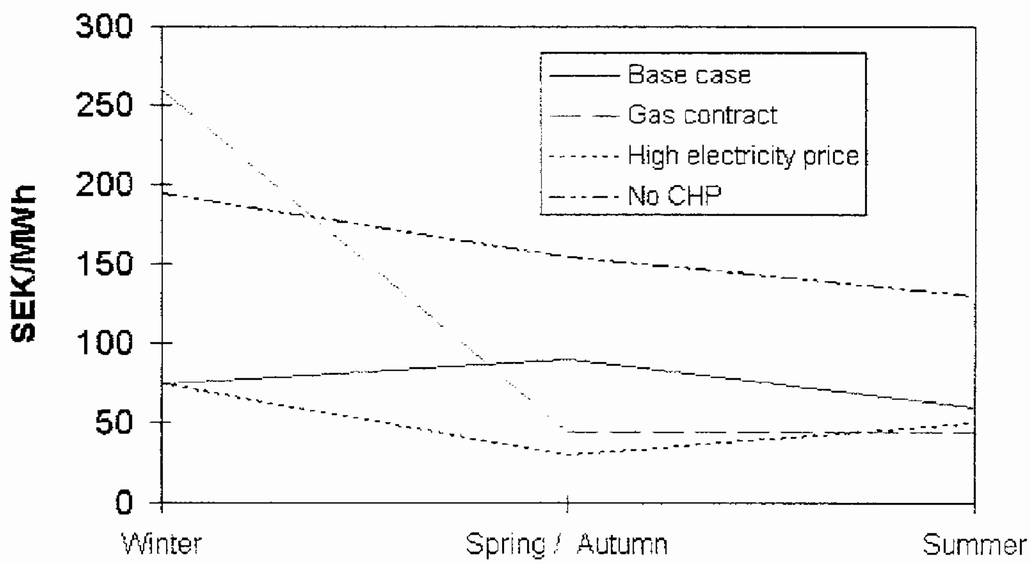


Figure 4-21: Shadow price for district heating production for each season

Figure 4-21 shows that there are significant differences between the scenarios. In the base case the shadow price remains fairly constant over the year. To a large extent CHP production determines the shadow price during winter and spring/autumn. Since the electricity price is higher during the winter than during spring/autumn, the resulting district heating cost is slightly lower.

The introduction of a natural gas contract that specifies the consumption profile has a drastic effect on the shadow price. Since the need for natural gas is higher during winter (due to high heating demand) the restriction on winter consumption to not exceed the average consumption by more than 35 % leads to a lack of gas. The very high shadow price of district heating is a consequence of this. However, for all seasons except winter the shadow price is lower than in the base case. This can also be explained by the natural gas contract. One way to be able to use more gas during winter, when the price is very high, is to increase the average consumption of gas. This could be expressed in a low gas price during all seasons except winter. This results in low shadow prices for district heating during these seasons.

The high electricity price scenario makes CHP production more competitive and thus the cost of district heating is reduced. This can be seen through the low shadow prices.

A situation without CHP production leads to a less energy efficient supply system. It is then not possible to take advantage of the more competitive electricity produced with CHP plants in order to lower the overall cost of district heating.

4.6.6 Robust recommendations and „if-then" hints

In order to derive recommendations from the scenario analysis, ***robust strategies*** are to be distinguished from „if-then" strategies. A robust strategy is defined by those elements which appear in (more or less) all scenarios, whereas an „if-then" strategy is based upon the choice of a few conditional elements appearing in specific scenarios only.

Two examples from the first ALEP study that were carried out in Jonkoping, Sweden in 1981:

(1) The competition between conservation and supply:
The comprehensive ALEP results show the robustness of energy conservation. As a result, the city council decided to boost the budget for energy conservation in buildings owned by the municipality by 5,5 million SEK.

(2) The optimal choice of fuel for D.H. production:
The comprehensive ALEP results show the robustness of building a D.H. system, but a big debate arose over which solid fuel to use in the CHP plant: hard coal or peat. The ALEP results show that the optimal choice is very sensitive to the assumptions used. The city decided to invest in fuel flexibility.

4.6.7 Derivation of recommendations

From the discussion of the scenario results recommendations can be derived for measures to be proposed by the Reference Group. In cases where the conclusions are not clear and recommendations for measures cannot be derived, the scenario computations must be repeated with a modified model structure and input data or/and a higher resolution.

The measures which are finally recommended and adopted by the Reference Group should first be separated into organisational and investment measures. They should then be categorised according to the time frame (ad-hoc, medium-term, long term measures) and characterised for possible interactions with each other – see chapter 5.4 as an example.

Finally priorities must be set by the Reference Group for the recommended measures in order to arrive at an action plan for implementation. Without such a prioritisation, implementation of measures will likely be rather unrealistic, since no clear signals are given to the executive bodies.

Ranking along priorities is a complex process of judgement and balancing of different criteria. Normally elements such as

- investments
- emissions of various pollutants and greenhouse gases
- technology development effects
- labour force effects

- social impacts
- external effects

and other items are to be considered in the assessment.

Example:* *Shortened "action plan" for Göteborg

Production and Distribution Systems:

A natural gas-fired combined cycle plant (~250 MW electricity)
- *Continue the planning for a new CHP plant. Responsible: Göteborg Energi AB*

The waste incineration plant - electric capacity more than 20 MW.
- *Utilise the power production possibilities at the waste incineration plant optimally. Responsible: GRAAB*

Integrate private and municipal owned heating systems not connected to the main D.H. system:
- *Continue the expansion of the main district heating system. Responsible: Göteborg Energi AB*

Emission reduction:

The City of Göteborg and Göteborg Energi AB are front-runners in the use of low emission fuels, low emission combustion technology, and flue gas cleaning technology:
- *Develop flue gas cleaning technologies further. Investigate NO_2 emissions from energy production plants. Responsible: Göteborg Energi AB*
- *Apply emission standards for new wood fired boilers in residential areas. Responsible: The consumer board*
- *Change from CFC to refrigerants which are less harmful to the ozone layer. Use environmental friendly cooling production. Responsible: Göteborg Energi AB*

The transportation sector is one of the largest single sources of emissions:
- *Demand that only vehicles with a higher environmental standard can be used in the central part of the city. Responsible: The transportation board*
- *Apply environmental standards when procuring transportation services. Responsible: All concerned committees and boards*

Renewable Energy Resources:

Biomass fuels are of increasing interest and can be integrated into Göteborg's energy production and supply systems.:
- *Study the possibility of using biomass as fuel in existing coal fired heating plants. Responsible: Göteborg Energi AB*

Energy production at the waste incineration plant could be increased through the use of construction waste and waste from forestry:
- *Expand the existing waste incineration plant. Responsible: GRAAB*

The sewage treatment plant produces a large quantity of sludge, from which methane gas can be extracted and used in vehicles, central heating plants, or both:
- *Utilise the available methane gas from the sewage treatment plant. Responsible: GRAAB, the transportation board*

Göteborg has several medium-sized wind power plants:
- *Participate in the building of further wind energy plants. Responsible: Göteborg Energi AB, the building committee*

Energy Conservation:

It is important for Göteborg to utilise the existing potential for energy conservation.

Reducing the overall electric and heating energy use by 2% per year:

- *Create task plans for more efficient use of energy. Increase investments in energy conservation measures. Evaluate the results of energy conservation annually. Responsible: The property management agencies*

Göteborg Energi must report to the City Council how much electricity, natural gas and district heating it delivers annually:

- *Evaluate how the use of energy develops. Responsible: Göteborg Energi AB*

The best time to influence the property owner is during initial planning for construction or during building is being renovated:

- *Provide an information and advisory center for developers, builders, consultants and contractors. Responsible: Göteborg Energi AB*

Research and Development:

Göteborg Energi's Board of Directors has authorised the Company to invest a specific budget for various research and development projects:

- *Cheaper systems for connecting single family houses to D.H. Responsible: Göteborg Energi AB*
- *Research & development efforts. Responsible: Göteborg Energi AB*

4.6.8 The documents

The presentation and publication policy for an ALEP-project is not a trivial matter, since decisions for specific energy strategies often involve a number of sensitive issues affecting various aspects of society. Release of information and presentation of results, therefore, have to be planned deliberately.

There are various recipients, expecting different types and details of information released from the ALEP -project:

– the Working Group – the Reference Group – the Steering Group	} *inside the ALEP -project*
– universities, scientific laboratories – consultants (mainly energy planners) – utilities – manufacturing industry – the public	} *outside the ALEP -project*

It is advisable to decide from the outset which information should be released and at which phase of the project to those expecting the information. The project management group should normally be given the responsibility of disseminating the information. The Reference Group and Steering Group should monitor the dissemination activities.

Written documents may comprise four categories:

- an Executive Summary (< 10 pages)
- a Main Report (100 - 150 pages)
- Material Documentation during the ALEP project
- Working Papers and interim reports.

It is advisable to provide sufficient working time for such material and make use of them for internal and external communication as well.

Chapter 5 Case Study Summaries

This guidebook on Advanced Local Energy Planning reflects the experiences that have been made by the participants of Annex 33 in carrying out six individual case studies where the comprehensive energy model MARKAL has been used throughout. The approach within these case studies and their results are summarized in this chapter. Whereas there exists a comprehensive report on the case studies in the individual native languages with all details of the projects, the summaries provided here focus primarily on methodological considerations that are of importance for this guidebook and the achieved results.

The following case studies are described in chapter 5:

5.1 Basilicata Regional Environmental Plan

5.2 The Torino Local Energy Planning Activities

5.3 The Aosta Valley Case Study – a MARKAL application for the Aosta Valley Energy Plan

5.4 Advanced Local Energy Planning in Göteborg

5.5 The Mannheim Energy Plan – a Comparison with Conventional LEP Results

5.6 Energy Supply for Greenhouse Garden Marketing, Delfland

5.1 Basilicata Regional Environmental Plan

C. Cosmi, V. Cuomo, M. Macchiato, L. Mangiamele, M. Salvia

5.1.1 Introduction

The aim of this study is to perform a local energy-environmental planning strategy in the framework of the Regional Plan for Air Quality Recovery and Protection for the Basilicata Region (Southern Italy). In this context the basic elements of energy-environmental planning were extended to include waste processing technologies in addition to the usual pollution sources.

To analyse the regional anthropogenic activities system, a comprehensive description was adopted to consider the complex interactions of the different variables involved (socio-economic and environmental). The first step of the study dealt with the set-up of a database usable for different models (MARKAL, EPA-RTDM, etc.). In this framework the following topics were characterised:

a) End-energy demands: Agriculture, industry, residential, services, transportation, municipal solid waste;
b) Energy supply;
c) Technologies;
d) Resources and material flows;
e) Flows of pollutants per unit of activity.

Preliminary thematic maps were developed to describe the different demand sectors on a municipal scale, emphasizing the most important features of the investigated system and pointing out homogeneous areas. This kind of approach makes it easier for planners to define suitable measures for recovery and underlines the role of Geographical Information Systems (GIS) in the planning process and in data management.

At the same time our research dealt with the application of the methodology in a specific case in order to determine integrated waste management strategies to be adopted by the regional waste management plan. For this purpose the **WAMMM**, **WA**ste **M**anagement **M**ARKAL **M**odel was implemented in the framework of a INFM (National Institute for Physics of Matter) project. WAMMM allows to singled out the main parameters which influence the choice of waste disposal technologies, and to estimate the environmental impact of the waste processing technologies in the context of the whole production system.

In this report, the application of WAMMM for the waste management system of the Basilicata region is described after a general description of the research project in progress in the ALEP framework.

5.1.2 Organisation of the case study

The ***stake holders*** of the regional project on air quality plans and monitoring techniques are: the Basilicata Region authority, the Department of Engineering and Physics of the Environment (DIFA - Dipartimento di Ingegneria e Fisica dell'Ambiente) of the University of Basilicata , the Department of Physical Sciences (DSF - Dipartimento di Scienze Fisiche) of the University of Naples, the National Institute for Physics of Matter (INFM - Istituto Nazionale di Fisica della Materia), and the Institute of Advanced Methodologies for Environmental Analysis (IMAAA - Istituto di Metodologie Avanzate di Analisi Ambientale) of the National Research Council.

Thus the ***project management*** included the University of Basilicata – DIFA (co-ordinator: Prof. Vincenzo Cuomo) and the University of Naples – DSF (co-ordinator: Prof. M. Macchiato), whereas the ***actual working team*** includes coworkers with different backgrounds, as shown below.

Prof. V. Cuomo Prof. M. Macchiato	Co-ordinators
Dr. F. Pesce Eng. M. Vita	Basilicata Region partners
Dr. C. Cosmi Eng. L. Mangiamele Eng. M. Salvia	Development of the MARKAL Basilicata model (including waste recycling)
Prof. A. Cappelli Eng. E. Conte	Transportation
Prof. V. D'Alessio	Emissions from industrial plants and combustion processes
Eng. G. Marmo	Inventory of the local emissions from the regional archive and development of a suitable database
Eng. S. Masi Eng. I. Mancini	Waste disposal management
Dr. M. Ragosta Dr. R. Caggiano Eng. R. Santangelo	Monitoring networks Heavy metals deposition measurements
Dr. A. Lanorte Dr. A. De Filippo Dr. L. Minervini	Implementation of thematic maps

The ***funding*** was provided by the Basilicata Region: Regional Plan for Air Quality Protection and Recovery and from the INFM – Progetto Sud (Action A): Innovative Optical Techniques for monitoring.

The ***work plan*** can be split into a general section which involves the air quality plan, and a more specific section focusing on the waste management plan.

With regard to the first issue (***air quality plan***) the main work phases are as follows:

- Plan definition: census and data base implementation, definition of objectives and actions to be taken (laws, limits, incentives, support for technological innovation, actions on fuel mixing);
- Plan handling: optimal resource allocation, decision tools (use of MARKAL model), databases updating, validation of results, learning process, operative tools (taxes, tariffs, incentives, pilot projects);
- Plan updating and corrections: this represents the last phase of the planning procedure aimed at attaining a flexible structure which satisfies all the changes that occurred in the anthropogenic system and in the planning framework (for instance the promulgation of new laws).

The general scheme of the Air Quality Plan is represented in figure 5.1-1.

The definition of a support study for the ***waste management plan*** included two main phases:

- Implementation of a suitable optimisation tool (MARKAL) capable of integrating the productive system with the waste management system;
- Optimisation of the waste management system using MARKAL and analysis of the scenarios results (optimal allocation of material flows to different waste processing technologies).

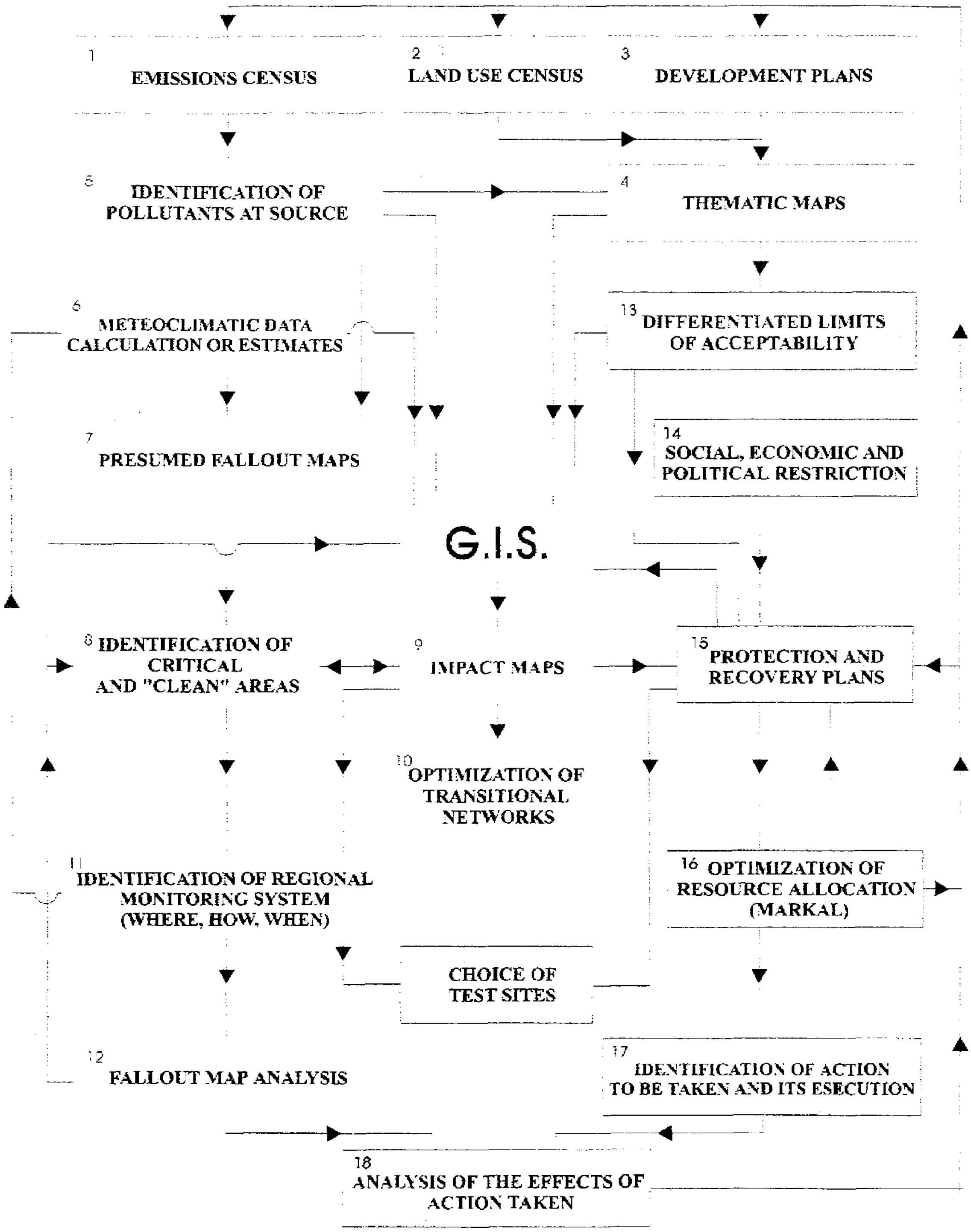


Figure 5.1-1: Scheme of the planning procedure.

Two kinds of results were achieved: methodological and operating results.

The ***methodological results*** are the link between energy planning and environmental planning at the local scale, in order to evaluate the effects of emission constraints on energy supply, fuel mixing and diffusion of innovative technologies. Another link with monitoring strategies was considered in order to assess the decrease/increase of pollutants due to variations in the fuel mix and in technological characterisation of the goods and services supply system. In this framework the waste recycling/disposal technologies become an important part of the goods and services production system, which must be optimised as a whole in order to focus on technologies and fuel mixes which are most appropriate for atmospheric emissions abatement. To achieve this goal the MARKAL model was implemented to describe the linkages between productive processes and waste disposal technologies (energy and material recovery).

The main ***operational results*** involve the characterisation of the anthropogenic activities (commodities production and waste disposal system), in terms of production activities, end-use demand, energy supply and conversion, end-use technologies, and atmospheric pollutant emissions. In the initial phase data were organised in a suitable database and GIS was used to display the emission sources and to represent different informative layers with thematic maps. The following step focused on the optimisation of the waste management system on a regional scale, predisposing the model for the global optimisation of the commodities system. The results of the optimisation model enable the development of environmental recovery strategies, in terms of fuel mix and technologies use, and economic strategies for promoting the market allocation of appropriate technologies (incentives, taxes, tariffs).

Several tools were used in this study. ***Comprehensive tools*** involved the MARKAL model, to optimise the use of resources and to define economic tools (tariffs, incentives, taxes), and ARC-INFO and ARC-VIEW as Geographical Information System. Moreover, ***high-resolution calculation tools*** were added: the EPA-RTDM and the EPA-ISC diffusion models for evaluating the ground level concentration of pollutant emissions from industrial sources. Finally, MS ACCESS and MS EXCEL were used for ***data collection and management***.

A good ***information exchange*** occurred between the involved groups, resulting in a useful *learning experience* with both local institutions/scientific partners and the Annex 33/ETSAP community. In this context the co-operation with the Department of Environment of Basilicata Region was essential for managing operative problems that arose in energy-environmental planning at the regional scale and to provide the working team with useful information exchanges between energy and waste management experts. The Annex 33 meetings promoted the comparison of experiences among the involved groups and demonstrated different aspects of the ALEP methodology. Moreover, the participation in the MARKAL courses was very useful for solving the specific problems that arose during its application. In particular, there was a useful discussion on the best way of modelling material flows.

The ALEP approach was applied on behalf of the Basilicata Region authority for the development of the regional Waste Management Plan and Air Quality Plan.

Evaluation and case study conclusions

The specific focus of this ALEP case study was the implementation of an integrated methodology in energy-environmental planning on a regional scale, which also includes the waste disposal system and its environmental effects on the whole anthropogenic system. This comprehensive approach allows the user to obtain exhaustive information on fuel mix and technology exchange, to evaluate the optimal strategies for emissions reduction, and on sustainable use of energy and material resources. A key point of the planning process is the use of GIS for the database management and for interfacing data and models.

In regard to the acceptance of this approach among local decision-makers, the experience with local institutions was very good. In fact the Basilicata Region authority, the sponsor of the regional plan for air quality protection and recovery, encouraged the application of the ALEP methodology also for the framework of the regional municipal solid waste management plan and, as a result our participation in their working group.

The applicability and the usefulness of the ALEP approach seems obvious and is confirmed by the experience with environmental planners in the Basilicata region. As a matter of fact, the results brought a lot of attention to this methodology. Local environmental planners would like to use ALEP as a regular tool in their activities.

In the framework of the wider project for the definition of the air quality plan for the Basilicata region, the following paragraphs will focus on the comprehensive study based on the WAMMM model to define suitable waste management strategies on a regional scale.

5.1.3 The integrated approach for waste management

The Basilicata region is a small area in southern Italy characterised by complex topography with no large urbanised areas, except in the surroundings of the main towns of Potenza and Matera. An insufficient road network makes transportation difficult in and out of the region.

Such characteristics are of importance in the definition of municipal solid waste strategies which fit with the actual needs of the local system. Other important constraints are provided by the legal and socio-economic framework, i.e. necessity to cope with the more recent directives on waste management and emissions abatement, and to define sustainable environmental strategies which are also economically and socially acceptable.

Up until now in most Italian regions, all the waste was disposed in landfills, which were often simply dumps without any kind of sanitary or environmental control. This situation resulted from a complicated regulatory framework based on a main law (DPR 951/1982) and on many subsequent decrees passed, from time to time, to solve specific problems. In 1997 the so called Ronchi law (D.lgs.22/1997) was promulgated in order to reorganise these complex regulations and to provide the guidelines for setting up regional waste management plans which comply with European directives. The constraints were introduced by the Ronchi law:

- Until 1/1/2000 landfills must only be used for the disposal of inert and/or of residual waste produced by other waste treatment processes (biological treatment, incineration, composting);
- Since 1/1/1999 only incinerators with energy recovery systems can be authorised;
- Since 1/1/1999 the "self-sufficiency requirement" can be enforced in order to dispose of non-dangerous urban waste in suitable areas inside the region in which they are produced.

Furthermore, each area has to achieve determined targets of separate collection of recoverable waste according to the following deadlines: 15% within 1999, 25% within 2001, and 35% within 2003.
Another strong environmental constraint on the planning process comes from the Kyoto protocol which schedules a 7% reduction of greenhouse gases within the industrialized countries by 2010 compared to 1990 levels (Contaldi and Tosato, 1998). These requirements can be supported by improved organisation of the production and waste management systems.

Modeling of such a complex problem in which many variables and many uncertainties are involved requires suited tools able to describe "continuous improvement processes", i.e. to trace the system changes and to calculate the improvements that have been achieved. At the same time it is important to run sensitivity analyses in order to understand the system variations and the influence of key-parameters.

Among several methodological tools, the LP (linear programming) IEA-MARKAL model was chosen and appropriately implemented to also take into account the waste management system. The result of this effort was **WAMMM**, the **WA**ste **M**anagement **Markal** **M**odel applied for the analysis of the municipal waste management system of the Basilicata region. A preliminary investigation of the local waste processing technologies and system features was performed to set up the Reference Energy and Materials System (REMS). Different strategies were identified and compared to minimise the total system cost in compliance with the superimposed constraints (limited use of landfilling, separate collection of secondary raw materials, reduction of greenhouse gases, etc.).

As shown in figure 5.1-2, the waste management system is based on the following alternatives:

a) only landfilling of unseparated municipal solid waste (actual situation);
b) separate collection of secondary raw materials (card and cardboard, metals, plastics, glass, organic matter);

c) screening of the remaining waste to separate the waste into two flows ("moist" and "dry") which are subsequently treated. Dry waste with high energy content can feed the incinerators, whereas moist waste, with a mainly organic content, can be organically stabilised. A composting process was also considered to dispose of very select organic matter (food scraps from refectories, pruning residuals, etc.) and suitable sanitary landfills were provided at the end of the waste management chain for the waste residuals of other technologies.

To build up the data-input of the IEA-MARKAL model, an accurate analysis of the waste management system was completed to determine the amount of waste produced and its composition (DIFA-ACTA, 1998), and to characterise energy and materials flows. Besides the technical aspects, the economical and environmental characteristics of each process were also defined in the Reference Energy and Materials System (REMS).

In order to investigate the requirements of waste processing technologies in the short and medium term several scenarios were defined (as shown in table 5.1-1) varying the following parameters: targets of separate collection (SC), wire mesh dimension and landfilling fees. Such an approach allows one to determine the effect of the separate collection and pre-selection process (screening) on the amounts and characteristics of the waste management streams (calorific value, process efficiency, density of landfilled residues, etc.). On the other hand, it allows one to evaluate the consequences of higher disposal fees on the total system (Co is the actual fee, which was increased to 3,5 times the basis value).

In particular the actual situation can be represented by a 5% SC (only a third of the law's target at 1999), whereas the medium term conditions can be characterised by a 35% separate collection target (as imposed by Ronchi's law in 2003). Between them, a 15% SC case added only the separate collection of fermentable waste to the base case.

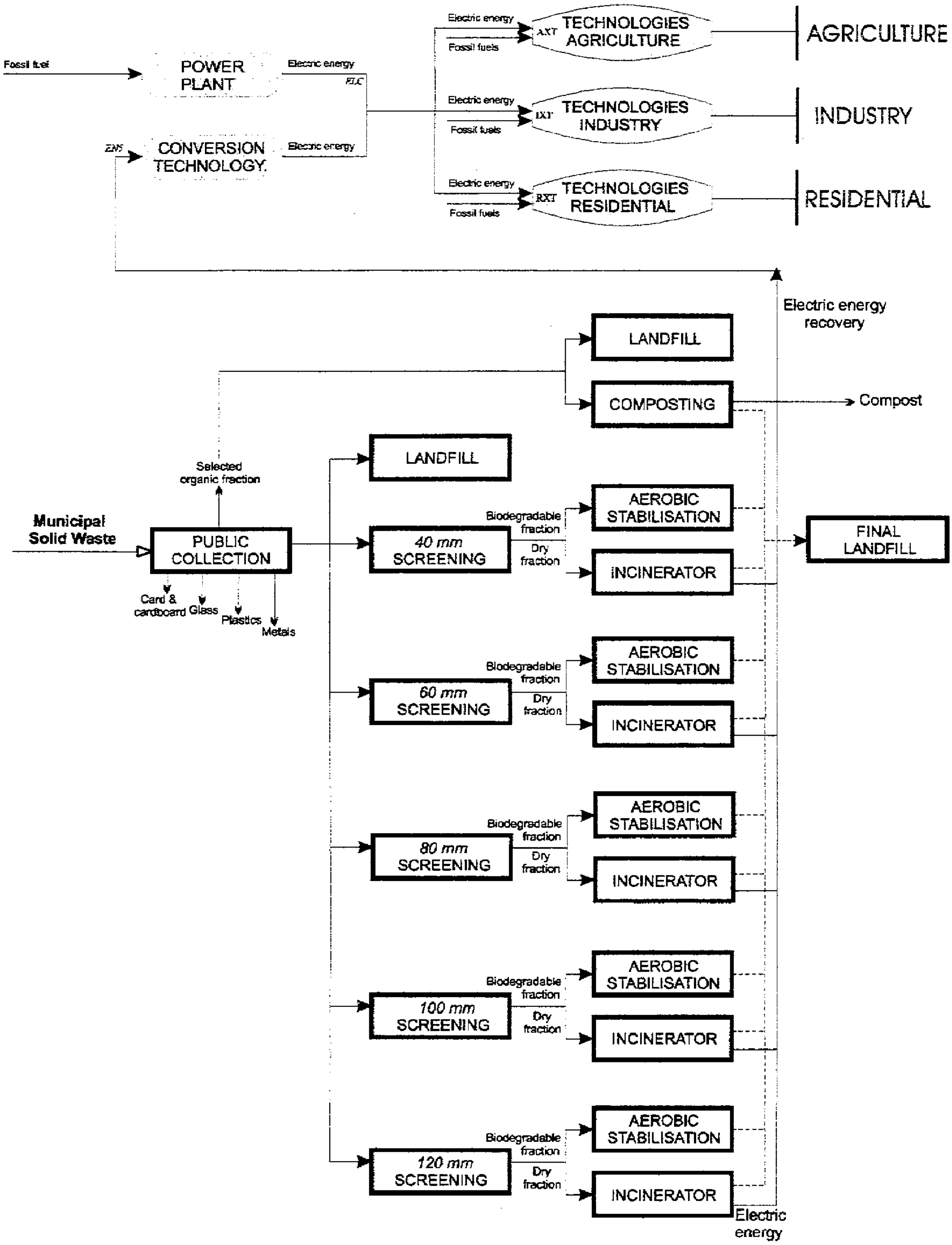


Figure 5.1-2: The Reference Energy and Material System.

	Scenarios	Wire mesh dimensions (mm)	Cases: landfilling fees			
SC: 5%	BASE	*No screening (Only landfilling)*	Co	1,5Co	2Co	3,5Co
	A1	40	Co	1,5Co	2Co	3,5Co
	B1	60	Co	1,5Co	2Co	3,5Co
	C1	80	Co	1,5Co	2Co	3,5Co
	D1	100	Co	1,5Co	2Co	3,5Co
	E1	120	Co	1,5Co	2Co	3,5Co
SC: 15%	BASE	*No screening (Only landfilling)*	Co	1,5Co	2Co	3,5Co
	A2	40	Co	1,5Co	2Co	3,5Co
	B2	60	Co	1,5Co	2Co	3,5Co
	C2	80	Co	1,5Co	2Co	3,5Co
	D2	100	Co	1,5Co	2Co	3,5Co
	E2	120	Co	1,5Co	2Co	3,5Co
SC: 35%	BASE	*No screening (Only landfilling)*	Co	1,5Co	2Co	3,5Co
	A3	40	Co	1,5Co	2Co	3,5Co
	B3	60	Co	1,5Co	2Co	3,5Co
	C3	80	Co	1,5Co	2Co	3,5Co
	D3	100	Co	1,5Co	2Co	3,5Co
	E3	120	Co	1,5Co	2Co	3,5Co

Table 5.1-1: Characteristics of the analysed scenarios

5.1.4 Characterisation of energy and material flows

The assessment of the amount and composition of the municipal solid waste produced in the region is the first step in defining of a waste management plan because of its relationship with the waste processing technologies. In particular, the evaluation of the total requirement of landfills is strictly linked to the characteristics of the waste, upon which the capacity and useable lifetime depend (e.g. the volume of one tonne of untreated waste is much higher than the volume of the same mass of residues from incineration or composting). Analogously, the electric energy generated by waste incinerating plants is strictly linked to the energy content of the input waste. A good compost, on the other hand, can only be achieved using a high-quality organic flow.

Therefore, to achieve an accurate description of the waste flows in different scenarios our approach was based on the following steps:

- Qualitative and quantitative characterisation of the municipal solid waste (MSW), on the basis of investigations of sample cases all around the region;
- Evaluation of the amounts of recoverable secondary raw materials, taking into account the specific composition of the waste;
- Analysis of the dry and the moist fractions coming from pre-selection and their characteristics;
- Assessment of the energy and material flows with regard to the different processes involved.

The total municipal solid waste produced in the region is about 226.000 tons/a. The average composition of MSW is summarised in table 5.1-2.

COMPONENTS	**%**
Fermentable matter	*50,9*
Paper and cardboard	*20*
Plastic and rubber	*12,5*
Textile, wood and leather	*3,5*
Metals	*5,3*
Glass	*7*
Others	*0,8*
TOTAL	**100**

Table 5.1-2: Composition of municipal solid waste in Basilicata.

Here there is a transition from a situation based uniquely on the use of landfills, in which disposal fees include neither environmental costs nor the costs of the site reclamation, to one based on the pre-selection of the waste and on following treatments aimed at valorisation of the components. This causes an increase of the total waste management system costs, which must be evaluated and related to technical and environmental considerations.

To promote the system's changes three key options can be considered:

- Emissions constraints in compliance with the Kyoto agreements;
- Increase of landfilling fees, taking into account all the costs, to discourage its use and to promote more complex waste processing technologies;
- Reduction of the volumes placed in the landfill.

In accordance with this procedure, a comprehensive analysis of the technical, economic and environmental aspects of different waste management strategies was undertaken. This analysis is briefly described in the next section.

5.1.5 The results of the WAMMM application

A medium-term analysis is affected by the uncertainties of the market boundaries (selling prices of secondary raw materials, costs and availability of technologies and other resources, etc.), as well as issues of social dynamics (e.g. co-operation by citizens). These uncertainties can be overcome by performing a sensitivity analysis showing the stability of the solution relative to variations in the system's parameters (technical, economic and environmental).

Thus for each scenario we analysed the relationships between the total system cost and the volume of landfill required, comparing the actual situation (landfilling only) with alternative strategies of waste management based on pre-selected operations with variations in landfilling fees. The results are synthesised graphically in figures 5.1-3, 5.1-4 and 5.1-5 which refer, respectively, to a 5%, 15% and 35% target for separate collection. In these graphs, the "screening dimension" refers to the dimension of wire mesh in the rotary drum used for screening.

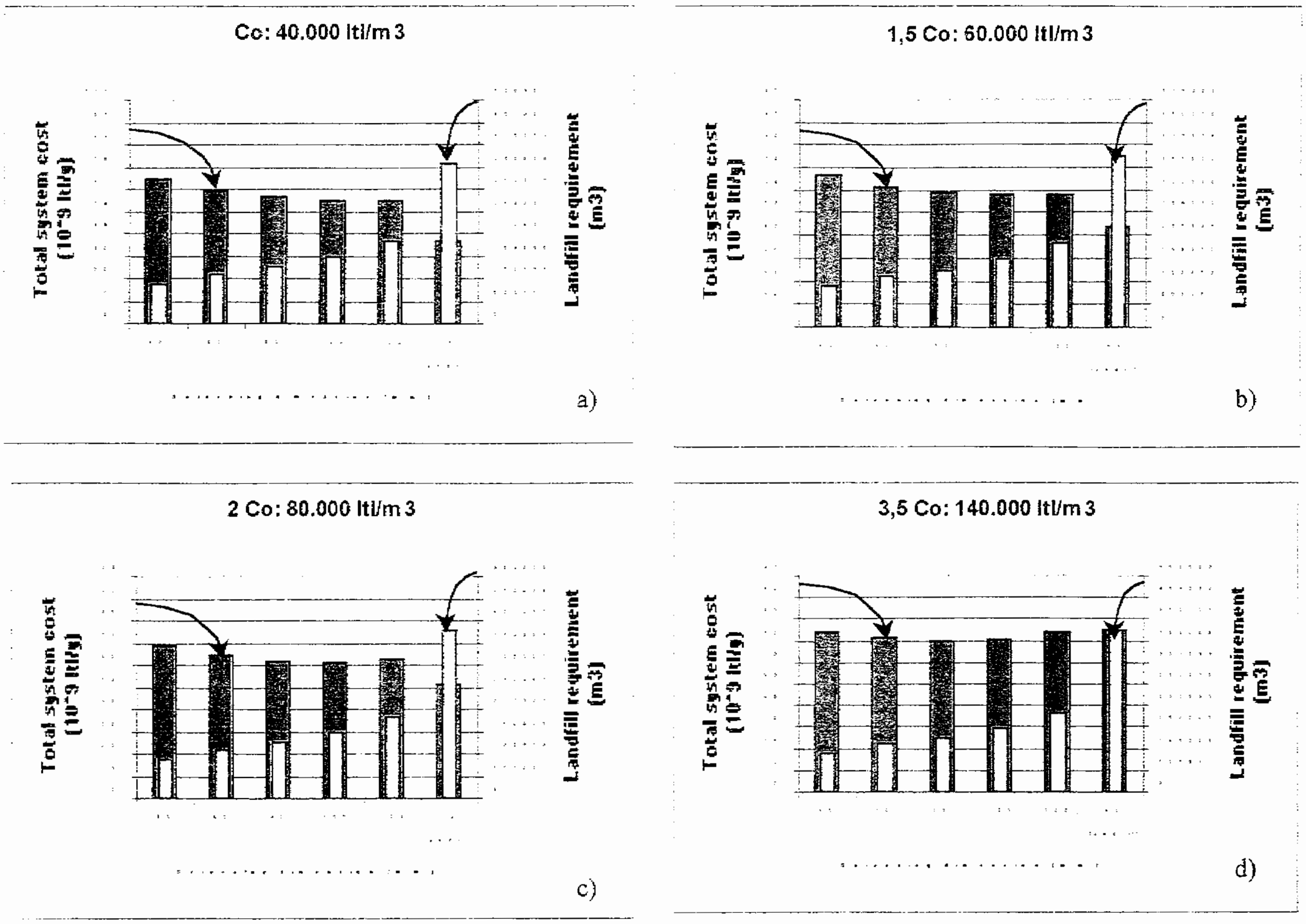
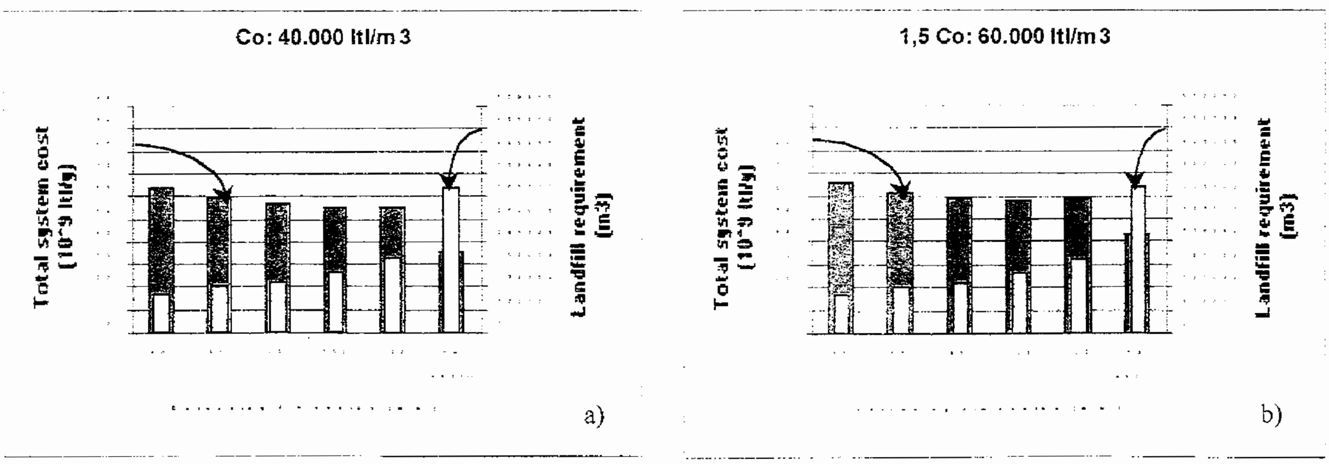


Figure 5.1-3: Effects of increases of landfilling fees on the total system cost and on the landfill volume required (5% target of separate collection).



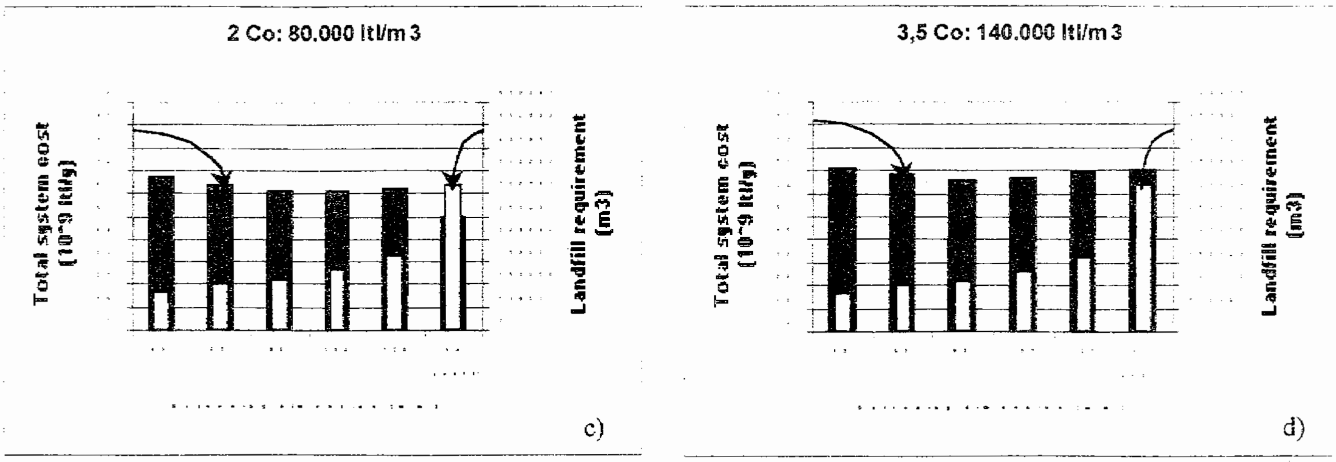


Figure 5.1-4: Effects of increases of landfilling fees on the total system cost and on the landfill volume required (15% target of separate collection).

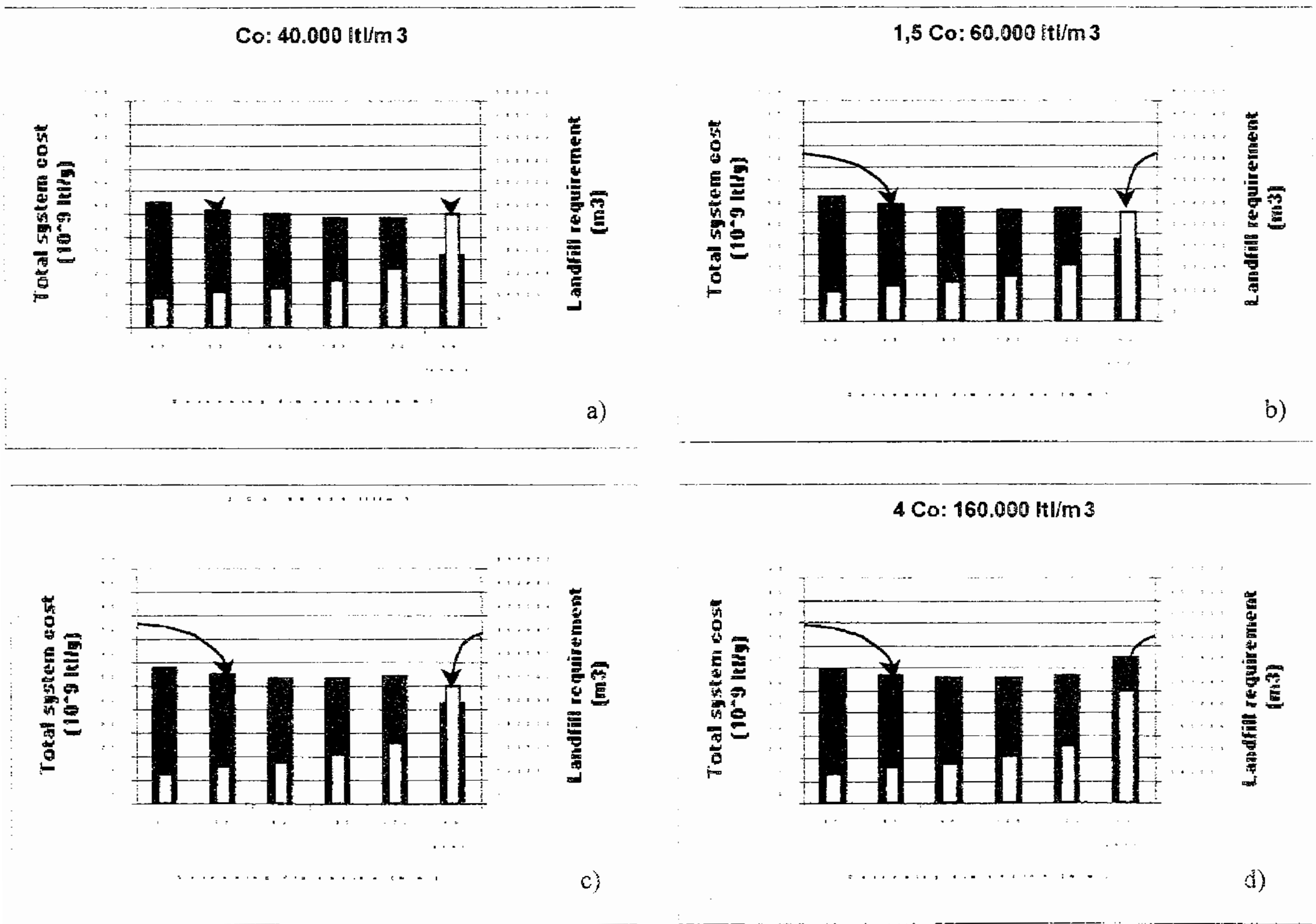


Figure 5.1-5: Effects of increases of landfilling fees on the total system cost and on the landfill volume required (35% target of separate collection).

Figure 5.1-3, 5.1-4 and 5.1-5 show that with the current fees (Co) the total system cost is obviously lower, but the cost difference is minimised by choosing an integrated waste management system based on the pre-selection of waste and increasing the screening mesh dimensions. In particular, for the SC: 35% target, increasing the fees to 3,5 times the base value (case 3,5Co). In this case the cost-curve shows a minimum of 80 mm for the screening dimensions.

With regard to the landfill volume required for each strategy, it should be noted that in choosing a 120 mm screening the annual needs for landfill is great reduced. Moreover, the more the screening dimension diminishes, the more the required landfill volume diminishes, reaching in the SC: 35% scenario, -75% for a 40 mm wire mesh. Comparing this result to the actual situation with a 5% separate collection target and a regional demand for landfill space of 360,000 m^3/y, we notice that only increasing the separate collection target (from 5% to 35%) results in a 30% reduction in the annual landfill volume required.

The effects of choosing a different waste management strategy were also examined in terms of the main greenhouse-gas pollutants: carbon dioxide (CO_2) and methane (CH_4), using the concept of Global Warming Potential (GWP). The GWP measures the possible warming effect on the atmosphere from the emission of each gas in relation to carbon dioxide (carbon dioxide equivalent). In particular, on a 100-year basis 1 ton of CH_4 has a GWP 21 times larger than that of CO_2 (IPCC, 1995). In the calculation of the Global Warming Potential the production of electric energy from incinerators and the conservation of fossil fuel through thermal power (ENEL, 1997) was taken into account. Emissions from landfills apply to the actual situation which is characterised by the absence of biogas recovery facilities. This is due to the small average size of the landfills in the Basilicata region, which make attempts to recover CH_4 ineffective.

Figure 5.1-6 shows that the largest amount of greenhouse gases are emitted in the base scenario (all waste placed in landfills), whereas waste pre-selection and subsequent treatment causes a significant decrease of GHG emissions. In particular, the smaller the mesh dimension, the more significant the emission reduction (in the 35% target case, there is a reduction up to 53% for a 40 mm size).

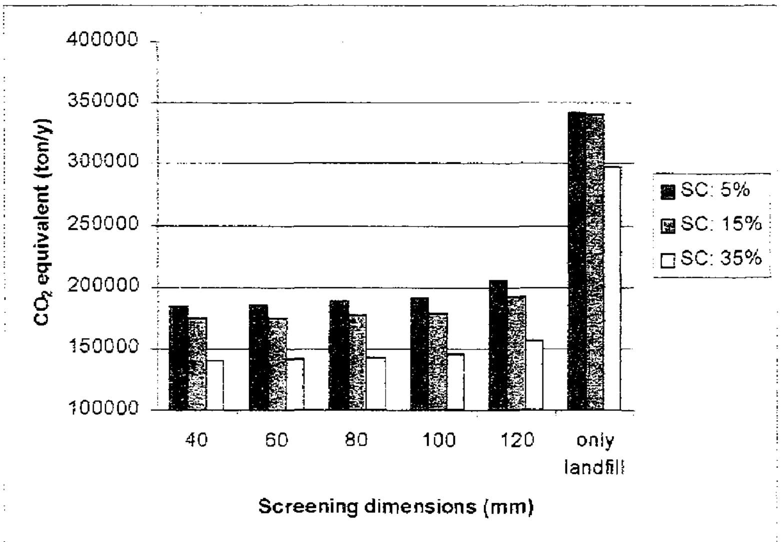


Figure 5.1-6: Greenhouse gas emission in different scenarios

This analysis shows that a significant reduction in greenhouse gas emissions caused by the waste management system can be obtained by preventing the landfill disposal of fermentable materials whose decomposition, during the anaerobic phase, are the main source of biogas production. Thus aerobic stabilisation can avoid the need for biogas recovery facilities (characterised by limited efficiency) with the environmental benefits of a reduction of atmospheric methane emissions.

In figure 5.1-7 the trade-off curves of the total system cost vs. greenhouse emissions (in terms of CO_2 equivalent) are presented.

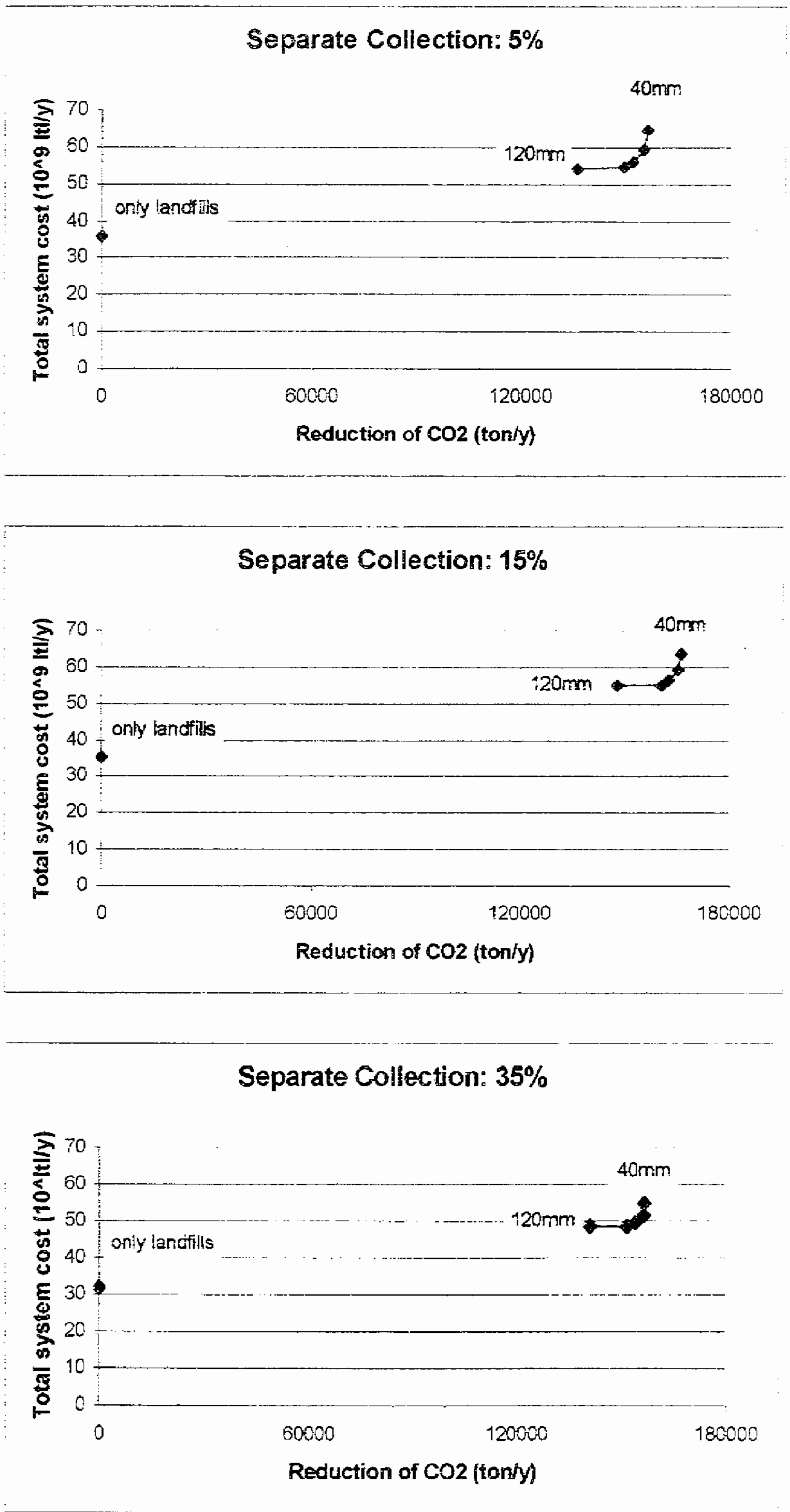


Figure 5.1-7: Trade-off curves: Total system cost vs. emissions of CO_2 equivalent.

As a result, one can conclude that in terms of cost-efficiency a transition to a modern waste-management system in the region of Basilicata would provide an efficient option for reducing GHG gases (approximately 130 x 10^3 ltl per tonne CO_2-equivalent).

5.1.6 Conclusions

In order to develop a sustainable waste management strategy for the Basilicata region, the WAMMM model was applied with the cooperation of the regional administration and several experts for waste disposal technologies.

The main results obtained by the integrated analysis can be summarised as follows (figure 5.1-8): economic evaluations (minimisation of the total system costs) direct the regional waste management system towards using screening operations with larger wire meshes which prevent the use of incinerators (more expensive than aerobic stabilisation). On the other hand, environmental considerations suggest the use of smaller wire meshes, which increase the energy recovered from incineration, and reduce the emissions of greenhouse gases (CO_2 and CH_4). Furthermore, increasing the landfilling fees in the minimum cost solution leads to a shift towards integrated strategies which use 80-100 mm screening operations.

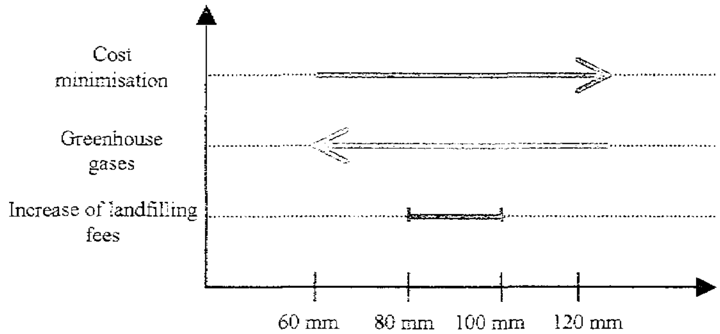


Figure 5.1-8: Results comparison

Therefore, this study suggests that waste management planning for the Basilicata region can be advantageously based on an integrated system in which separate collection, pre-selection (screening), incineration, organic stabilisation and composting, are closely linked in order to valorise each component of the waste, and sanitary landfilling only closes the waste chain. This configuration also fulfills the legislative requirements: in fact, the use of landfilling is limited to the disposal of inert or treated waste. Moreover, a sensitivity analysis shows that variations in the dimension of the wire mesh screening (i.e. the pre-selection process) has important consequences for the entire system. In particular an 80 mm wire mesh is a good compromise between cost and greenhouse gas emission reduction for the local case. The optimal integrated system can be supported by fixing limits on the annual landfill volumes, through environmental constraints on greenhouse gases or by levying a duty on the landfilling of untreated waste.

The necessity for a political decision based on these alternatives remains a task for decision-makers and the regional administration, who can base their strategy on the results of the systems analysis achieved using MARKAL.

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5.2. The Torino Advanced Local Energy Planning activities

5.2.1 Introduction

The Advanced Local Energy Planning practice in the Torino area has been characterised by several phases with different partners on the planning side, various analytical and modeling approaches as working tools and with reference to different areas, from Torino City to the whole Torino Metropolitan Area and, eventually, to Torino County.

The first phase began in 1992 with the assessment of the first Torino City Energy Balance (B.En.Co. – Bilancio Energetico Comunale) and the subsequent Torino City Energy Plan (P.En.Co. – Piano Energetico Comunale) included in the new master plan. A study was developed, as a preliminary energy analysis with a MARKAL application for the Torino City energy system, with the aim of analysing some simplified scenarios and technological options. The second phase involved, in addition to Torino City, for which a multi-regional analysis had been performed with simpler software (WINGRAF and LEAP), also some of the surrounding municipalities, through the development of their individual energy balance and plan, in order to enlarge the urban area taken into consideration. The last phase was performed by using RMARKAL, which allows for regional description and optimisation, by taking into account energy and material transfers between sub-regions, with reference to the energy systems of Torino County (Provincia di Torino), where urban and extra-urban territories are present. This territory was described as one whole, for a ***global analysis***, and then it was subdivided into five macro-areas, which constitute the county administrative units, for a ***regional approach.*** This second approach allows consideration of different options for energy related technologies, plants and infrastructures, and for the transfer of energy carriers between the macro-areas.

5.2.2 The Torino City MARKAL

5.2.2.1 General information on Torino City and its Metropolitan Area

The urban area involved by the ALEP project is the Torino Metropolitan Area, with the capital, Torino City (about 1 million inhabitants), and 52 other municipalities, 23 of which are located in a "first ring" and 29 in a "second ring". The total population is about 1.7 million inhabitants. In this area, the principal energy related infrastructure includes:

- two electricity grids (owned by ENEL and AEM),
- a natural gas main grid (operated by SNAM) and a distribution network (operated by Italgas),
- three district heating systems - Le Vallette, Mirafiori Nord and Torino Sud (owned by AEM) - supplying more that 18 million cubic meters of buildings (about 200,000 inhabitants)
- two metropolitan systems for sewage (Po – Sangone Company) and urban solid waste management (AMIAT),
- a public owned transportation system, with several operators: FS for national railway network, SATTI and ATM as Local Transit Authorities for rail, tramways and buses.

Presently, in the space heating sector no priorities have been established by the master plan or by the City Regulatory Board for gas, oil or DH zoning.

5.2.2.2 Organisation and goals of the case study

The Torino City Energy Balance (B.En.Co. – Bilancio Energetico Comunale) and the following Torino City Energy Plan (P.En.Co. – Piano Energetico Comunale) were developed in 1992, during the final stage of the new master plan approval. These activities were performed by an *ad hoc* working group, sponsored by the City Council, constituted by members of the local electricity authority (AEM – Azienda Energetica Metropolitana), owned by the city, and a consultant board with members of the energy department of the Politecnico di Torino. The working group involved ENEL, the national authority for electricity, SNAM and Italgas, the natural gas suppliers, and the oil companies operating in the Torino Metropolitan Area, as well as other institutions able to provide all the data needed for the planning of the energy budget.

All the fossil fuels used into the area are imported and the only local renewable energy source is the San Mauro AEM hydro power plant; nevertheless, the other AEM hydro power plants sited outside the area (in the Orco River Valley and in the Susa Valley) have also been included in ToRES because:
- these plants are only supplying users located inside the Torino Metropolitan Area,
- the second electricity distribution grid is owned by ENEL (the National Utility) and is connected to the national electrical system and supplied by external power plants.

The other power plants located inside the area belong to the industrial sector.

The conversion plants and energy carriers are listed in Table 5.2-2, while the demand categories and devices are listed in Table 5.2-3. As usual for MARKAL applications, each demand device has been fully described in the terms of its technological and economic characteristics and market availability, while also taking into consideration the evolution of these parameters in the subsequent time periods.

Conversion Plants	**Power**
AEM San Mauro Hydro Plant (MWel)	7,5
AEM Orco River Valley Hydro Plant (MWel)	267,9
AEM Susa Valley Hydro Plant (MWel)	29,5
AEM Pont Ventoux Hydro Plant (MWel)	150
FIAT Combined Cycle Plant (Mwel)	123,3
FIAT High and Medium pressure Plant (MWel)	58,5
FIAT Turbogas Plant (MWel)	34
AEM Mirafiori Combined Heat and Power Plant (MWel)	22
AEM Mirafiori Heating-Only Plant (MWth)	35
AEM Le Vallette Combined Heat and Power Plant (MWel)	22
AEM Le Vallette Heating Only-Plant (MWth)	38
AEM Moncalieri Power Plant (MWel)	206

Energy Carriers
Gasoline
Unleaded gasoline
Electricity
Kerosene
LPG
Diesel oil
Low sulphur content oil
Natural gas
Process heat
Low temperature heat

Table 5.2-2: Conversion Plants and Energy Carriers

Demand categories	Demand devices
Fiat space cooling Other industries cooling	Cooling device
Fiat lighting Other industries lighting	Lighting device
Fiat mechanical end uses Other industries mechanical end uses	Mechanical device
Fiat process heat Other industries process heat	Process heat device
Fiat electrical end uses Other industries electrical end uses	Electrical device
Fiat space heating	Natural gas heating plant Diesel oil heating plant Oil heating plant
Other industries space heating	Natural gas heating plant Diesel oil heating plant Oil heating plant
Commerce and services space heating	Natural gas heating plant Diesel oil heating plant Oil heating plant DH heat exchanger
Commerce and services electricity	Electrical device
Residential space heating	Natural gas heating plant (centralised) Natural gas heating plant Diesel oil heating plant (centralised) Diesel oil heating plant Oil heating plant (centralised) DH heat exchanger
Residential space cooling	Cooling device
Residential lighting	Lighting device
Washing	Washing device
Food refrigeration	Refrigerator
Sanitary hot water	Hot water device
TV	TV
Building services	Electrical device
Street lighting	Lighting device
Heavy goods transportation	TIR
Light goods transportation	Lorry
Passenger transportation	Diesel car Unleaded gasoline car Super gasoline car Electrical vehicle Pullman Bus Tramway Train Plane
Municipal Solid Waste Management	MSW landfill Incinerator (with energy recovery)

Table 5.2-3: Demand categories and related demand devices

The environmental impact produced by this energy system is characterised by the emission of

- carbon dioxide - CO_2
- carbon oxide - CO
- sulphur oxides - SOx
- nitrogen oxides - NOx

The principal exogenous variables taken into consideration as driving forces for the development of energy demand were:

- population
- GDP – Gross Domestic Product
- residential building stock
- industrial activity.

5.2.2.4 Complementary tools

During the development of the Torino Local Energy Planning study, additional tools were developed with the following goals:

- to perform Local Energy Balances:
  an ad hoc software was designed, based on very simple algebraic formulas, with input and report tables and diagrams
- to reproduce in graphical form the RES structure:
  the **ESP** software reads the **.dd* MARKAL files and allows the representation of the entire - or part of the - Reference Energy System
- to perform quick preliminary analyses of local systems:
  the **WINGRAF** software allows the study of particular configurations of the Reference Energy System and the evaluation of energy and material flows, individual processes global costs, and pollutant emissions for fast parametric analyses within defined boundsand scenarios
- to design local district heating systems:
  the **CAPLEP** software helps to design the main characteristics and components of such a system – supply plant size and site, distribution network layout, direct/indirect costs and pollutant emissions, etc. – by using a simple interface with GIS tools.

5.2.2.5 Scenarios used for long-term simulation

Five scenarios were studied:

- BASE (or Business As Usual), without any constraints on CO_2 emissions
- CO_2 stabilisation (BASES), with CO_2 emissions in 2002 – 2032 reduced to 1992 levels
- CO_2 reduction (BASED), with CO_2 emissions in 2002 stabilised to 1992 levels and reduced linearly from 2002 to 2032 until the minimum amount possible is attained within the system options
- two levels of taxation (BASET and BASET1) on CO_2 emissions, instead of CO_2 constraints.

5.2.2.6 Results and conclusions

In this first attempt, in Italy, at an ALEP study with a MARKAL tool, two main energy trajectories have been studied:

- the feasibility and the potential of a CO_2 emission reduction policy made possible by the development of district heating to meet space heating demand
- the choice between landfill and incineration (with energy recovery) in the Urban Solid Waste Management system.

5.2.3 Torino Metropolitan Area

Since Torino City and its surrounding Municipalities constitute an urban "continuum", it is more interesting and productive to consider the entire Torino Metropolitan Area (TMA) for an effective planning approach. For this reason, the two largest Municipalities of TMA (Rivoli and Mon-

calieri) have also been involved in energy analyses similar to those performed for Torino City. Moreover, a ***multi-zone approach*** was developed for Torino City itself, in order to take into account the different options available for space heating in the residential sector, arising from the presence, in the various districts, of existing energy infrastructures and the characteristics of the building stock.
For this analysis more simple software tools than MARKAL have been applied (WINGRAF and LEAP).
As mentioned in the previous paragraph, WINGRAF is useful for RES static behaviour simulations: energy and material flows, individual and global costs, as well as pollutant emissions can be easily and quickly evaluated for parametric analyses.

LEAP software has also been utilised for the analysis of the Torino, Moncalieri and Rivoli Energy systems. The main result of these modeling applications was the assessment of local energy balances and the evaluation of possible scenarios and suitable technological options for meeting the energy demand in the residential sector.

5.2.4 The Torino County Energy Study

In the last phase of the Torino ALEP study, Torino County (Provincia di Torino), where urban and extra-urban territories are both present, was analysed on a ***global,*** as well as a ***multi-regional*** approach. For this second option, the energy systems of the five macro-areas that constitute the individual administrative units of the county, were taken into consideration. The five areas show particular characteristics of three main components:

- the **physical** territory
  involving land, water and other "natural" resources, including biomass
- the **institutional** territory
  related to the administrative/political structures
- the **functional** territory
  identified by large technical infrastructures, e.g. energy plants and networks, road and railway systems.

For these analyses, RMARKAL was the main software tool, while the WINGRAF package was employed for the preliminary testing of the RES structure (base year = 1997).

Referring to the industrial sector, some additional remarks and comments are necessary. For a very local level approach, such as ALEP, reliable and significant support cannot be obtained from statistical data bases due to the limited number and typology of the product units to be considered; as a consequence, the detailed technology data-base for industry, that was built and is currently utilised in the Italian MARKAL, was not used. Probably, only a "technology cluster" approach would be useful.

5.2.4.1 The global approach

The analyses performed with the global approach mainly focused on these aspects:

- the competition among the principal technologies available for residential space heating: gas and oil fired centralised and decentralised plants, and low temperature heat from district heating systems
- the market competition between landfill and incinerator (with energy – electrical and thermal - recovery) in the Urban Solid Waste management system
- the role of local production (hydro, thermal and combined-heat-and-power plants) and the import of electricity from the national grid.

Figure 5.2-1 shows the parts of the RES (obtained through the ESP software) related to space heating for residential and service sectors: demand, demand devices, supply technologies and sources.

Figure 5.2-2 shows the configuration utilised to describe the Urban Solid Waste management system: a virtual carrier - SMA - expressing fulfilment of the waste management service, instead of the effective material flow of urban waste, is taken into consideration.

The main boundary conditions for technologies and energy carriers are the following:

- the district heating systems can be increased only by limited incremental steps in the existing building stock in Torino City of 8.9 Mm^3 (million cubic metres), up to a final value, in the last period (2009 – 2011), of 55.2 Mm^3, corresponding to new systems in other cities, if requested by the optimisation procedure
- the annual growth for some other technologies available in space heating and sanitary water production sectors was set at a value of 5 % (gas fired for centralised plants and chopped wood for decentralised one), according to the actual trend;
- the planned (by ENEL) Chivasso power plant expansion (from 250 to 1000 MW) will be completed by the year 2003;
- the availability of incinerators for Urban Solid Waste systems will begin in 2003, with an installed maximum capacity of 30 MW_{el} and 110 MW_{th}, corresponding to the values assumed in the sectoral county plan, which prescribes a significant level of separated collection and a reasonably high recycling of wastes;
- the renewal of the AEM Pont Ventoux hydro power plant could provide a new potential of 150 MWe starting in the third period.

The results of a MARKAL run without any additional CO_2 emission constraints (the BAU scenario) are reported in figures 5.2-3.a – h:

- figures 5.2-3.a and 5.2-3.b show the trends of plants contributions to electricity production; since in 2006 the Chivasso re-powering plant will become available, the model chooses to stop electricity import and to exploit the renewed Chivasso power plant; the slight increase in combined-heat-and-power plant utilisation is due to the incinerator installation in 2003 and to an enhanced exploitation of Moncalieri plant;
- figure 5.2-3.c, 5.2-3.d and 5.2-3.e show the contributions of different plants to the low temperature heat supply and the expected increase in the role district heating;
- figure 5.2-3.f , 5.2-3.g and 5.2-3.h are related to the CO_2 emission patterns; in figure 5.2.3.g the amount of CO_2 is associated to the consumption in each demand sector (for the industrial sector, only electricity related emissions are considered); in figure 5.2-3.g the "local" emissions of each sector are presented.

In general, the "energy trajectories", produced by MARKAL optimisation with reference to the BAU scenario, are characterised by two principal and subsequent aspects:

- the relevant increase of the low temperature heat production mainly supplied by combined-heat-and-power plants
- the substitution of the imported electricity from the Chivasso power plant.

As a consequence, the CO_2 emissions decrease due to the first aspect, until the third period, when they increase due to the second aspect.

The same contents as in figures 5.2-3.a – h, but with reference to a different scenario (named CO_2_A) with additional constraints on CO_2 emissions (8000 kt/year in 2009) are displayed in figures 5.2-4.a – h.

The analysis of these results indicate that this goal can only be achieved with the required electricity import in all periods (always more than 40 %) and constant operation of the Chivasso power plant. In fact, the imported electricity comes from the national grid and is produced by a mix of hydro and thermal power plants; the Chivasso plant is gas-fired and, consequently, is characterised by higher CO_2 emissions.

As far as the low temperature heat contribution to space heating is concerned, the "energy trajectory" of this scenario has the same general characteristics in the first period, while in the last period, there is a reduction due to the decreased use of gas fired combined-heat-and-power and heating only plants.

A third scenario (named CO_2_B), with the same CO_2 constraints, but including the possibility of recovering additional low temperature heat from the Chivasso power plant (considered to be a true combined-heat-and-power plant), has also been analysed (see figure 5.2-5.b). The low temperature heat supply reaches (and maintains) a higher value than in the previous scenario, due to the contribution of the re-powered Chivasso plant. As a consequence the amount of imported electricity is lower.

The seasonal patterns of plant utilisation are presented in figure 5.2-6.a (for 1997), figure 5.2-6.b (for 2009, BAU scenario), figure 5.2-6.c (for 2009, CO_2_A scenario) and figure 5.2-6.d (for 2009, CO_2_B scenario).

5.2.4.2 The regional approach

As far as the regional approach is concerned, for each of the five regions the following apply:

- the **residential** sector
  is described with 23 technologies for space heating and electrical uses in multi- and single-family buildings
- the **transportation** sector
  has 26 technologies for urban and extra urban services, for passengers and freight.
- the **service** and **waste management** sectors
  are described with 10 technological options
- the **industrial** sector
  has only 8 sectors: this very rough description will be improved (at least within some of the macro-areas) in a future study program in connection with the assessment of the County Industrial Development Plan.

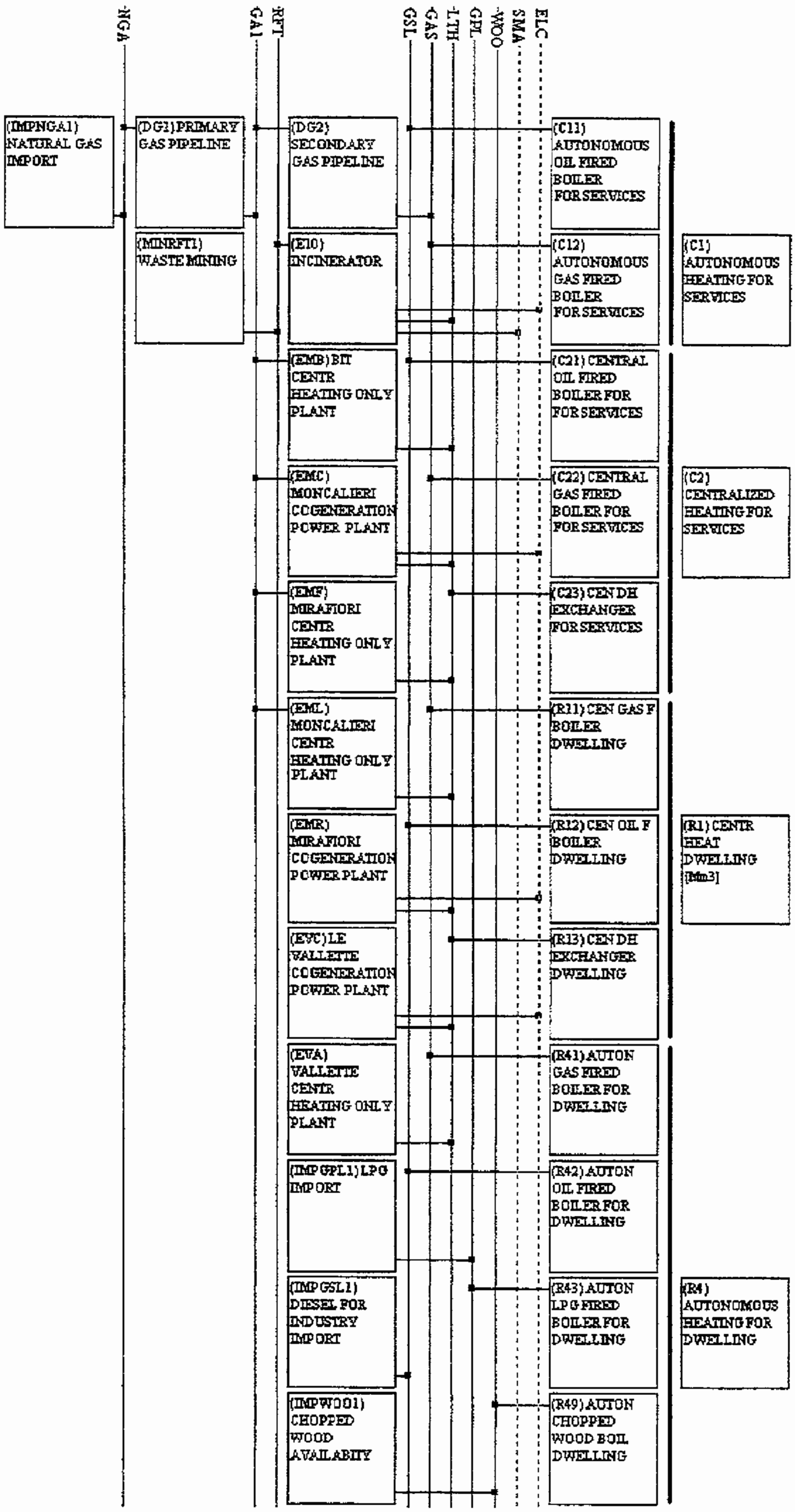
Through the application of RMARKAL for the five macro-areas in Torino County it is possible:

- to reach a more detailed description of plants and infrastructures,
- to analyse the internal trade of energy carriers (electricity, solid waste management),
- to evaluate the externalities resulting from local pollutants (SOx, NOx, particulate, VOC), along with the global ones (such as CO_2) currently taken into account.

This implies particular attention to fixing suitable bounds for capacities, options and related investment costs. From the supply-side point of view, the five regions show remarkable differences in electricity production (hydro and thermal), as well as in the natural gas network distribution.

A preliminary review of the RMARKAL approach to energy exchanges between regions revealed an inaccurate description of electricity and low temperature heat trades, resulting in an incorrect evaluation of energy flows, installed capacity and related costs. These inaccuracies were not previously discovered, because RMARKAL was never widely tested for local energy planning applications, but only for CO_2 permits trading and related problems. To avoid these mistakes, suitable changes were introduced for the balance and peak equations. A more reliable and accurate solution will be assured through the conversion of the existing data-base from RMARKAL to TIMES (The Integrated MARKAL-EFOM System), which seems to avoid most of the problems previously encountered.

Figure 5.2-1 A part of the Torino RES



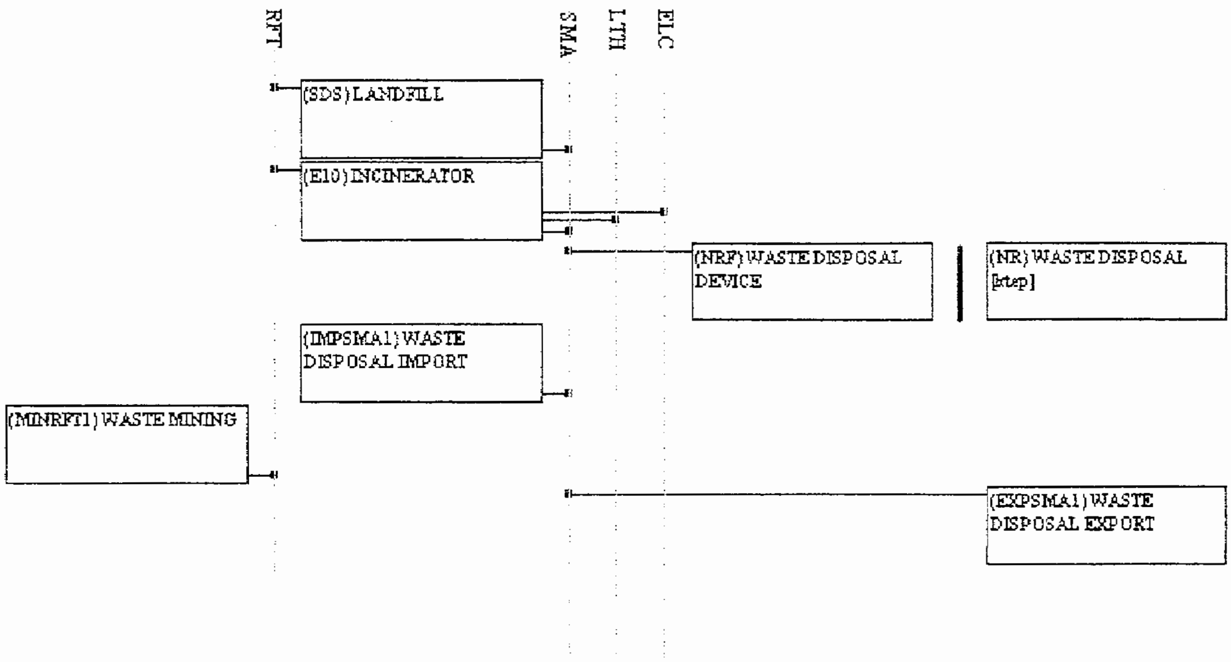


Figure 5.2-2 The Torino Waste Management System

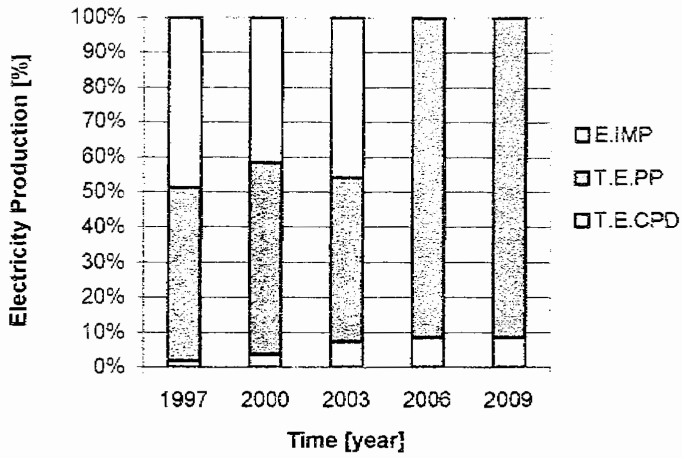


Figure 5.2-3.a: Plants contribution to electricity production - BAU Scenario

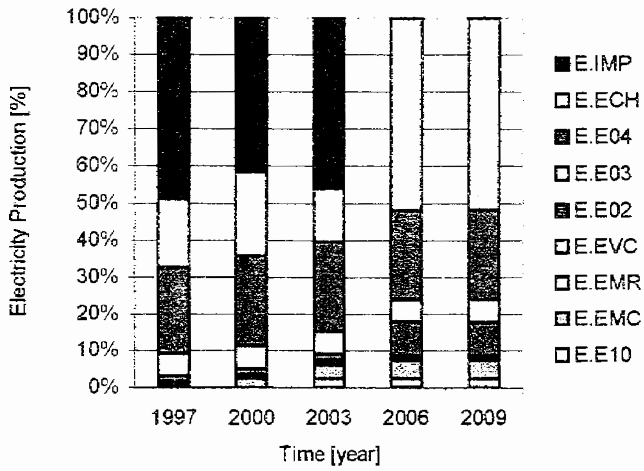


Figure 5.2.3-b: Plants contribution to electricity production - BAU Scenario

E.IMP	Electricity Import
T.E.PP	Electricity Production by Power Plants (PP)
T.E.CPD	Electricity Production by Combined Heat and Power Plants (CPD)
E.ECH	Electricity Production in Chivasso PP
E.E04	Electricity Production in ENEL Hydro PP
E.E03	Electricity Production in Valle Orco Hydro PP
E.E02	Electricity Production in Valle Susa Hydro PP
E.EVC	Electricity Production in Le Vallette CPD
E.EMR	Electricity Production in Mirafiori CPD
E.EMC	Electricity Production in Moncalieri CPD
E.E10	Electricity Production in Incinerator

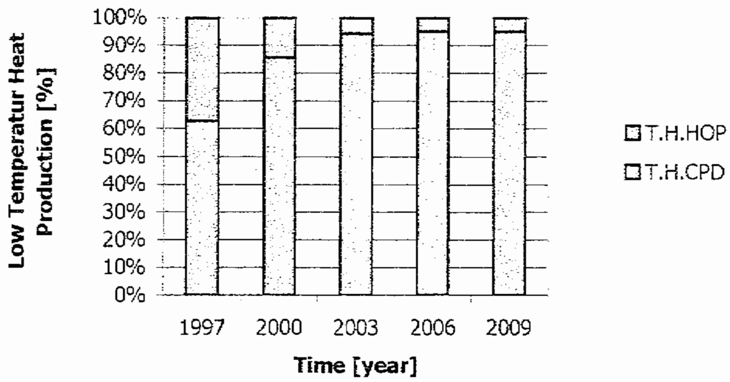


Figure 5.2-3.c: Plants contribution to LTH production - BAU Scenario

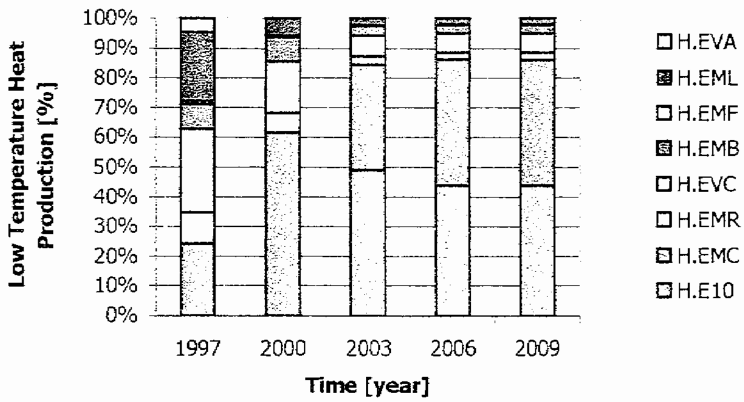


Figure 5.2-3.d: Plants contribution to LTH production - BAU Scenario

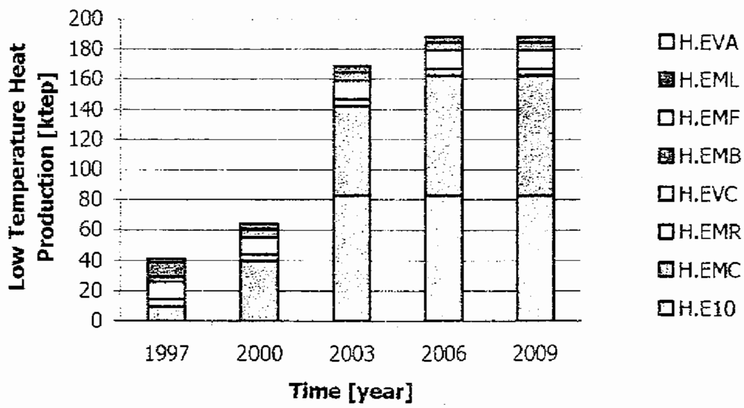


Figure 5.2-3.e: Plants contribution to LTH production - BAU Scenario

T.H.HOP	LTH Production in Heating Only Plants	H.EMB	LTH Production in BIT HOP
		H.EVC	LTH Production in Le Vallette CPD
T.H.CPD	LTH Production in CPD	H.EMR	LTH Production in Mirafiori CPD
H.EVA	LTH Production in Le Vallette HOP	H.EMC	LTH Production in Moncalieri CPD
H.EML	LTH Production in Moncalieri HOP	H.E10	LTH Production in Incinerator
H.EMF	LTH Production in Mirafiori HOP		

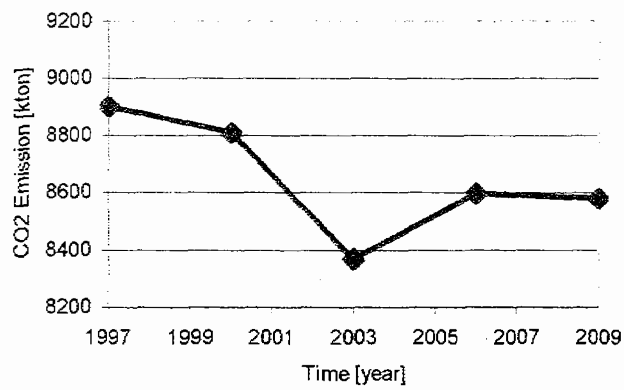


Figure 5.2-3.f: Total CO_2 emission trend - BAU Scenario

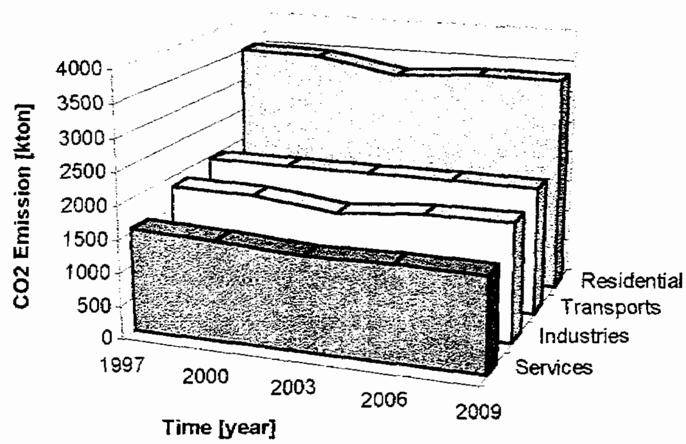


Figure 5.2-3.g: Contribution of each Demand Sector to CO_2 emission - BAU Scenario

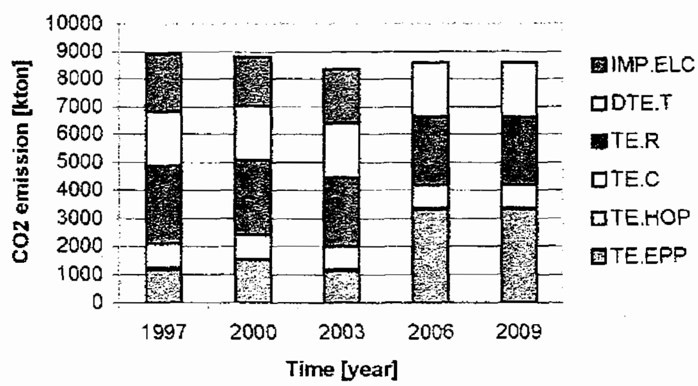


Figure 5.2-3.h: CO_2 emission by sector - BAU Scenario

IMP.ELC	Total CO_2 Emission due to Electricity Import
DTE.T	Total CO_2 Emission from technologies belonging to Transport Sector
TE.R	Total CO_2 Emission from technologies belonging to Residential Sector
TE.C	Total CO_2 Emission from technologies belonging to Services Sector
TE.HOP	Total CO_2 Emission due to local Heating Plants
TE.EPP	Total CO_2 Emission due to local Power Plants

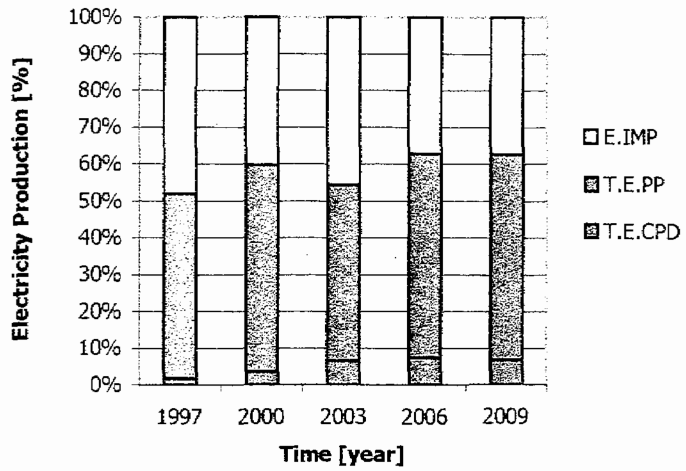


Figure 5.2-4.a: Plants contribution to electricity production - CO2_A Scenario

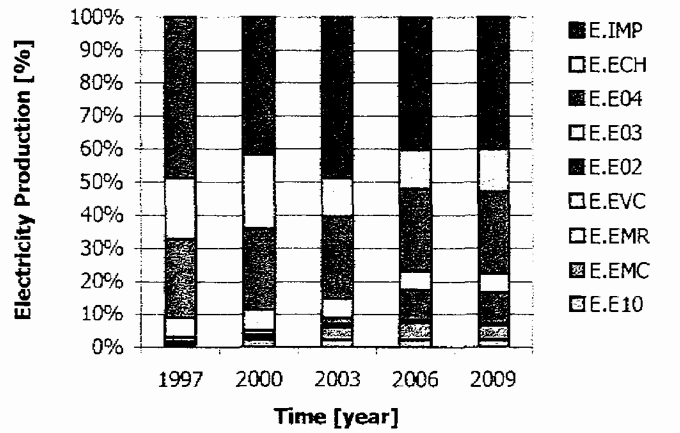


Figure 5.2-4.b: Plants contribution to electricity production - CO2_A Scenario

E.IMP	Electricity Import
T.E.PP	Electricity Production by Power Plants (PP)
T.E.CPD	Electricity Production by Combined Heat and Power Plants (CPD)
T.E.PP	Electricity Production by PP
T.E.CPD	Electricity Production by CPD
E.ECH	Electricity Production in Chivasso PP
E.E04	Electricity Production in ENEL Hydro PP
E.E03	Electricity Production in Valle Orco Hydro PP
E.E02	Electricity Production in Valle Susa Hydro PP
E.EVC	Electricity Production in Le Vallette CPD
E.EMR	Electricity Production in Mirafiori CPD
E.EMC	Electricity Production in Moncalieri CPD
E.E10	Electricity Production in Incinerator

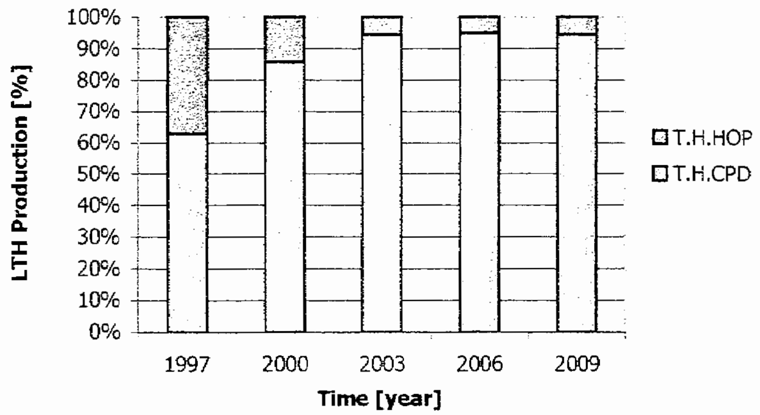


Figure 5.2-4.c: Plants contribution to LTH production - CO2_A Scenario

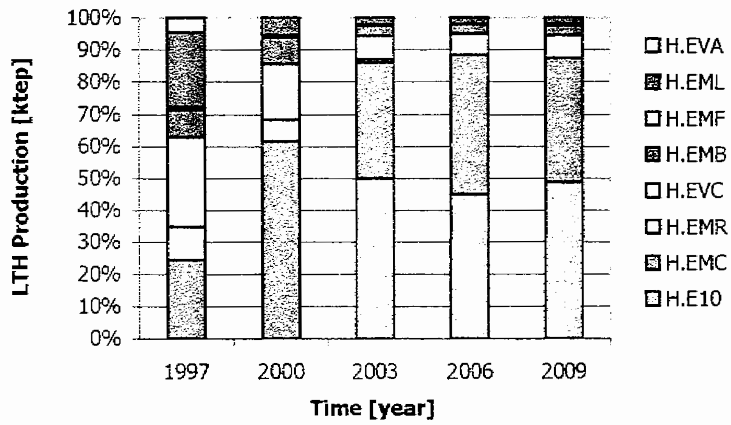


Figure 5.2-4.d: Plants contribution to LTH production - CO2_A Scenario

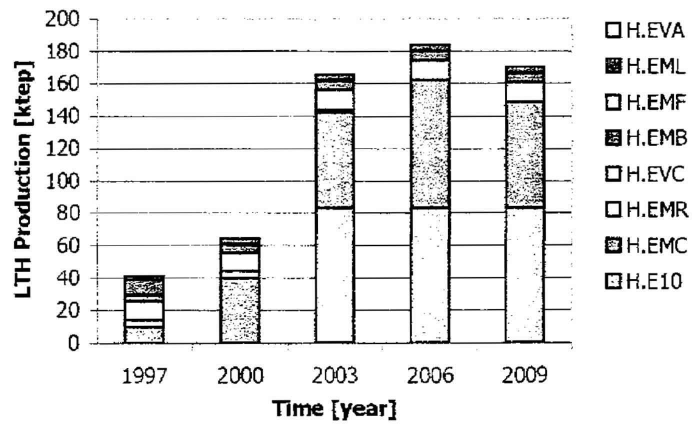


Figure 5.2-4.e: Plants contribution to LTH production - CO2_A Scenario

T.H.HOP	Total LTH Production in Heating Only Plants	H.EMB	Total LTH Production in BIT HOP
T.H.CPD	Total LTH Production in CPD	H.EVC	Total LTH Production in Le Vallette CPD
H.EVA	Total LTH Production in Le Vallette HOP	H.EMR	Total LTH Production in Mirafiori CPD
H.EML	Total LTH Production in Moncalieri HOP	H.EMC	Total LTH Production in Moncalieri CPD
H.EMF	Total LTH Production in Mirafiori HOP	H.E10	Total LTH Production in Incinerator

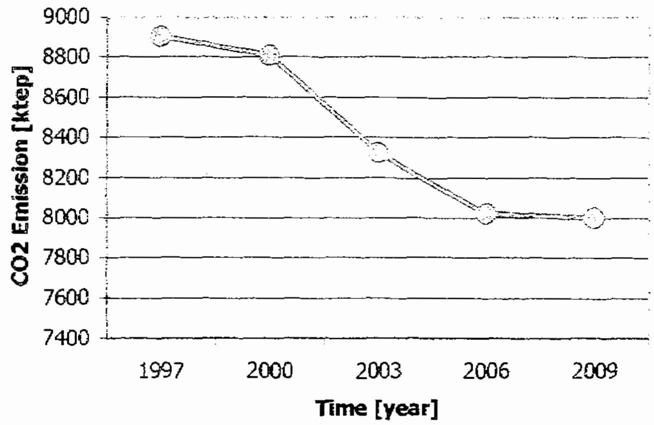


Figure 5.2-4.f: Total CO2 emission trend - CO2_A Scenario

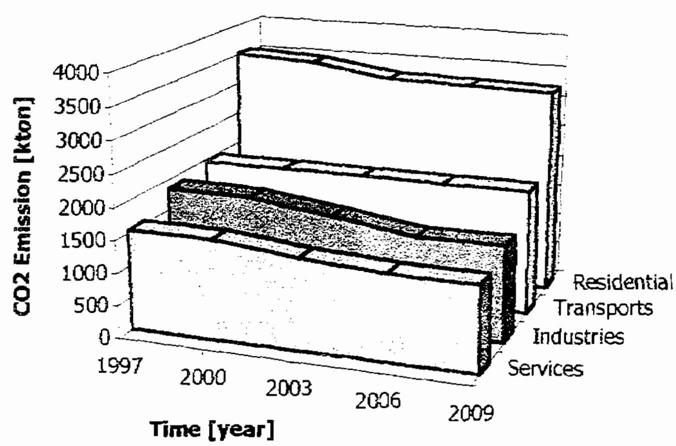


Figure 5.2-4.g: Contribution of each Demand Sector to CO2 emission - CO2_A Scenario

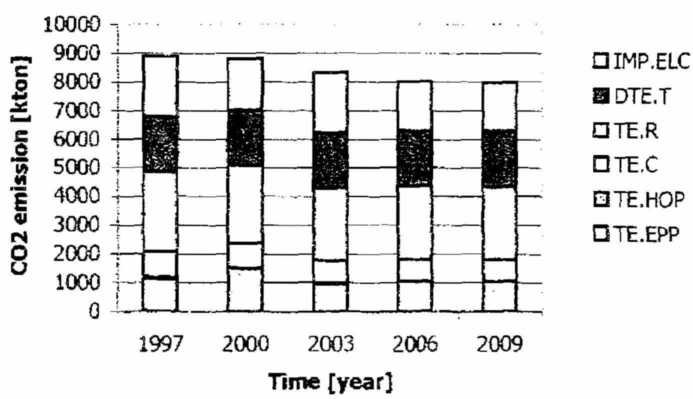


Figure 5.2-4.h: CO2 emission by sector - CO2_A Scenario

IMP.ELC	Total Co2 Emission due to Electricity Import
DTE.T	Total Co2 Emission from technologies belonging to Transport Sector
TE.R	Total Co2 Emission from technologies belonging to Residential Sector
TE.C	Total Co2 Emission from technologies belonging to Services Sector
TE.HOP	Total Co2 Emission due to local Heating Only Plants
TE.EPP	Total Co2 Emission due to local Power Plants

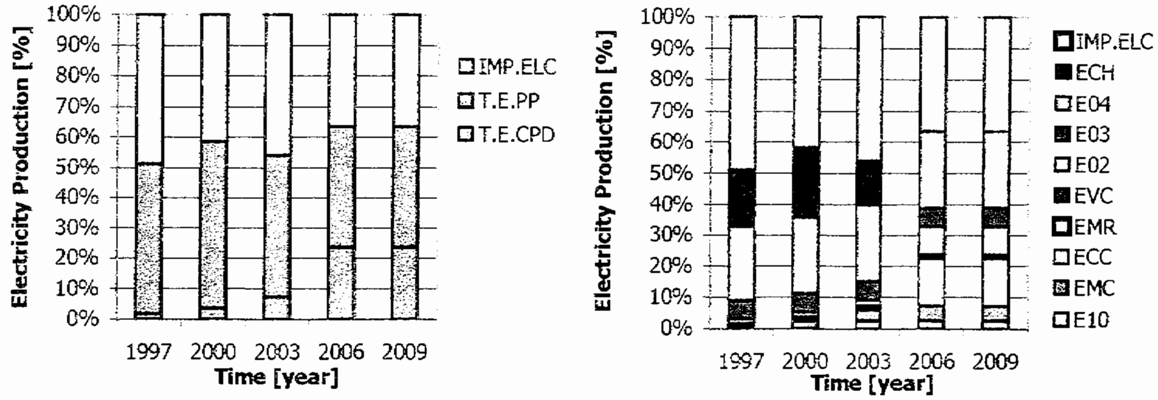


Figure 5.2-5.a: Plants contribution to electricity production - CO2_B Scenario

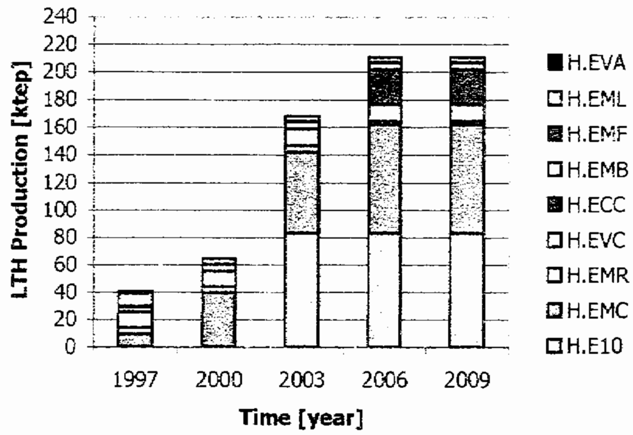


Figure 5.2-5.b: Plants contribution to LTH production - CO2_B Scenario

E.IMP	Electricity Import
T.E.PP	Electricity Production by Power Plants (PP)
T.E.CPD	Electricity Production by Combined Heat and Power Plants (CPD)
E.E04	Electricity Production in ENEL Hydro PP
E.E03	Electricity Production in Valle Orco Hydro PP
E.E02	Electricity Production in Valle Susa Hydro PP
E.EVC	Electricity Production in Le Vallette CPD
E.EMR	Electricity Production in Mirafiori CPD
E.ECC	Electricity Production in Chivasso CPD
E.EMC	Electricity Production in Moncalieri CPD
E.E10	Electricity Production in Incinerator
H.EVA	Total LTH Production in Le Vallette HOP
H.EML	Total LTH Production in Moncalieri HOP
H.EMF	Total LTH Production in Mirafiori HOP
H.EMB	Total LTH Production in BIT HOP
H.ECC	Total LTH Production in Chivasso CPD
H.EVC	Total LTH Production in Le Vallette CPD
H.EMR	Total LTH Production in Mirafiori CPD
H.EMC	Total LTH Production in Moncalieri CPD
H.E10	Total LTH Production in Incinerator

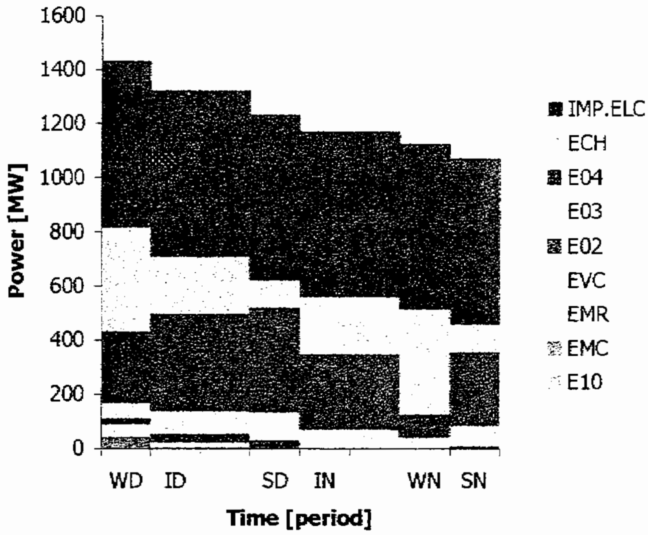


Figure 5.2-6.a: 1997 plants utilisation

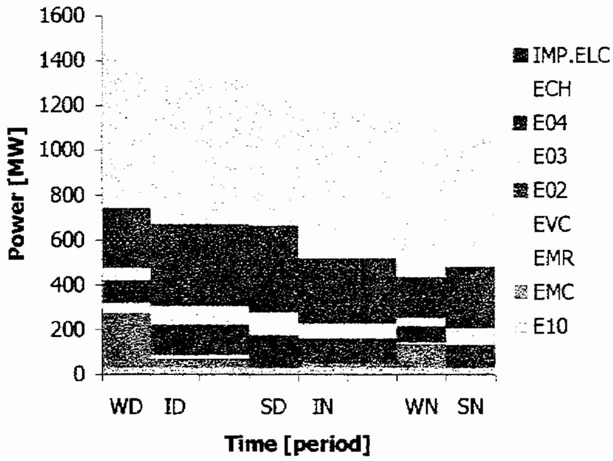


Figure 5.2-6.b: 2009 plants utilisation - BAU Scenario

IMP.ELC	Electricity Import
ECH	Chivasso Power Plant (PP)
E04	ENEL Hydro PP
E03	Valle Orco Hydro PP
E02	Valle Susa Hydro PP
EVC	Le Vallette Combined Heat and Power Plant (CPD)
EMR	Mirafiori CPD
EMC	Moncalieri CPD
E10	Incinerator
WD	Winter Day
ID	Intermediate Day
SD	Summer Day
IN	Intermediate Night
WN	Winter Night
SN	Summer Night

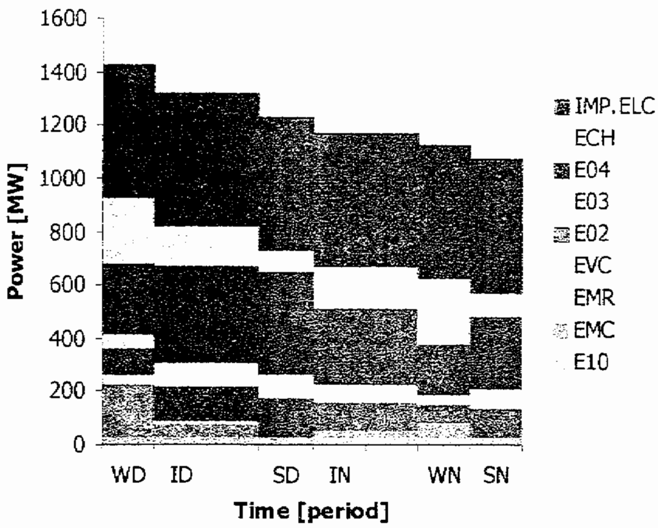


Figure 5.2-6.c: 2009 plants utilisation - CO2_A Scenario

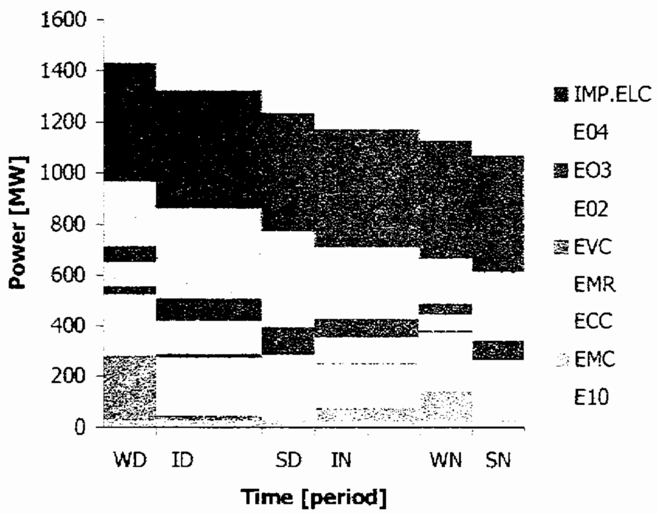


Figure 5.2-6.d: 2009 plants utilisation - CO2_B Scenario

IMP.ELC	Electricity Import	SN	Summer Night
ECH	Chivasso Power Plant (PP)	EMR	Mirafiori CPD
E04	ENEL Hydro PP	ECC	Chivasso CPD
E03	Valle Orco Hydro PP	EMC	Moncalieri CPD
E02	Valle Susa Hydro PP	E10	Incinerator
EVC	Le Vallette Combined Heat and Power Plant (CPD)	WD	Winter Day
IN	Intermediate Night	ID	Intermediate Day
WN	Winter Night	SD	Summer Day

5.3 The Aosta Valley Case Study a MARKAL application for the Aosta Valley Energy Plan

5.3.1. The Aosta Valley Region

Aosta Valley is located in North-West part of Italy, near the French and Swiss borders, with a predominantly mountainous territory. The total population amounts to about 110,000 inhabitants; the main town, Aosta City, has 38,000 inhabitants and the remaining population lives in small towns and villages. The economic system is based on a medium sized steel industry, several small other industrial activities, and a very active tourism sector.

The local energy system includes several hydroelectric plants, with a capacity of three times the local requirements, as well as the import of any other energy source (fossil fuels).

5.3.2. Organisation of the case study

In 1995, the Aosta Valley Regional Administration decided to implement Act 10/91 that requires the realisation of a Regional Energy Plan. Finaosta, a company owned by the regional administration itself, was charged with developing analyses, suggestions and specific guidelines for the assessment of a mid- and long-term Regional Policy for the energy sector.

In this framework, the Energy Department of the Politecnico di Torino was involved in order to perform a comprehensive study of the regional energy system. Among the activities developed by the Energy Department, a central role was assigned to a MARKAL analysis of the local energy system, in order to study energy options and scenarios for:

i) the electricity production sector, on the supply side, and
ii) the space heating sector, mainly in Aosta City, on the demand side, in connection with the development of the natural gas network and local district heating with heat pumps.

The interest in the first issue was justified by the fact that a new configuration of the entire Italian electricity sector (with a new tariff structure) was expected, and the regional government was interested in analysing different scenarios for local resource development.

The study was developed in two main phases:

- in the **first phase**, the main efforts were focused on the regional energy balance and a model of the regional energy system, through the assessment of the Aosta Valley Reference Energy System (AV-RES),
- in the **second phase**, the working team developed several feasibility studies, an energy related Geographical Information System (GIS) and several MARKAL runs employing different scenarios,

taking into account the principal objectives established by the Local Administration, the needs of a local planning approach and the constraints related to environmental preservation.
The study began in November 1996, with the assessment of the Regional Energy Balance (BER – Bilancio Energetico Regionale). In February 1997, the working team started to define the structure and content of the Reference Energy System which was to be used in the MARKAL model. Next, the technological options and the scenarios of interest for the local Administration were defined through several meetings with Finaosta and Regional Administration experts. Fi-

nally, the results of the MARKAL runs were analysed, interpreted and utilised for the Aosta Valley Energy Plan, which was approved at the beginning of 1998.

5.3.3. The existing system of goals as a basis for the evaluation of different strategic options

The working team focused its attention on the analysis of

- the electrical energy production system, presently composed of hydroelectric generation plants, which are almost completely owned by the national utility (ENEL),
- the space heating technologies for households and service buildings, presently represented by oil fired heating plants.

The total installed power of the hydro generating plants amounts to about 790 MW: 740 MW belonging to ENEL and the remaining 50 MW to a small local utility owned by the Regional Administration (CVA), which supplies all its production to the national grid. Presently, the electricity prices are determined at the national level and the Regional Administration expressed a specific interest in attaining some energy autonomy, in order to support the development of local activities with a more flexible electricity price structure. As an alternative, some kind of partnership with ENEL has also been considered. Many relevant changes are expected to develop into the electricity sector: ENEL will be split into three main branches (production, transport and distribution) and more effective competition will be allowed in electricity generation.

As far as the natural gas distribution system is concerned, the present network supplies only Aosta City (since 1991) and the Lower Valley towns. The Gas Company (Digrava), which assures the local distribution, and the Regional Administration made large investments in the construction of the distribution networks.

The main interest is in an evaluation of the competitiveness of natural gas for space heating purposes with the present operating conditions of the Gas Company; then, an assessment of reliable criteria concerning the opportunity for subsidising the conversion of private heating facilities from oil to gas burners, or promoting new technologies for space heating demand (such as, for instance, heat pumps).

Aosta Valley plays a central role into the traffic system between Italy and France, which is home to the most important highway and tunnel to this country; as a consequence, heavy lorry and private car traffic comes through the Valley (with high pollution generated). However, the transportation sector was not included in the MARKAL analysis because the Regional Government's main interest was first devoted to analysing

- **the electricity sector**:
  supply/demand coupling;
  load curves (base load and peak requirements);
  existing and new power plants;
  construction and operating costs;
  options for local energy autonomy or for
  a more consistent role of the local Utility (CVA);

- **the potential role of new technologies and renewable sources** with reference to
  energy saving;
  economic benefits;
  environmental improvements;

- **the energy saving policies** and economic benefits from a new configuration of the global energy system.

5.3.4. Calculation and evaluation tools used in the case study

MARKAL as a "comprehensive analysis" tool was associated with other "*high-resolution evaluation*" tools, such as feasibility studies and GIS (Geographical Information System) applications. In particular,

a) feasibility studies were performed on:

   - a district heating network supplied by heat pumps (for the base load) and heating only boilers;
   - biomass (wood) energy utilisation in small villages;
   - a Combined Cycle Power Plant (available also in a Combined-Heat-and-Power configuration) to meet the electrical base load of a planned CVA - Users Consortium;
   - the utilisation of an abandoned mine as an underground site for an Urban Waste Incinerator;

b) GIS based applications for better understanding of the local energy system were developed; in particular,

   - a GIS for Energy Plants and related Infrastructures to be included in the Regional Information System;
   - a multi-media hypertext of the local environmental impact of High Voltage Transmission Lines, to be included in the annexes of the Aosta Valley Master Plan.

As usual, the numerical data retrieval and collection presented several problems, mainly in regard to the availability and reliability of the data bases at the required level of detail. Moreover, a new Act concerning the protection of personal privacy actually limits the use and availibility of detailed Census data as would be necessary for this kind of analysis.
The main sources were the Regional Energy Balance (BER), the 1991 National Census, the National Boards for electricity production and distribution (ENEL), and for fossil fuels supply (Eni-Snam), and several National and Regional Administrative Authorities.
Other technical and economic data were extracted from studies and reports, or directly collected from equipment sellers or installation firms.

5.3.5. Scenario used for long-term simulation

For the construction of the Reference Energy System, the electrical energy production sector was described through a classification system based on the ownership and the hydraulic typology (flowing water, night/day basin, and seasonal reservoir). Each class of hydro-plants was divided into sub-classes depending on size and production activities in order to be characterised by reliable technical and economic data.

The plants have been classified as follows:

- CVA plants, flowing water typology
- ENEL water plants
- ENEL night-day basin plants
- ENEL seasonal reservoir plants, high fixed and variable costs
- ENEL seasonal reservoir plants, low fixed and variable costs

Various scenarios and sensitivity analyses were used in order to take into consideration the activities of the power plants for different electricity price situations, some hypotheses on the possibility of managing the local electrical system more autonomously and the influence of electricity import from France.

Referring to the demand for space heating (for residential and service sectors) there are several alternatives for energy carriers (oil, natural gas, LPG, electricity, wood), as well as for equipment; the list of the demand devices also includes new facilities, at a commercial level or in a developing stage. The space heating requirements for the tourist sector is considered as a separate demand, because of its particular load curve, which is high both in summer and in winter.

In order to take into consideration the significant demographic and socio-economic differences between Lower Valley, Aosta City and Higher Valley, the regional demand for the residential sector has been disaggregated into three separate demands. It was assumed that, globally, the energy demand remains constant over the whole analysis time (27 years), with the exception of a small growth rate in the industrial sector.

Two price scenarios for fossil fuels were defined:

- a BAU (Business As Usual) scenario, where during the first 9 years there is a strong fuel price growth followed by a much lower growth trend;
- a scenario with a quite constant fuel price situation, as a consequence of a new equilibrium between energy consumption and technological improvements.

5.3.6. Results of scenario calculation and conclusions

The optimisation of the residential space heating sector in the base scenario produces a high modification in the mix of energy carriers, replacing, as soon as possible, oil boilers with gas boilers, heat pumps and electric boilers.

In each scenario, natural gas utilisation reaches its upper limit. Electricity consumption increases as a consequence of its low cost compared to oil, and of the limits to the availability of gas (as previously mentioned). The utilisation of heat pumps is dependent on the cost of locally produced electricity (the threshold value for market penetration is close to the national electricity cost, about 200 Itl/kWh).

Figures 5.3-2 and 5.3-2 show a small reduction in total consumption. This reduction is possible because of the substitution of normal boilers, either by boilers that also warm sanitary water or by heat pumps.

In Aosta City, a different development for energy carrier consumption from the entire Regional development can be observed. This difference is due to a larger gas consumption capacity and the lower availability of LPG and oil.

Wood energy use has been kept constant over the whole period. A detailed feasibility study of its use for space heating in small villages showed that the potential development of this kind of local resource (with a limited amount of subsidies) for public buildings is associated to the reduction of its use in private households.

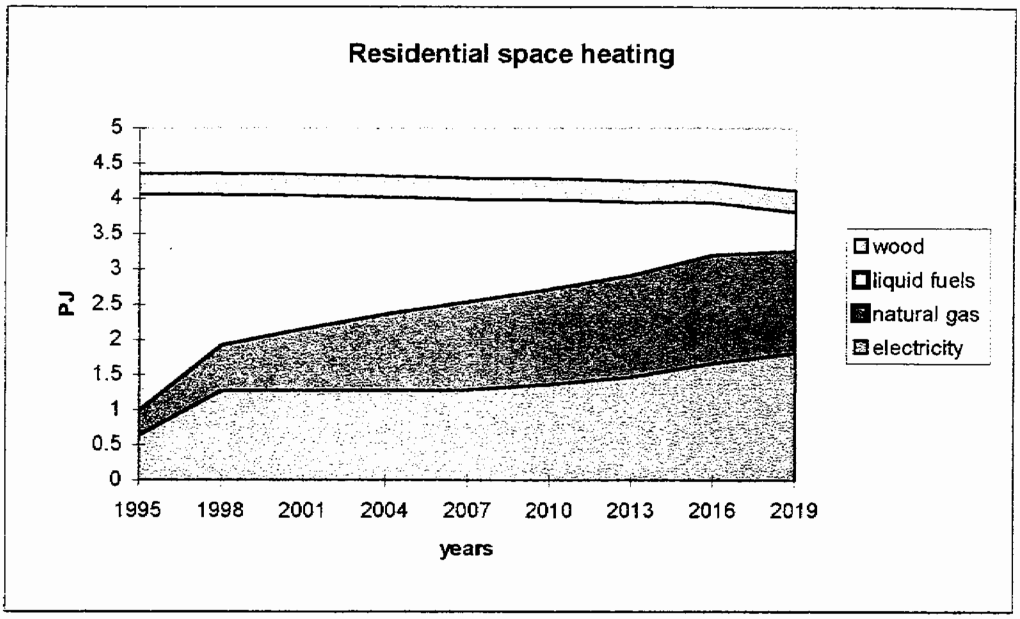


Fig. 5.3-1: Evolution of energy carrier use in the Aosta Valley Region (base scenario)

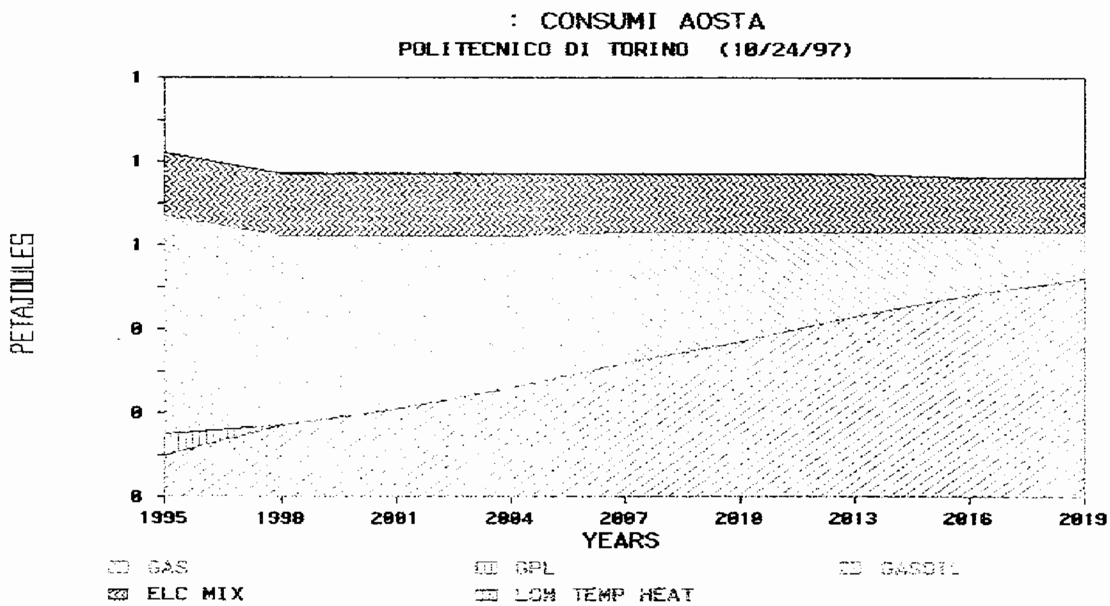


Fig. 5.3-2: Evolution of energy carriers' consumption for Aosta City (base scenario)

Figure 5.3-3 shows the growth in electricity consumption if the electricity price is reduced from 200 Itl/kWh to 50 Itl/kWh. This kind of sensitivity analysis was used since the Regional Administration is interested in increasing its electricity independence. As a matter of fact, the Regional Government is taking into consideration the possibility of buying some hydro plants from the national enterprise (ENEL) and using these plants to meet the "local" electricity demand, e.g. through the institution of a partnership between the local electricity Authority (CVA) and a consortium of users.

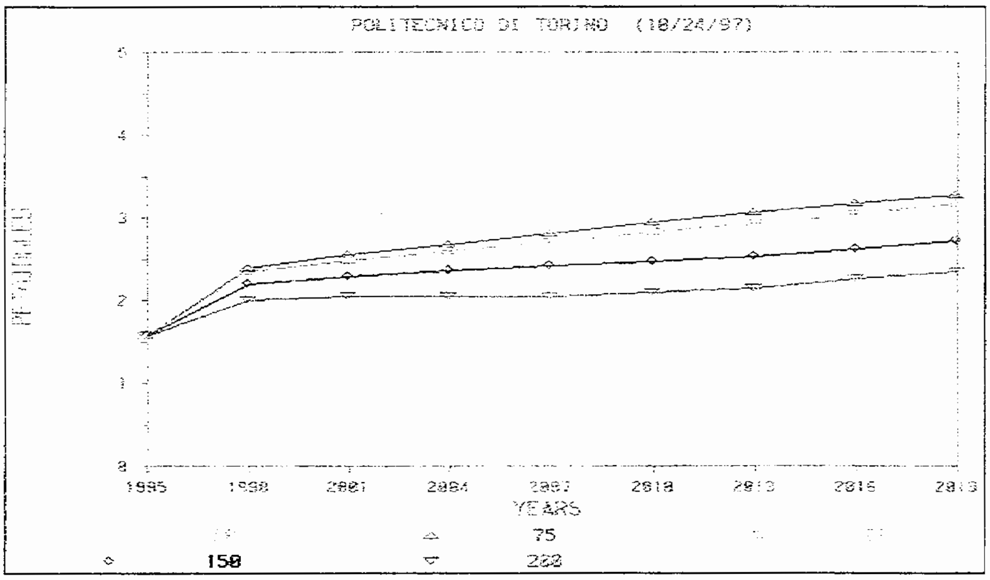


Fig. 5.3-3: Electricity consumption for electricity prices ranging from 50 Itl/kWh to 200 Itl/kWh

The analysis shows that there will not be any contribution from some plants, while other plants increase their production. As a result, the global production cost per GWh delivered will increase. This means that ENEL Company is managing the hydro plants in a manner that is not the best solution for preserving local resources. It appears that it is advantageous for the Regional Administration to acquire a set of hydro plants and to attain some electric energy independence, with electric production costs lower than the national ones.

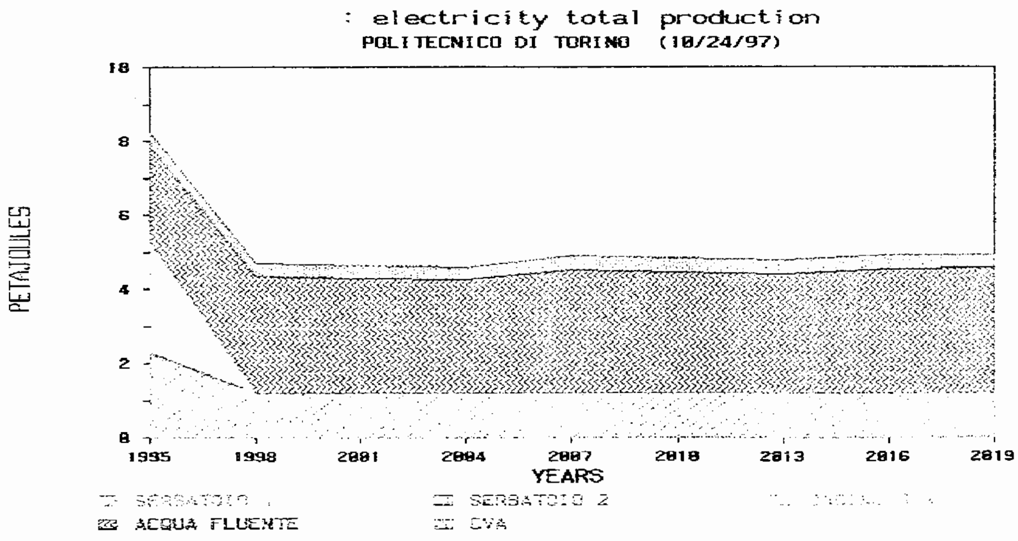


Fig. 5.3-4: Production of electricity (per year) for the 5 typologies of hydro plants

One of the most important goals for the Regional Government is environmental improvement in terms of better air quality. However, as explained before, the industrial and transportation sectors have not been included in the optimisation procedure. As a consequence, only the emission reductions due to alternative choices in the demand for residential and commercial sector space heating have been taken into account.

In the base scenario, the optimal solution is also the best solution with respect to atmospheric pollutants emission (figure 5.3-5). If more severe limits on emissions are established, then no solutions will be found for the assumed technical options, because all the possible substitutions of fossil fuels were already obtained. Moreover, electricity will replace fossil fuels because of its availability and low price.

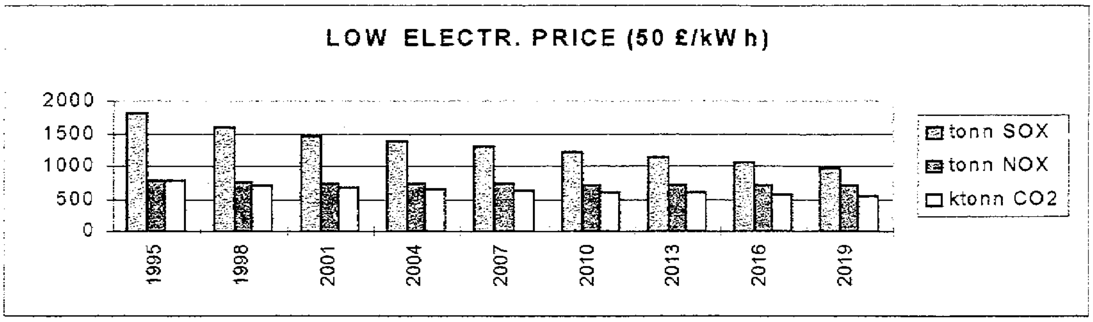


Fig. 5.3-5: Emissions evolution in the base scenario

The SOx reduction is due to the gradual substitution of oil boilers with gas boilers in the residential space heating demand sector (LPG and natural gas fuelled); this also leads to a strong reduction in CO_2 emissions.

Since the transportation demand sector has not been included, no real reduction in NO_x emissions were realised in any of the analysed scenarios.

The next steps in modelling and analysing the Aosta Valley energy system should be:

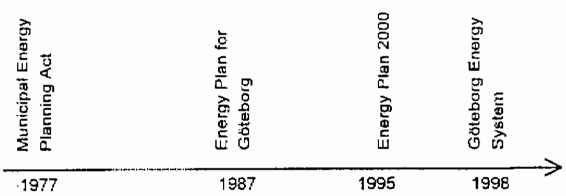
- to include the transportation sector in the Reference Energy System, also taking into account new technologies and carriers
- to develop alternative uses of electricity in low demand periods in order to improve the valorisation of electricity
- to modify the "boundary conditions" of the electricity sector, up-dating the role of the national Authority and other Companies, the new market rules and the tariff structure.

In future analyses, an interesting option would be a hydrogen cycle, with H_2 production assured by hydro-plants and final use, associated with fuel cell - electrical motor vehicles, in two public transportation companies: the Aosta City Transit System and the Torino – Aosta Railways presently operated by fuel engine powered trains. These options have been included in the new Regional Energy Plan and will be developed in the framework of Local Programmes financed by National Carbon Tax revenue.

5.4 Advanced Local Energy Planning in Göteborg

5.4.1 Introduction and organisation of the energy planning process

Local energy planning is an ongoing process in Göteborg which started two decade ago. It has been characterised as advanced (ALEP) since 1987. We present the "Energy Plan 2000" from 1995 as the case study in this guidebook. It is not the latest plan, but it is more typical for advanced local energy planning than the latest plan, and it includes all the parts which characterise advanced local energy planning. (In the appendix we briefly present the latest plan. It focuses on the long-term development of the energy system.)



Energy planning milestones since 1987.

In Sweden, the Municipal Energy Planning Act became law in 1977. This Act requires all municipalities to develop a plan for the supply, distribution and use of energy. Göteborg adopted the "Energy Plan 2000" in 1995. The previous "Energy Plan for Göteborg" comes from 1987.

Göteborg's energy demand and supply have undergone dramatic changes over the last twenty years. The use of oil has been drastically reduced, replaced by a new natural gas system and a greatly expanded district heating system. The district heating system makes use of industrial waste heat, heat generated from waste incineration, and a large heat pump plant that recovers the heat energy from the city's sewage treatment plant discharge.

This has resulted in a drastic reduction in air pollutants from stationary sources, and a more reliable energy delivery system. These changes came about as a result of a planning process The initiative for the new Energy Plan 2000 came from the Environment Policy Steering Group, a group of key politicians with special interest in environmental issues. They gave the

implemented almost two decades ago. The basis of the present energy plan in Sweden is to attain a sustainable development for the future.

Between 1987 and 1995 several basic conditions changed, requiring a change in the "Energy Plan for Göteborg". Energy tax structures and levels were changed, charges for pollution emissions increased, and the relative price level between fuels and energy sources changed. Furthermore, the impending deregulation of the electric energy market was expected to result in new electricity prices driven by market forces different from the current regulatory framework. All these conditions made it necessary to update the "Energy Plan for Göteborg".

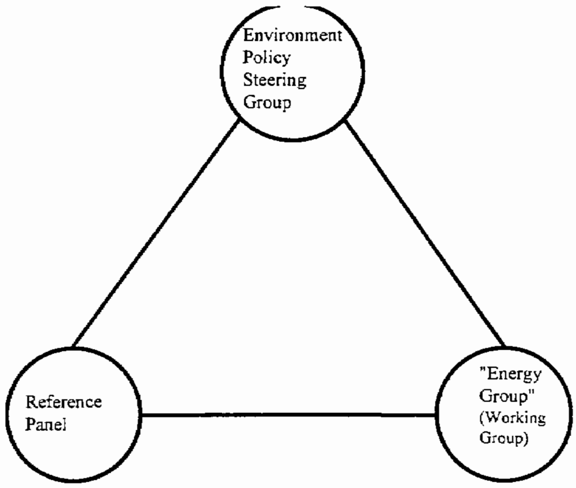
The objective of the "Energy Plan 2000" is to provide a broad direction for Göteborg's energy policy. The plan is used as an instrument to co-ordinate the community's joint efforts. Furthermore, it is used to develop a process that will lead to improved utilisation of resources and better prepare Göteborg for its energy future. Energy efficiency is promoted along with reliable and sufficient energy supply.

The base year for the "Energy Plan 2000" is 1993.

Local energy planning is a broad and extensive process in Göteborg. Therefore it was necessary to limit the presentation in this paper. We concentrate the presentation on a few examples of scenarios and results from the comprehensive and subsystem analyses. In the section on the action plan however, we have tried to present a major part of the actual plan. This means that in this summary of ALEP in Göteborg a number of items in the action plan are presented without the analyses which "back up" the specific actions.

task to the Göteborg Planning Commission, who thereby became responsible for the preparation of the Energy Plan. This plan was then developed by the Energy Group, which was chaired by a City staff person, and consisted of personnel from Göteborg Energi AB (the utility), the Planning Commission, the Agency for Environmental Protection, the Agency for Traffic, and the Agency for Real Estate. The Environment Policy Steering Group was kept well informed about the development of the Energy Plan during the whole planning process. They, of course, also influenced the direction of the work.

The Energy Group established a Reference Panel with experts in different fields. Experts from this panel were then invited to hearings when certain issues were discussed. This was felt to be a very effective way of getting the opinions of experts outside of the Energy Group into the planning process.



The institutional organisation for Local Energy Planning in Göteborg.

5.4.2 Important goals and issues for the Energy Plan

The overall goal of the Energy Plan 2000 is to;
(1) ensure a reliable energy supply,
(2) ensure competitive energy costs,
(3) minimise energy's impact on the environment, and
(4) ensure that energy efficiency is given equal importance alongside energy supply options.

Each of these goals is then split up into specific, detailed goals for the different subsectors of the energy system.

1. Reliable energy supply is paramount in Göteborg's Energy Plan. Reliability is addressed through the broad mix of energy sources, thereby decreasing dependence on any one source of supply. Reliability has long been a characteristic in the development and operation of the distribution systems.

2. It is important for the economic well being of the community that energy costs remain competitive. The plan addresses this goal in much the same way as reliability. A varied supply mix ensures that no one single fuel will dominate in the overall costs for energy.

3. Preservation of the environment is an important aspect of Swedish life. Energy use has had an ever increasing impact on the environment. By the year 2000, Göteborg intends to achieve the following emissions reduction goals as a part of the Energy Plan 2000, which are consistent with Agenda 21 from the Rio de Janeiro Conference;

- reduce sulphur emissions by 30 percent
- reduce nitrogen oxide emissions by 30 percent
- maintain carbon dioxide (CO_2) emissions at constant levels

The most challenging task will be to keep carbon dioxide levels unchanged.

Beyond the year 2000 the goal is to continue the reduction of sulphur and nitrogen oxide emissions, and begin decreasing carbon dioxide emissions.

Another goal that will impact future energy production and use is to eliminate the clorofluorocarbons (CFCs). As a first step, some CFC applications can be replaced by HCFCs.

4. Another way to reduce energy's impact on the environment is to make more efficient use of energy for process needs, heating, transportations, etc. The technical, economic and market potential for energy conservation is substantial. However, investments must be made in information systems, technical advisory services, and financial support for energy conservation to be a viable alternative to supply options.

At the very beginning of the planning process existing initiatives were identified in order to find relevant issues for subsystem and component analysis. Examples of such issues are:

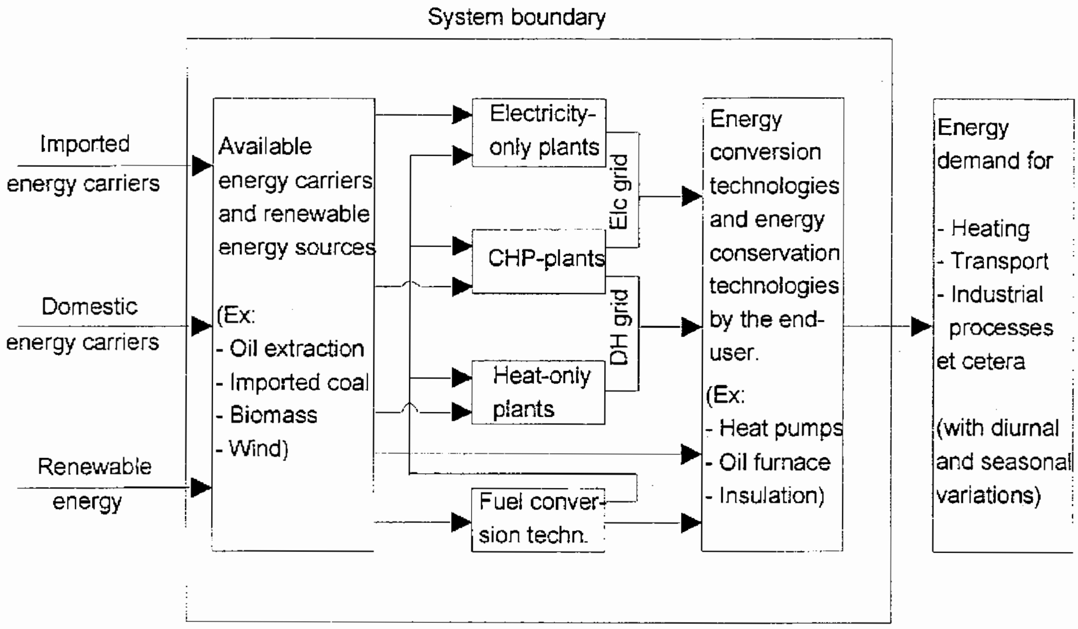
- Large scale introduction of natural gas fired combined heat and power production, CHP, in the district heating system.
- Seasonal heat storage in existing rock stores, previously used for oil storage.
- Waste incineration; expansion and increased electricity production.
- Alternative fuels for vehicles, e.g. electricity and natural gas
- Efficient use of energy in housing and commercial buildings.
- The competition between district heating, natural gas and other alternatives for heating of single family houses.

5.4.3 Calculation and evaluation tools used in the case study

5.4.3.1 Representation

For the comprehensive analysis a Reference Energy System (RES) type of representation was chosen. A RES describes the energy system with its technologies, from the extraction of primary energy through central conversion and distribution, to the final conversion to useful energy by the consumers, including all energy flows in-between these technologies. The existing energy system is described together with all possible alternative technologies and energy flow paths. By describing the energy system as a RES, competition and synergies between different parts of the energy system can be studied, e.g., competition between energy supply and conservation, as well as combined heat and power to supply both electricity and heat demand. A principle diagram of an RES is presented below.

The RES representation facilitates the learning process for the people involved in planning, since it clearly shows how different parts of the energy system interact with each other.



Principle diagram of a Reference Energy System (RES)

5.4.3.2 Methods and models

The comprehensive study is done in the form of a scenario analysis. A base scenario was first calculated and the results led to the development of to alternative scenarios. The scenarios were set up to analyse the period from 1993 to 2020. However, the focus was on the short term development of the energy system. The scenarios automatically include an analysis of the present situation.

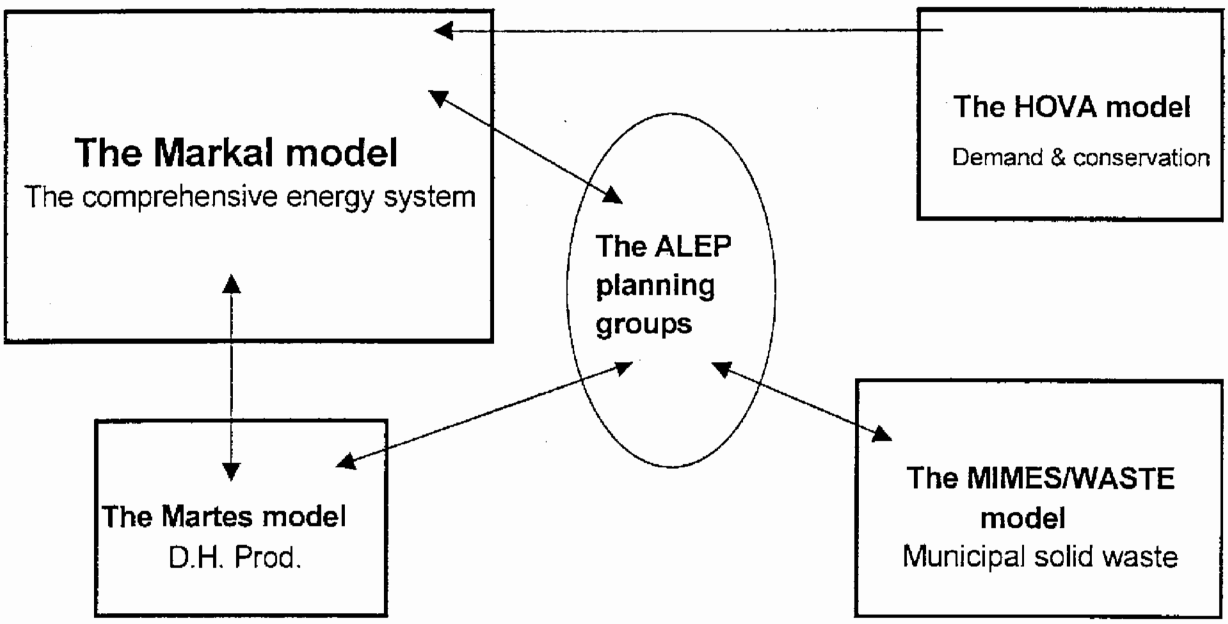
During the planning process there was an ongoing exchange of information between the comprehensive analysis and the detailed studies of subsystems and components. This is valuable since the results for one subsystem is often influenced by the development of other subsystems and the total energy system.

The MARKAL model was used for the comprehensive study. MARKAL is an optimising model based on the RES representation of the energy system. This model had been used extensively since 1987 for analysis of the Göteborg energy system within several projects involving Göteborg Energi AB, Chalmers University of Technology and Profu. Therefore an existing database could be used after some updating of input data in the Energy Plan 2000 study. During the planning process there was a continuous exchange of information between those responsible for running the model and the Energy Group. The majority of people involved in this process already had some experience with MARKAL, which of course facilitated the transfer of information.

A wide range of tools were used for the detailed analysis of subsystems and components, from advance computer tools like MARKAL (which was also used in a couple of the detailed studies) to completely manual calculations.

For the analysis of the district heating production the Martes model was used. Martes is a user-friendly, simulation model for detalied analysis of district heating production, including total cost, marginal costs, production strategy emissions, etc. Simple spread-sheet models were also used for some of the detailed analysis.

For the analysis of the municipal solid waste system, the MIMES/WASTE model was used. The HOVA model was used for structuring and aggregating the data for the different demand sectors and the conservation measures, before they were entered as input into MARKAL.



Models used in the ALEP planning process in Göteborg

5.4.4. Scenarios used for long-term simulation

5.4.4.1 Present Energy Supply and Demand

In 1979, final energy demand in Göteborg was 17,6 TWh. Intense efforts to reduce the dependence on oil, as well as efforts to make heat production and use more efficient, resulted in an overall decrease in the final energy demand. In 1984 energy use had dropped to 15,6 TWh. A large proportion of this reduction is attributable to the development and use of industrial waste heat, heat from waste incineration, and recovering heat from the city's sewage treatment plant to supply much of the City's heating needs.

Development and growth caused final energy demand to increase through the late eighties, and in 1993 it had increased to 16,5 TWh.

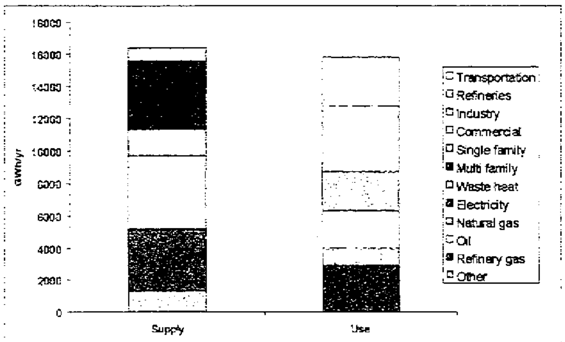


Figure 5.4-1: *Primary energy supply and final energy demand in Göteborg 1993 [GWh]*

The supply of oil for stationary needs has continued to drop, replaced by electricity and natural gas. However, use of oil for transportation fuels has increased.

Efforts to reduce the use of oil, improve energy efficiency, and increase the use of waste heat has resulted in a dramatic decrease in emissions from energy conversion processes controlled by Göteborg Energi AB (see Reference Energy System, RES, presented in figure 5.4-3). However, energy conversion processes account for a part of total emissions. Other sources of emissions are the transportation sector, refineries and other industries, shipping activities in the harbour heavy equipment.

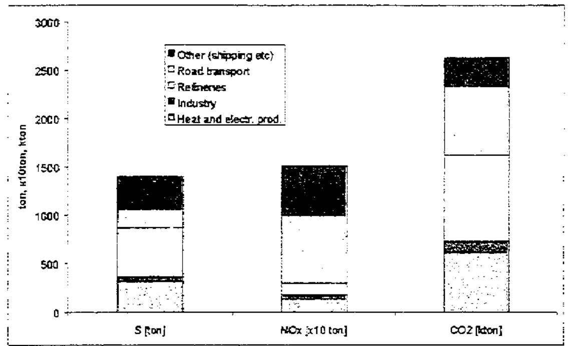


Figure 5.4-2: *Emissions of sulphur (1400 tons), nitrogen oxides (15000 tons) and carbon dioxide (2600 ktons), 1993.*

A detailed description of the energy system in Göteborg in 1993 is presented in figure 5.4-3. It is shown as a Reference Energy System, RES. At the far right of the figure the different demand sectors are shown with the final energy demand for different energy types, e.g oil, natural gas, electricity, district heating, etc. Moving left in the figure the distribution systems for natural gas, town gas, district heating and electricity can be found. Further to the left large scale energy conversion plants are shown. Finally, to the far left the primary energy can be found.

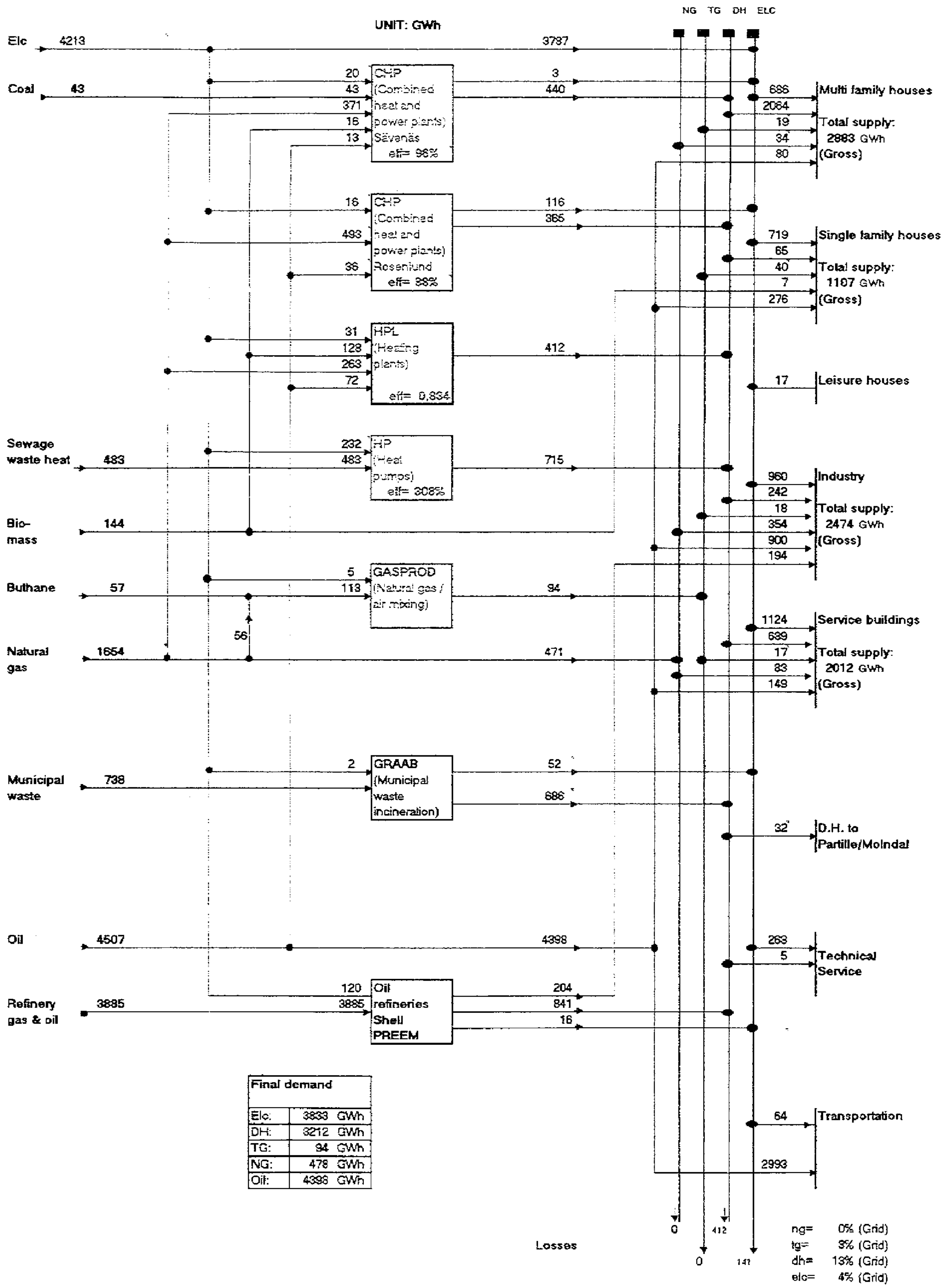


Figure 5.4-3: *Reference Energy System for Göteborg, 1993. Energy conversion plants operated by Göteborg Energi AB are indicated by red text. All numbers showing energy flows are expressed in GWh.*

5.4.4.2 Description of scenarios

Five different scenarios have been analysed in this planning project. The scenarios are defined by a number of assumptions describing the context of the energy system.

The following scenarios have been calculated and analysed:

- Base scenario: This scenario is based on the assumptions which were considered most probable. We assume that the price of raw power increases 50%, up to 320 SEK/MWh, and that the seasonal differences decrease significantly compared to the base year 1993. In 1996 additional industrial waste heat becomes available (from the Preem refinery). For the emissions calculation we assume that imported raw power is produced in coal fired condensing power plants. If gas fired CHP production is introduced, we limit the allowed size to 350 MW electricity.
- Unlimited CHP expansion: Here we do not limit the size of a possible gas fired CHP plant. Apart from this, the assumptions of this scenario are identical to those of the base scenario.
- Low electricity price: In this scenario we assume that the raw power price remains at the present level. Except for this, the assumptions of the base scenario have been used.
- High real yield requirements: The real interest rate is used for the calculation of present values, etc. Here we assume 12 % instead of 5 % in the base scenario. All other assumptions are identical to those of the base scenario.
- Limited gas supply: Most scenarios show a large expansion for the use of natural gas. This would make Göteborg very dependent on natural gas, which is presently available from one supplier only. Therefore we have designed one scenario where the supply of gas is limited to 3 TWh/yr, to illustrate a situation where dependence is not allowed to reach the same level as other scenarios.

These five scenarios have been chosen since they illustrate a couple of different development trends, which differ greatly in some cases. When analysing the results it is important to observe how different parameters are influenced by the different scenario assumptions. Comparison of the scenarios indicate the robustness of different strategies.

5.4.5 Results of scenario calculations and conclusions

5.4.5.1 Comprehensive analysis

The development of the energy system assuming different prerequisites for important factors was studied as a scenario analysis (see above). The MARKAL model was then used to calculate the development of the energy system in the different scenarios. This means that the energy system development is a result of calculation and not input.

Here we concentrate the presentation on two of the scenarios, the base scenario and the low electricity price scenario. The difference between the two scenarios is merely the electricity price. In the base scenario the price on the national grid is assumed to increase by 50 % from the present to the year 2010[1]. In the low electricity price scenario, however, constant price is assumed. This difference in assumptions leads to large consequences for the optimal development of the energy system.

The development of the Göteborg energy system can be illustrated by a change in energy supply in both scenarios. Figure 5.4-4 shows the development in the base scenario, while figure 5.4-5 shows the low electricity price scenario. The scenarios of the comprehensive analysis concentrated on heating for residential and commercial buildings, district heating production and industrial energy use. However, energy use in the two refineries and the trans-

[1] The price increase can be explained by the demand for new production due to increasing demand and the phasing out of nuclear energy. The increased coupling to the German electricity system, with higher price levels, also contributes to the price increase.

and commercial buildings, district heating production and industrial energy use. However, energy use in the two refineries and the transportation system were not analysed in the scenarios.

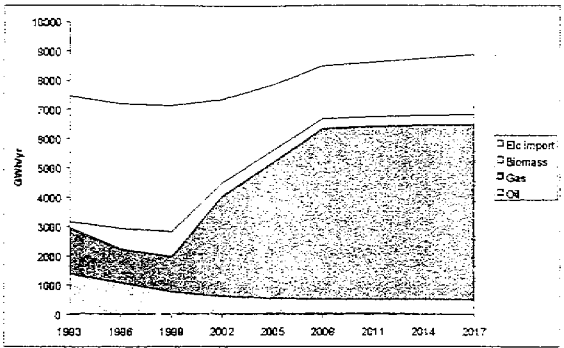


Figure 5.4-4: *Energy supply, base scenario*

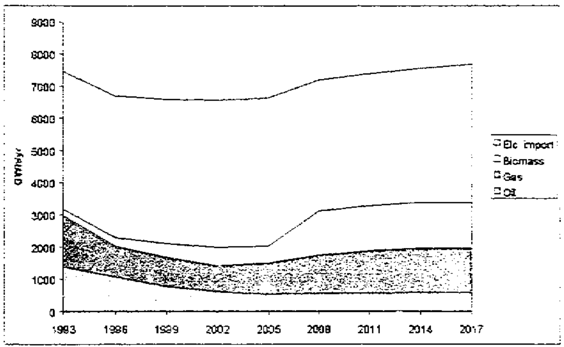


Figure 5.4-5: *Energy supply, low electricity price scenario*

The difference in the development of the energy supply is caused by the sum of many factors. There is, however, one difference which is more important than the others and that is CHP production. In the base scenario a large natural gas fired CHP plant is introduced after the year 2000. In the low electricity price scenario however, there is a much smaller CHP plant used, fired by biomass. This is discussed further in the section dealing with the subsystem and component studies.

The emissions of carbon dioxide in the two scenarios are shown in figures 5.4-6 and 5.4-7. The figures show emissions from the energy system, excluding the transport system and the refineries. For electricity "imported" to the community we have assumed that it reflects the marginal production in the "North-european" electricity system. The assumption here is that coal condensing plants make up the marginal production.

Figure 5.4-6 shows that the CO_2 emissions from the energy system within the municipality of Göteborg will increase, mainly as a consequence of the CHP introduction. However, if emissions outside the municipality caused by Göteborg´s energy use are added, the result is very different. Then the introduction of CHP leads to a considerable reduction of CO_2 emissions, since the "import" of electricity can be reduced and the CHP production leads to a higher overall efficiency than the condensing plant production.

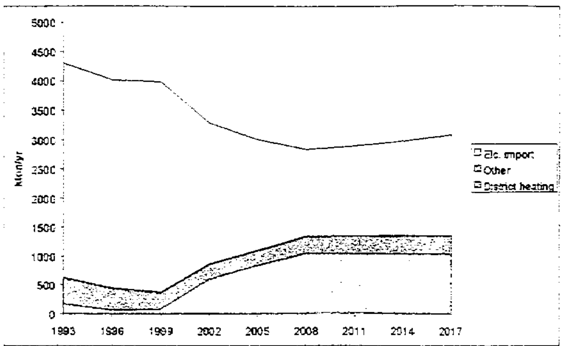


Figure 5.4-6: *Carbon dioxide emissions from the energy system (excluding transportation and refineries), base scenario [kton/year]*

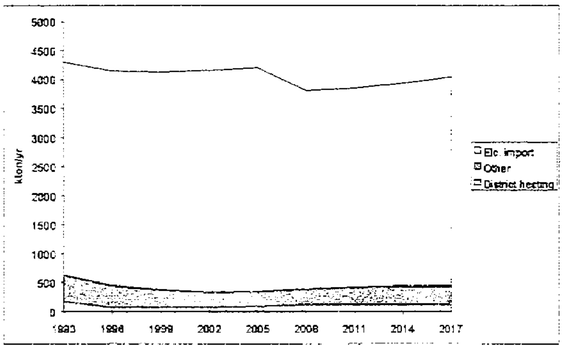


Figure 5.4-7: *Carbon dioxide emissions from the energy system (excluding transportation and refineries), low electricity price scenario [kton/year]*

In the low electricity price scenario, figure 5.4-7, the CO_2 emissions are in principle constant, both within Göteborg and those resulting from the "import" of electricity. Since the effect of CO_2 emissions is a global concern, it is more relevant to compare the total emissions related to energy use in Göteborg than only the emissions within the municipality. This means that the base scenario is better than the low electricity price scenario in terms of CO_2 emissions.

An important assumption here is how the "imported" electricity has been produced. We have assumed the use of coal fired condensing plants. Such plants are used for marginal production during the whole year in the Nordic production system. Other assumptions about

Analyzing other emissions, the effects can be local or regional. Therefore it may be more important to look at the consequences within the municipality of Göteborg.

The comprehensive study has valuable input for the subsystem and component analysis of specific issues. The competitiveness of district heating and natural gas for single family housing is e.g. coupled to the production of district heating, which is analysed in the different scenarios of the comprehensive study.

The comprehensive analysis comprises a long time period, 25 years. This does not mean that the energy plan should contain detailed planning for such a long period. Specific goals and the action plan typically deal with a period of 0-5 years, while more general goals could be specified for perhaps 10-15 years. The 25 year period is relevant for plans and for analyses which deal with investments in new technology. If you e.g. want to study the possibilities for combined heat and power production you must take into account costs and incomes for the assumed life of the plant, often 20 years. It is also valuable to analyse a long period in order to make sure that actions suggested for the near future are not in conflict with long-term visions.

Conclusions of the comprehensive study

The comprehensive study shows that CHP production is robust. It appears in all studied scenarios. However, fuel and size differs between the scenarios. This is discussed further in the chapter "component and subsystem analysis". The introduction of CHP production is well in line with the goal to increase energy efficiency.

In order to fully appreciate the effect of increased energy efficiency it is necessary to broaden the system boundaries and include the production of electricity, which is "imported" to Göteborg. Since increased CHP production (with high efficiency) leads to reduced electricity production in fossil fuelled condensing plants (with low efficiency), the suggested development leads to more efficient use of limited resources.

The conversion from electrical heating and oil-fired heating to district heating in parts of the single family houses also contributes to improved overall energy efficiency. This is most obvious in the scenarios with high electricity price, since this improves the competitiveness of district heating, both through more expensive electrical heating and through more competitive CHP production.

The introduction of CHP is also positive from an environmental point of view, basically for the same reasons as discussed above. All scenarios meet the emission goals if the effect on electricity production outside Göteborg is taken into account. If only the emissions within Göteborg are included, scenarios with a large CHP production would be in conflict with this goal.

Reliability is also improved since new production plants are introduced. The goal of keeping competitive energy costs is met, since the optimisations are made with the goal of minimising costs. This means that given any set of prerequisites, the scenarios show the solution with the minimum costs.

5.4.5.2 Component and subsystem analysis

In this section we present a few examples from the complete set of results. We concentrate here on two issues: CHP production in the district heating system and efficient use of energy in housing and commercial buildings.

CHP production

The development of district heating production is shown in figure 5.4-8. In the base scenario there is a large amount of natural gas fired CHP production introduced (with a high electricity to heat ratio). The capacity of the plant is 350 MW electricity. There is also an increased demand for district heating. The price of the district heating production drops, since more and more heat will come from the waste heat of CHP production. This makes district heating competitive.

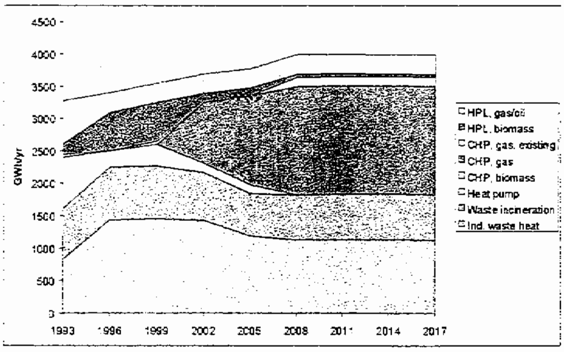


Figure 5.4-8: *District heating production, base scenario*

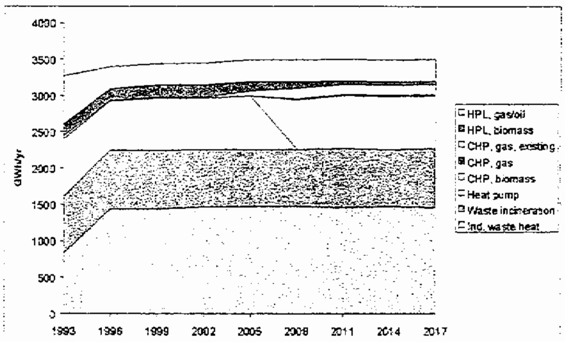


Figure 5.4-9: *District heating production, low electricity price scenario*

However, if constant electricity prices are assumed (low electricity price scenario) the development of district heating is significantly different. First of all there is no introduction of natural gas fired CHP production. Instead, the existing heat pump is used for the rest of its assumed lifetime. When this has to be replaced, a biomass fired CHP plant (with low electricity to heat ratio) is preferred. The capacity of this plant is only 50 MW electricity. Other differences compared to the base scenario are that the total district heating is more or less constant, and that there is no decrease is the use of refinery waste heat.

The results presented above are calculated by means of the same optimizing model which has been used for the comprehensive analysis. This means that the calculation not only will show the production mix, but also the total demand for district heating in each scenario. Since this model lacks detail with respect to the description of production plants, load curve, etc., it was natural to make alternative calculations using another tool; the MARTES model.

Results from this detailed simulation model are shown in figures 5.4-10, base scenario, and 5.4-11, low electricity price scenario. The results concern the year 2005. If these results are compared to the results from the MARKAL model, then the major trends are similar.

A CHP plant of the same magnitude is introduced in the base scenario, while the heat pump is still used in the low electricity price scenario. The use of industrial waste heat is also greater in the low electricity price scenario.

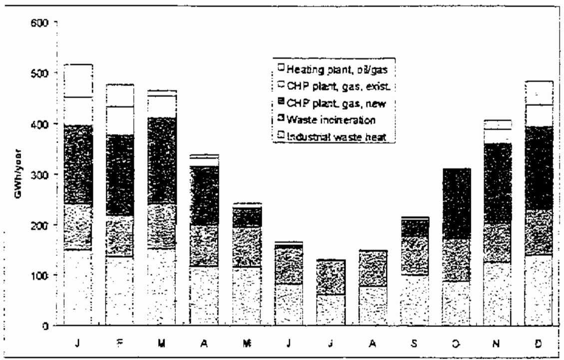


Figure 5.4-10: *District heating production, base scenario*

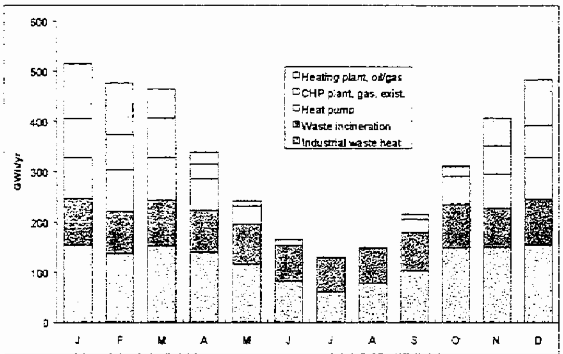


Figure 5.4-11: *District heating production, low electricity price scenario*

There are, however, also differences between the results from the MARKAL model and from the MARTES model. This is only natural since two completely different models have been used. After analysis it is possible to understand the differences and to suggest adjustments to both models. Through iterations it is then possible to gradually decrease the differences and find a more reliable solution.

Conclusions of the CHP study

Although all scenarios indicate that CHP will be competitive, there are important uncertainties. The most important uncertainty is the electricity price. Other uncertainties are:

- the natural gas price
- sources for natural gas (today only one source)

- taxes

The conclusion is that CHP looks favourable, but the uncertainties must be reduced. Further investigations are therefore recommended.

Efficient use of energy in housing and commercial buildings

One important aspect of efficient energy use in housing and commercial buildings is the technical and economic potential. This has been analysed in one of the detailed studies of the Energy Plan 2000. In this study a large number of energy saving measures were identified. For each of these measures important data was collected and calculated, e.g.:

- specific energy saving
- investment cost
- life
- O&M costs
- percent of buildings where it could be introduced
- percent of buildings where it has already been introduced

By using knowledge about the number of dwellings in single family and multi-family houses and the number of square metres of commercial buildings, it is then possible to calculate the technical potential for each measure.

Depending on the cost of the avoided energy supply it is also possible to calculate the economic potential, using different levels of profitability. The calculations were made both by using tariffs and marginal costs. This corresponds to different perspectives in the evaluation.

In addition to the technical and economic potential, the emission consequences of different energy savings levels were calculated. Sulphur, nitrogen oxides and carbon dioxide were considered.

The study shows that if a 5 % real interest rate is used, the profitable energy savings for heating of residential and commercial buildings amounts to 400 GWh/year, while the profitable energy savings for electricity use in appliances amounts to 700 GWh/year.

Conclusions of the efficient use of energy study

Although a significant potential for energy savings has been identified it is important to realize that the municipality and Göteborg Energi AB can only control a small part of the affected buildings. In these buildings a good example should be set. Since efficient use of energy is an important goal of the energy plan Göteborg Energi AB should also continue their efforts to spread information to other house owners within the community. They should also try to include this aspect in their business relations with customers.

5.4.5.3 The action plan

This section includes the most important conclusions from the analysis of the comprehensive and subsystem studies. It also comprises parts of the action plan, including which organisation is responsible for the realisation of each of the specific goals discussed above. For each of these responsibilities the economic consequences are discussed briefly in the action plan.

It has not been possible to include all analyses and results from local energy planning in Göteborg in this paper. Therefore a number of items in the following action plan are presented here without the analyses that make up the foundation for the specific action. Such analyses are however available in the complete energy plan.

Production and Distribution Systems

A natural gas-fired combined cycle plant in Göteborg could provide up to 50 % of the electricity and district heating system needs. However, existing price and taxes on natural gas, in comparison to those on electricity, limit the implementation of the combined cycle plant option at present. Nevertheless, other opportunities utilising smaller combined cycle generators in conjunction with electric and district heating customers are also being studied.

Continue the preparations and planning for a new CHP plant. *Responsible: Göteborg Energi AB*

The waste incineration plant, operated by GRAAB, will supplement its existing electric generator with a second generating unit, doubling its electric generating capacity to more than 20 MW.

Optimally utilise the power production possibilities at the waste incineration plant. *Responsibility: GRAAB*

When possible, private (or municipally owned) district heating systems not connected to the main district heating system will be integrated. Furthermore, efforts will continue to improve the efficiency of existing production plants, heat exchangers and piping systems.

Continue to study possibilities of expanding the main district heating system. *Responsible: Göteborg Energi AB*

Reducing Emissions

The City of Göteborg and Göteborg Energi AB are front-runners in the use of low emission fuels, low emission combustion technology, and flue gas cleaning technology. National and local environmental regulations are strict enough to meet more stringent requirements in the future. Use of low sulphur fuel oil will be encouraged, and natural gas use will increase.

Develop flue gas cleaning technologies further. Investigate N_2O emissions from energy production plants. *Responsible: Göteborg Energi AB.*
Apply emission standard for new wood fired boilers in residential areas. *Responsible: The consumer board*

To address the CFC issue, increasingly stringent regulations and controls in its distribution and use are being implemented. Göteborg Energi AB is in the process of changing the refrigerant used in its large heat pumps to a less harmful HCFC. Furthermore, a study is underway within Göteborg Energi to introduce waste heat absorption cooling machines to replace existing CFC based cooling equipment within buildings in areas served by the district heating system. Waste heat absorption chillers would improve the utilisation of the district heating system in the summer months.

Change from CFC to refrigerants which are less harmful to the ozone layer. Use environmental friendly cooling production. *Responsible: Göteborg Energi AB*

The transportation sector is one of the largest single sources of emissions, especially nitrogen oxides. The City of Göteborg is supporting a number of demonstration projects aimed at reducing emissions from this source. These demonstration projects include using natural gas and electric vehicles in a variety of roles. The requisite infrastructure needs are also being addressed. Additional projects are underway to further improve existing gasoline and diesel engines.

Demand that only vehicles of a certain environmental standard be used in the central part of the city. *Responsible: The transportation board*
Apply environmental standards when buying transportation services. *Responsible: All concerned committees and boards*

Renewable Energy Resources

Biomass fuels are of increasing interest in Sweden. The Energy Plan addresses the need to implement a study to determine the extent that biomass can be integrated into Göteborg's energy production and supply systems. For example, a biomass central heating plant in the district heating system supports the goal of maintaining carbon dioxide emissions at their 1991 levels. The study must however, address the supply availability of this fuel source, as well as the impact of the added transportation requirements to bring the fuel into the area.

Study the possibility of using biomass as fuel in existing coal fired heating plants. *Responsible: Göteborg Energi AB*

Energy production at the waste incineration plant could be increased through the use of construction waste and waste from forestry. The sewage treatment plant produces a large quantity of sludge, which is presently transported to a land fill. A study is planned to determine the economics of extracting the methane gas from the sludge and using it in vehicles, central heating plant production or both.

Expand the existing waste incineration plant. *Responsible: GRAAB*
Utilise the available methane gas from the sewage treatment plant. *Responsible: GRAAB, GRYAB, the transportation board*

Göteborg has several medium-sized wind power plants, which to date have been technically successful. Based on the level of acceptance by the private investors in these projects, it also appears to be economically successful. However, limited land area within Göteborg prohibits large-scale utilisation of this technology.

Participate in the building of further wind energy plants. *Responsible: Göteborg Energi AB, the building committee*

Energy Conservation

It is important that Göteborg utilise the potential of energy conservation to its fullest extent. This section describes development planning on a regional basis that encompasses energy efficiency as another infrastructure consideration, efforts in establishing building standards with expanded emphasis on energy efficiency, and planned activities in both the public and private sectors.

An issue addressed in the energy conservation section of The Energy Plan is community development planning. Göteborg is a city with dispersed population centres. City planning should focus on concentrating population centres to better utilise the present infrastructures. Planning should also consider energy efficiency as another infrastructure requirement. This dictates that energy efficiency planning be carried out from a regional perspective. Additionally, local climate conditions should be considered when planning and orienting buildings.
The physical planning of the citiy should facilitate good public transport and give priority to areas which could be supplied by district heating or natural gas. *Responsible: The building committee*

As the largest landlord in Göteborg, the City's various property management agencies should set an example as to how to become more efficient in the institutional, commercial, retail and residential use of energy. The Energy Plan recommends that these organisations set a goal that leads to reducing their overall electric and heating energy use by two percent per year through the year 2000. The responsible bodies are to prepare a task plan indicating how they propose achieving their goals, and report the results annually.

Create task plans for more efficient use of energy. Increased investments in energy conservation measures. Yearly evaluation of energy conservation results. *Responsible: The property management agencies*

Göteborg Energi must report to the City Council how much electricity, natural gas and district heating it delivers annually. This reporting is segregated by customer categories.

Evaluation of how the use of energy develops. *Responsible: Göteborg Energi AB*

The best time to influence the property owner is during initial planning for construction or when the building is being renovated. The Energy Plan addresses this issue with a test project that is to be implemented with the planning commission. The objective is to determine the effectiveness of establishing a small information and advisory centre specifically for developers, builders, consultants and contractors.

Create a special information and advisory centre for developers, builders, consultants and contractors. *Responsible: Göteborg Energi AB*

Research and Development

Göteborg Energi's Board of Directors has authorised the Company to invest a budgeted amount of money in various research and development projects. These funds are targeted for energy related endeavours. Göteborg Energi has the support of NUTEK as well as Chalmers Technical University in these efforts.

Cheaper systems for connecting single family houses to district heating.
Responsible: Göteborg Energi AB

Research and development efforts.
Responsible: Göteborg Energi AB

5.4.6 Information exchange between the involved groups

The plan was developed by "the Energy Group", consisting of selected representatives from the different municipal agencies, commissions and the energy utility Göteborg Energi AB. (The institutional setup of the energy planning task is described in greater detail in chapters 2 and 3.) This project group organisation facilitates the involvement and committment of all parties in the development of the plan. If there were different opinions in specific matters, these were settled at an early stage of the process through discussions and "second opinions" from external experts in the reference panel. This may have slowed the preparation of the plan somewhat. However, the positive result of this process was that when the plan was ready it was supported by all parties. This is, of course, very valuable.

5.4.7 Evaluation and case study conclusions

Advanced local energy planning has a long tradition in Göteborg. One would have to go back 15 years to find an energy planning situation which is not characterized as advanced, e.g. without the use of comprehensive computer models. Therefore ALEP was not something new in the Energy Plan 2000.

Examples of the advanced aspect of local energy planning in this plan are computer model based scenarios for the long-term development of the energy system, and analysis of the competitiveness of district heating and natural gas for single family houses coupled to district heating production. At least four different computer models were used in the energy planning process.

The energy plan was never formally implemented by the local government. The reason was not that the politicians had doubts with respect to the content of the plan. There was a more indirect reason for the lack of political decision. The local government in Göteborg decided in 1994 that there should be no sector plans. Plans like the energy plan should instead be incorporated as a guideline in the budget process of the municipality and in the municipal companies´ operations. This was done to a great extent, which is shown by the following evaluation of the present status of the different items in the action plan.

Com-pleted	
	Production and Distribution Systems
X	A natural gas-fired combined cycle plant Continue the preparations and planning for a new CHP plant. Responsible: Göteborg Energi AB
X	The waste incineration plant - electric capacity more than 20 MW. Utilise the power production possibilities at the waste incineration plant optimally. Responsibility: GRAAB
X	Integrate heating systems not connected to the main D.H. system: Continue the expansion of the main district heating system. Responsible: Göteborg Energi AB
	Reducing Emissions
X	Investigate N_2O emissions from energy production plants. Responsible: Göteborg Energi AB
o	Apply emissions standards for new wood fired boilers in residential areas. Responsible: The consumer board
X	Change from CFCS to refrigerants which are less harmful to the ozone layer. Use environmentally friendly cooling production. Responsible: Göteborg Energi AB
x	The transportations sector: Demand that only vehicles meeting a certain environmental standard be used in the central part of the city. Responsible: The transportation board
X	Apply environmental standards when buying transportation services. Responsible: All concerned committees and boards
	Renewable Energy Resources
X	Study the possibility of using biomass as fuel in existing coal fired heating plants. Responsible: Göteborg Energi AB
X	Energy production at the waste incineration plant: Expand the existing waste incineration plant. Responsible: GRAAB
X	Utilise the available methane gas from the sewage treatment plant. Responsible: GRAAB, GRYAB, the transportation board
X	Göteborg has several medium-sized wind power plants: Participate in the building of further wind energy plants. Responsible: Göteborg Energi AB, the building committee
	Energy Conservation
x	Reducing the overall electric and heating energy use by 2%: Create task plans. Increase investments. Yearly evaluation. Responsible: The property management agencies
X	Göteborg Energi must report to the City Council: Evaluation of how the use of energy develops. Responsible: Göteborg Energi AB
X	Create an information and advisory center for developers, builders, consultants and contractors. Responsible: Göteborg Energi AB
	Research and Development
X	Cheaper systems for connecting single family houses to D.H. Responsible: Göteborg Energi AB
X	Research & development efforts. Responsible: Göteborg Energi AB

***X**=completed, x=started, o=not started*

5.4.8 *"Göteborg Energy System"* A scenario analysis with a 50 years perspective: the latest energy planning phase in Göteborg

In the following we briefly present the most recent developments in the field of advanced energy planning in Göteborg. This planning focuses on the long-term development of the energy system. Although the focus of the study is on the development over a 50 year perspective, the goal is to use the analyses as a basis for decision-making in the short term. This work is the latest step in the ongoing process of energy planning in Göteborg.

We have included this work as an appendix to the previous energy plan presented in the main report. The reason for choosing to present the previous plan, which by now is a couple of years old, as the Göteborg case study is that it is more typical for advanced energy planning and it includes all parts which characterize advanced local energy planning. The latest plan is interesting and has been very useful, but the long-term perspective makes it less suitable as an example of a typical Swedish advanced local energy planning project.

Short project specification

This document summaries the results of the project "Göteborg Energy Systems". Its purpose was:

A strategic analysis with the objective of finding actions that can realise the objectives of Göteborg Energi AB and the Municipality of Göteborg at the right time and through the right measures. The emphasis is to provide a basis for decision-making that is well suited to the decision-making process and functions as a complement to conventional energy planning.

The project was implemented as a broad scenario analysis with focus on three different societal trends (scenarios), which are described in detail below.

The Göteborg energy system and its long- and short-term development was analysed from three perspectives.

(1) Resource economy and the environment
(2) The future Göteborg technical energy system in light of new external factors.
(3) The energy markets

These sections naturally overlap and their interaction was required, which was an important aspect of this project.

The analysis methods in the project were both manual and computer-based. In a forecast study of this nature (until 2050), the most important source was the experience of all those taking part in the project groups and discussions. The calculations using the various computer-based analysis models however served as an important complement to obtain consistency of results. Here, the MARKAL model was frequently employed.

Presentation of the three scenarios

Three scenarios were studied, defined by a number of assumptions describing the context of the energy system whose development in these three scenarios becomes a result of the analysis. The scenarios have been chosen so that they reflect three entirely different development routes. None of them are designated as the basic case and no position is taken with regard to the probability of the various outcomes.

Large-scale and political control
distinguishes the first scenario. Powerful politicians are in control in Sweden and elsewhere. The environmental issues are judged important enough to include as goals. The means of control are mainly the taxes and regulations

imposed on an energy system that resembles today's large-scale one. The energy needs of end-users are of the same order of magnitude as today. Electricity prices are at a higher level than today, while at the same time taxes reward effective solutions, which means that co-generation becomes extremely competitive. This also makes expansion of district heating profitable. Initially natural gas becomes a very important fuel and, in line with more stringent environmental requirements (or rising taxes), more and more biomass enters the fuel mix. The transport sector continues to grow, and more efficient vehicles means that energy needs still remain at current levels. Petrol and diesel continue to be used to a major extent. Vehicle fuel alcohol produced in Göteborg from biomass is also introduced in line with stricter emission limits. The degree of refuse incineration is somewhat greater than today and the electric power yield is higher.

- Controlled by powerful politicians
- Large-scale solutions
- Environmental issues important
- Normal yield requirements
- Electricity prices: up to 0,4 SEK/kWh
- Demands as in the present
- District heating, not de-regulated

Short-term and profit maximisation
can characterise the second scenario. The politicians had increasing power over the market actors. District heating is deregulated and there is competition on the production side. Profit maximisation becomes dominant and no political measures are taken to reduce carbon dioxide emissions. This may be because they prove no serious threat or because the threat is real, but the costs of limiting these emissions are too high for international agreements to be reached. The availability of fossil fuels remains high and taxes are lower than today after Sweden adapts to international levels. Electricity prices rise only slowly and energy needs continue to grow, if only at a moderate pace. Despite low electricity prices, certain combined heat and power systems are profitable, although high yield requirements mean that further district heating expansion is unprofitable. The development of alternative energy technology stagnates. The transport sector grows and al-though vehicles becomes somewhat more economical with fuel, energy needs increase. The trade in waste-based fuel grows and there is a considerable expansion of refuse incineration in Göteborg.

- The markets are in control
- Short-term solutions
- Environmental issues less important
- High yield requirements
- Electricity prices: 0,2 SEK/kWh
- Higher energy demands
- Deregulated district heating

Low-energy and small-scale
are key words in the third scenario, in which the greenhouse effect and the earth's shrinking supplies of finite resources lead to widespread awareness that the entire development of society must change. There has always been a trend towards the small scale. Energy prices are considerably higher and our dwellings have become smaller, while we demand less energy. Combined heat and power has become profitable, but since demand for district heating has dropped, there is no heat base for especially large electricity generation. The very high energy prices stimulate technical development in the energy field and in time alternative technologies become competitive. Initially, natural gas is used for combined heat and power production, but the amount drops in line with stricter emission limits and is thus replaced by bio-fuels. The transport sector shrinks as vehicles become more efficient and travel is reduced. Petrol and diesel are replaced to some extent by alcohol produced from biomass in Göteborg. At the same time, one of the present refineries disappears, although the quantities of waste heat for district heating remain unchanged. Resource economy also leads to a decrease of refuse incineration.

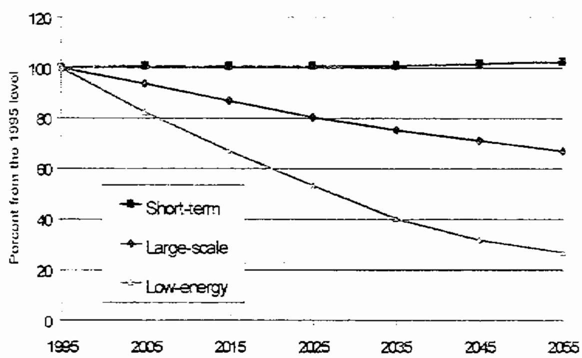
- Resource economy as the guiding principle for all actors
- Long-term solutions
- Small-scale gets priority
- Low yield requirements
- Electricity prices: up to 0,6 SEK/kWh
- Lower energy demands
- District heating, not de-regulated

Results

CO_2 emission can be cut drastically

None of the scenarios show any significant increase in carbon dioxide emissions, although many believe that considerable cuts are needed in total emissions in order to stop the greenhouse effect. In the large-scale scenario, emissions are cut by 35% by 2050. Hence, a one-third cut in emissions can be achieved, while increasing energy use at the same time.

In the low-energy scenario, the reduction is no less than 75%. Reaching such low levels, however, requires a far-reaching change of the entire society in the direction of considerably lower energy demand, in which case, improvements to the energy supply system are not sufficient.



Carbon dioxide emissions do not increase in any of the scenarios. The figure covers all the emissions generated by Göteborg inhabitants.

Commitment to all markets
- district heating, gas, electricity & motor fuels

It is vital for Göteborg Energi to make a wider and deliberate commitment to all three of its line-energy markets: district heating, gas and electricity.

The scenario analysis clearly demonstrates the importance of investment in district heating, for two reasons. Preparation for combined heat and power production (CHP) and/or for a possible deregulation. While the utility is capturing larger market shares on the demand side, it should also consolidate its position on the supply side right away.

Irrespective of the wider trend, natural gas will be an important fuel for Göteborg Energy System. This may involve larger direct deliveries to customers, more gas for combined heat and power production or as a motor fuel. If bio-gas is added in the long run, then the distribution network, facilities and customer relations will all prove very valuable.

Today, the commitment to the electricity market is intensive, which is not contradicted by anything stated in this scenario review.

District heating and natural gas are a safe investment
The scenario analysis does not point to any actual threat to district heating as a system. In two of the three scenarios, district heating instead captures larger market shares and becomes the predominant heating alternative on all municipal markets.

By contrast, possible deregulation of the district-heating market must be seen as a threat to Göteborg Energi as an actor in the energy market. However, this threat can be effectively countered by the company consolidating its position, in both supply and demand. The overall conclusion of the scenario analysis is thus that the company should retain or increase its district-heating commitment, irrespective of the trend.

Natural gas use will increase in all scenarios, even in the one with strict resource economy. Hence, it must be considered an important investment in the coming decades.

Energy efficiency and conservation
The scenario analysis shows clearly the environmental value of energy efficiency and resource management. Without the energy conservation measures taken in the low-energy scenario, in combination with the forced technical developments in supply technologies, it is not possible to achieve the major cuts in emissions foreseen in this scenario.

District heating is right, even in the small-scale society
The reduced energy needs in the low-energy scenario make it more expensive to expand district heating as the investment is spread over fewer kilowatt hours. Despite this, district heating gains market shares from other heating alternatives, even the small-scale ones being developed for the low-energy society.

The reason is that the very high profitability of CHP, which is built on a large scale, ensures low production costs for district heating. The driving force behind CHP is the rapidly escalating electricity prices in the scenario. Hence, the conclusion is that a Göteborg district heating system is a long-term solution, even in a society characterised by a strict resource economy.

Biomass for production of motor fuels, electricity and heating
Two of the three scenarios indicate profitability in twenty to thirty years for bio-fuel based on simultaneous production of electricity, alcohol for motor fuel and heating, in a plant fired with wood chips.

At least two important conclusions can be drawn from these results:
- Unprocessed bio-fuels are transported to Göteborg for processing there, because of the major value found in the town's heat sink.
- The motor fuels market may in the long run be more interesting for investment for Göteborg Energi. Today's alternatives of natural gas and electricity may then be supplemented by biologically based motor fuels.

"Tomorrow's energy technologies"

The scenario analyses provides several results relating to the competitiveness of the energy technologies in the various scenarios. For certain areas, previous sections have shown similar results, e.g., for district heating production. This section discusses other scenario results, technology by technology.

Wind power
Wind power is an electricity generation technology that currently enjoys relatively high profitability, largely through government support. However, within the Municipality of Göteborg, it is judged problematic to locate large amounts of wind power. There, a maximum potential of over 100 GWh/year has been determined, of which the greater part is maritime-based. (Current wind power generation amounts to around 10 GWh/year). Wind power is attractive for expansion in two of the scenarios: large scale and low energy.

Small-scale co-generation
All scenarios point to an expansion of co-generation in the district heating system although the magnitude and timing vary considerably. Small-scale co-generation, by contrast, does not make any noticeable breakthrough and is defined in everything from a few kW to a few MW. Small-scale co-generation in the latter category could be profitable in a neighbourhood heating system outside the major district heating system. However, in the municipality, further expansion of district heating, even to the outer areas with their private homes, is more effective. Really small-scale co-generation, house by house, has also not proven to be competitive.

District heating for private houses
This is thus competitive in the large-scale and low-energy scenarios, and even in private houses in the low-energy scenario, despite the low heating needs. The reason is the wide availability of waste heat, in combination with the low yield requirements that characterise the scenario. By contrast, in the short-term scenario, the high yield requirements lead to the avoidance of alternatives needing heavy investment, and thus the district heating of private homes cannot compete. Here too, there is no environmental impetus increase CHP production.

More electricity in refuse incineration
The role of refuse incineration is relatively large in all scenarios, and is largest in the short-term scenario and smallest in the low-energy one. With its current configuration, it has a relatively small electricity generation in relation to heat production. However, it is feasible to consider refuse-fuelled co-generation with a greater electricity yield, especially if the refuse is combined with other fuels of higher quality. This becomes especially attractive in scenarios with emission limits that favour municipal electricity generation. However, this issue has not been analysed in detail within the framework of this project.

Bio-fuelled combined plant
In the long-term, bio-fuel is attractive in the scenarios with limits on total carbon dioxide emissions. Here, the bio-fuels are used for integrated production of electricity, district heating and motor fuel (alcohol). The bio-

fuelled combined plant has the advantage of highly efficient utilisation of the bio-fuel and, as a result, a reduction in the use of oil products within the transport sector is possible. Alternative motor fuels can also be produced outside the municipality, closer to the biomass supply, but the disadvantage here is that in the open countryside it is difficult to make use of the waste heat from the process.

Solar cells
Solar cells have the ability to convert sunlight into electricity, which makes this technology a highly attractive solution in scenarios with emission limits. Currently, electricity from solar cells is very expensive, but it has been assumed that the investment costs will fall as total world production increases. Based on these assumptions, an introduction of solar cells has been included in the low-energy scenario. This begins around 2020 and then this type of electricity generation rapidly assumes considerable size. Since the conditions for solar cells are poor in Sweden, it is probable that solar electricity will be generated at more favourable sites in the international electricity supply system. Even in the large-scale scenario solar cells are introduced, but first in fifty years. In the short-term scenario they are not included.

Alternative motor fuels
These may become important in order to reduce the use of oil products in the transport sector, which is evident in those cases where carbon dioxide emissions are limited. The competitiveness of biomass-based vehicle fuels has already been discussed, and there are also other alternative fuels that have only been touched on. Natural gas is already available and has, even if it is a fossil fuel, lower emissions than oil products. Biogas, e.g., from digestion, is another alternative that further reduces carbon dioxide emissions. Electric cars increase municipal electricity needs and, as a marginal note, consume electricity generated in condensing power plants fired with fossil fuels. Despite this, they are environmentally positive, since the electric motor is efficient and emission controls in large power plants can be considerably more efficient than in individual vehicles.

Fuel cells
These have the potential of achieving high levels of efficiency in converting fuel to electricity and a variety of applications can be envisaged, but a common feature is the mainly small-scale use. Fuels could, e.g., be used for vehicle operation, as well as for small-scale co-generation. However, the scenario analysis shows that small-scale co-generation is not competitive in Göteborg, which rules out fuel cells. However, fuel cells can very well be placed in vehicles, especially in the low-energy scenario which assumes global co-operation on resource economy.

Biogas for electricity generation
Biogas, i.e., gas produced from renewable biological raw materials, could prove a valuable supplement, as both a motor fuel and a fuel for combined heat and power production, since electricity generation from gas gives a high electricity yield. Biogas produced elsewhere for use in a co-generation plant in Göteborg seems, however, for reasons of efficiency, a poorer alternative than using the bio-fuel directly in the co-generation plant. If biogas production is sited outside of the major cities, it will in fact be difficult to find a market for the waste heat that is generated by gasification, which therefore makes it more profitable to transport the bio-fuel to the cities.

Energy efficiency
The widest introduction of increased energy efficiency takes place in the low-energy scenario, although the other two contain a commitment to raising energy efficiency to at least as great an extent as is currently being done. This means that the scenario analysis considers that raising energy efficiency will also be important in the future.

5.5 Mannheim Energy Plan – a Comparison with Conventional LEP Results

5.5.1 Background

The main purpose of the Mannheim case study is to analyze and possibly verify the existing local energy plan for the city of Mannheim with a comprehensive computer model. This existing local energy plan was developed during the 80ies by MVV Energie AG, the municipal utility, using traditional means. The intention was to learn about new planning approaches and their capabilities in a practical application. Since MVV Energie AG has its own consulting department which supports internal departments and external contractors in the fields of energy planning (power plants, incineration plants, district heating, etc.), it was also of interest to MVV if this tool was usable in this context. During the course of the project, additional questions on the effects of market liberalization on MVV arose and were treated by the working group.

Mannheim is a highly industrialised city of 320,000 inhabitants in the Rhine valley south of Frankfurt. More than 80 % of its low temperature heating demand ist supplied today by either district heating or natural gas. Whereas gas supply – with „city gas", produced as a by-product of coke production – already has 100 years tradition in Mannheim, serving primarily stoves and street lighting, district heating was first developed during the 60ies as a result of the newly installed „Großkraftwerk Mannheim", a very large combined heat and power plant driven with hard coal. This power plant consists of several blocks providing a maximum of 2,125 MW of electrical power and a base load of 465 MW of thermal power at 120 °C for the district heating network of Mannheim and Heidelberg. MVV owns 28 % of this plant. The maximum thermal output during winter results in a reduction of electric output of 73 MW or 0,16 kWh_{el}/kWh_{th}. This is a very good output for conventional coal power plants, which makes district heating so attractive as an energy saving technology.

MVV operates an additional CHP-plant for the production of industrial process steam (20 MW_{th}) and smaller cogeneration plants located at customer sites. In addition, a large incineration plant of 55 MW_{el} and 215 MW_{th} is also operated by MVV. The total thermal peak load of district heating served by MVV was 776 MW_{th} in 1995/96.

5.5.2 Organisation of the case study

(1) Stake holders

The initiator of the case study for MVV was the company's chief executive officer, who was interested in strategic questions on the development potential of MVV Energie. He instructed an internal working group to follow the case study and to provide all data that are necessary to model the local energy system within MARKAL. This working group consisted of the heads of the departments of planning and of marketing, and their co-workers, as well as MVV's consulting group. This „reference group" was to be addressed by the working group with questions on data procurement and scenario definition. Intermediate and final results of the work were to be reported to this group.

MVV Energie AG is the local energy utility of Mannheim, providing electricity, district heating and natural gas. It is 100 % owned by the City of Mannheim. There are attempts to develop an individual energy policy within the municipal administration, e.g. municipal support programs fostering solar energy or energy conservation in buildings. The main direction of the municipal energy policy, however, is traditionally dominated by the utility. In particular, local energy planning has always been considered to be the responsibilty of the utility only, influenced by the municipal government via the control board of the company and the lord mayor of Mannheim. Therefore, a coupling of the project work to other bodies outside MVV was not considered to be necessary.

(2) Project management and involved working team

Two employees of MVV were appointed with internal project management and co-operation with external consultants from IC Consult, Aachen and profu AB, Gothenburg (MARKAL modelling) and University of Stuttgart / IER (demand simulation model, model interfaces). MARKAL was used by IC Consult and by MVV as well. Both had to start with work on MARKAL „from scratch", after instruction by profu AB. The outcome of the work was regularly discussed with the other participating working groups of Annex 33. The structure of the project is shown by the following diagram (fig. 5.5-1).

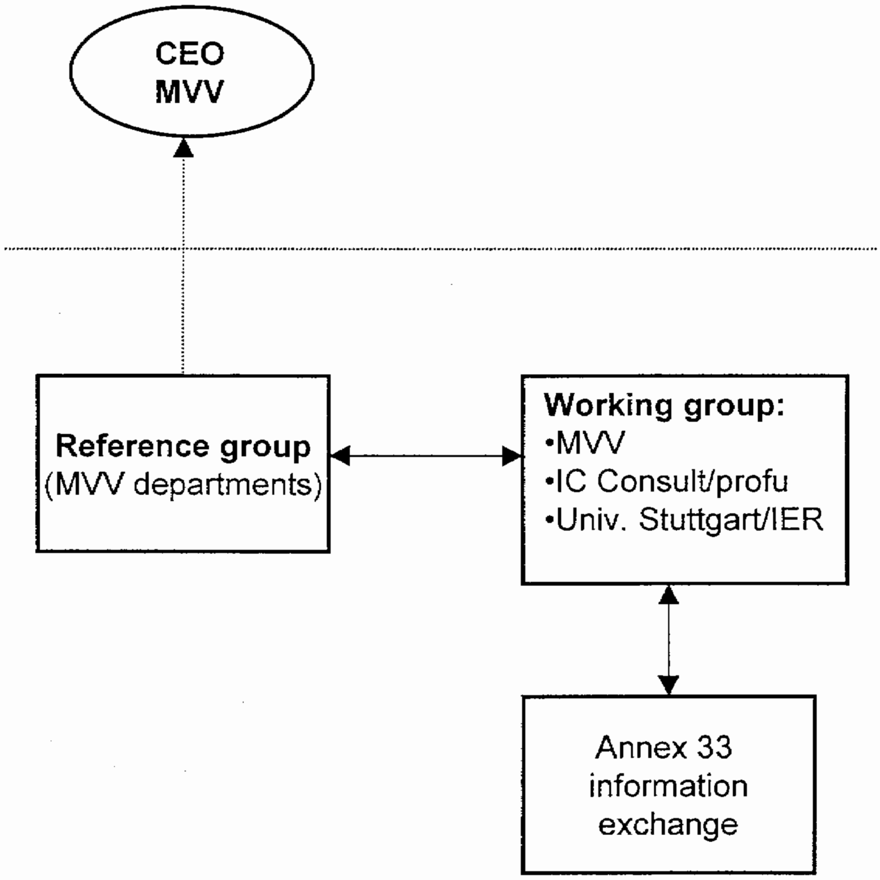


Fig. 5.5-1: Structure and working relations of Subtask 5.3, Case Study Mannheim

(3) Work Plan

Step	Item	Responsibility		
		MVV	IC Consult-/Profu	IER
1	Data definition and collection	x	x	
2	Definition of system of goals and scenarios	x	x	
3	data input for Markal		x	
4	Set-up of a demand model			x
5	simulation and iterative optimization runs of model	x	x	x
6	Evaluation and result representation to reference group	x	x	x
7	Documentation and final report	x	x	x

Contrary to the guidebook on ALEP, no pre-studies or new organisational set-up were necessary, since this case study was elaborated by a functioning structure within MVV Energie AG in co-operation with external sub-contractors, based on an existing local energy plan of MVV. This situation is not representative of other LEP-projects, since usually different groups of decision-makers, such as the municipal administration, one or more utilities, dwelling companies or environmental groups, are involved in the work throughout the course of the project. This then requires defined project organisation and a continuous adjustment of the work between the different parties involved, as described in Chapter 2. In the Mannheim case study, ALEP was considered as a purely internal project of MVV Energie AG, with results to be put into the company's strategic plan only.

(4) Intended results

The main expectations of MVV for the project were three-fold:

- learn about the practical applicability of existing systems analysis models
- recalculate (and confirm) the existing traditional Local Energy Plan of Mannheim using a comprehensive model
- provide a means for strategic planning which is able to analyze long-term developments of Mannheim's energy system under varying boundary conditions.

5.5.2 System of goals

The main goal of the company is a long-term economic optimisation of the energy supply (electricity, heat, steam, gas) of Mannheim under conditions of market liberalisation. The goal of using coal to a large extent for the local energy supply, which was part of a national „coal policy" for a long time, was substituted recently by the general goal of a sustainable development aimed at reducting energy intensity, a decrease of the emissions of CO_2 and atmospheric pollutants and an increased use of renewable energies. A baseline for the intended targets is the existing national CO_2-reduction target of 25 % in Germany by the year 2005, and the goal of doubling the contribution of renewables within the European Union by 2010. The long-term objective is to find a strategy which primarily achieves the economic goals, and at the same time, also enables the goals of sustainability to be achieved to the largest extent possible.

5.5.3 Calculation and evaluation tools used in the case study

The primary tool for the Mannheim case study was MARKAL, as in all other case studies of Annex 33. In addition, the simulation model PLANET was used to evaluate the development of the demand for heating and tap water in different demand sectors in Mannheim. PLANET is a model which was developed by the University of Stuttgart. It, like MARKAL, works with the structure of a local Reference Energy System (RES) and is coupled with an information system which contains all parameters used in the RES. It is also able to include information from the technology data base IKARUS, which provides actual data of all significant energy technologies which may be used in Mannheim.

The simulation results of PLANET, according to the given scenarios, were fed back into the MARKAL modesl to provide the necessary input on the demand development in Mannheim. An optimisation of energy conservation measures was therefore not explicitly included in the MARKAL models.

The data on customer demand structure was extracted from an internal customer data base of MVV, called WIS. Other internal calculation tools for cogeneration plants and other combined heat and power plants were also used as input sources for the MARKAL-RES, but without coupling them directly. No GIS system for the energy network structure of MVV was available during the project.

Consequently, MARKAL, PLANET and IKARUS were used in the Mannheim case study as ALEP tools without direct coupling of hard or soft interfaces to other LEP tools. The results of the case study may be used as input for other planning tasks, e.g. supply planning of new dwelling areas or the waste management in Mannheim. However, this will be outside the realm of the case study.

5.5.4 Scenarios used for long-term simulation

Due to the business oriented questions that were to be treated by the MARKAL models, the scenarios were defined according to those variables which are of the highest interest in the long run from a business point of view: the development of energy prices, and of the heating and electricity demand and their influence on a cost minimising overall supply system in Mannheim. In addition, according to the supply strategies of the past two decades, the effects of a preference for either district heating or natural gas as a dominate energy source in Mannheim should be considered. Out of these basic questions, the following group of scenarios (fig. 5.5-2) was derived:

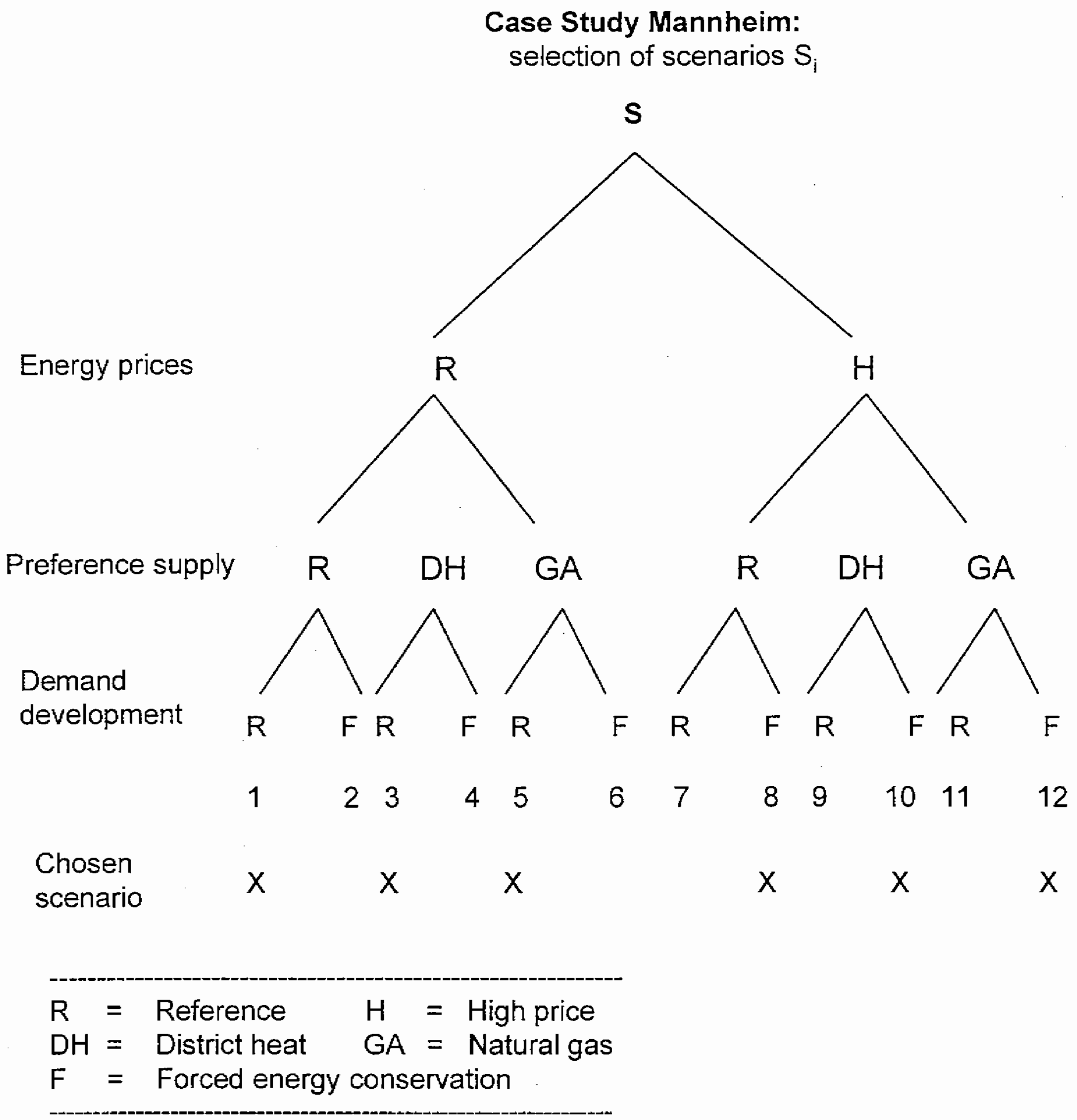


Fig. 5.5-2: Scenario definition: Choosing 6 meaningful scenarios from 12 logically possible scenarios (with 2 different assumptions on energy prices and demand development and 3 different assumptions on the „preference supply")

From the 12 logically possible scenarios, only 6 „meaningful" combinations of boundary conditions were chosen for further investigation.

None of the scenarios include „radical" parameter developments. In particular, the increase of future energy prices was assumed to be very modest. In the reference case, the gas und heating oil prices were estimated to increase about 25 % until 2018, corresponding to a mean annual increase of 1 %. Coal has a price increase of 1,5 % p.a. Electricity prices, however, *decrease* in the medium-term due to market liberalisation and will achieve their initial level in 2018 again.

In the „high-price scenario", the effect of the (very modest) energy tax proposal of the European Commission on energy prices from 1996 has been modelled. This leads to an increase of 2,5 % p.a. for oil and gas (corresponding to a price increase of 65 % in 2018) and an electricity price increase by

2 Pf/kWh for electricity until 2018. (In the meantime, consumer prices of electricity have been increased by 2,5 Pf/kWh already by the introduction of new energy taxes in Germany since 1st April, 1999).

For the heating energy demand, a decrease by 8 % until 2010 in the reference scenario (caused by the normal retrofit rates of existing buildings) and by 17 % in the „forced energy saving" scenario was assumed, according to higher realization rates of economic energy conservation potentials in the building stock. The electricity demand was considered to be more or less constant.

5.5.5 Results of scenario calculations and conclusions

The first question to be answered was the future least-cost development of the system under more or less unchanged boundary conditions (reference scenario). This was also the crucial question from MVV, since if the results of the model under this scenario deviate remarkably from „conventional wisdom", the credibility of the model would be impaired significantly in the eyes of the conventional planners.

The results of this scenario show that, despite the almost constant boundary conditions and the rather constant energy demand in Mannheim over the whole time period, there are some changes in the supply structure. Whereas import remains the dominating source of electricity, it slightly decreases and is substituted by new local cogeneration plants of roughly 75 MW_{el}. They provide some 15 % of the electricity demand in Mannheim. The change is primarily caused by new production plants for the industrial steam grid, which substitute existing gas boilers with a CHP-plant. These changes are explained by the data entered into MARKAL and thus confirm the confidence in the model. The main result of the reference scenario is shown in Fig. 5.5-3. The message is that under constant boundary conditions the existing supply system in Mannheim is already close to its economic optimum and no major changes are expected or recommended.

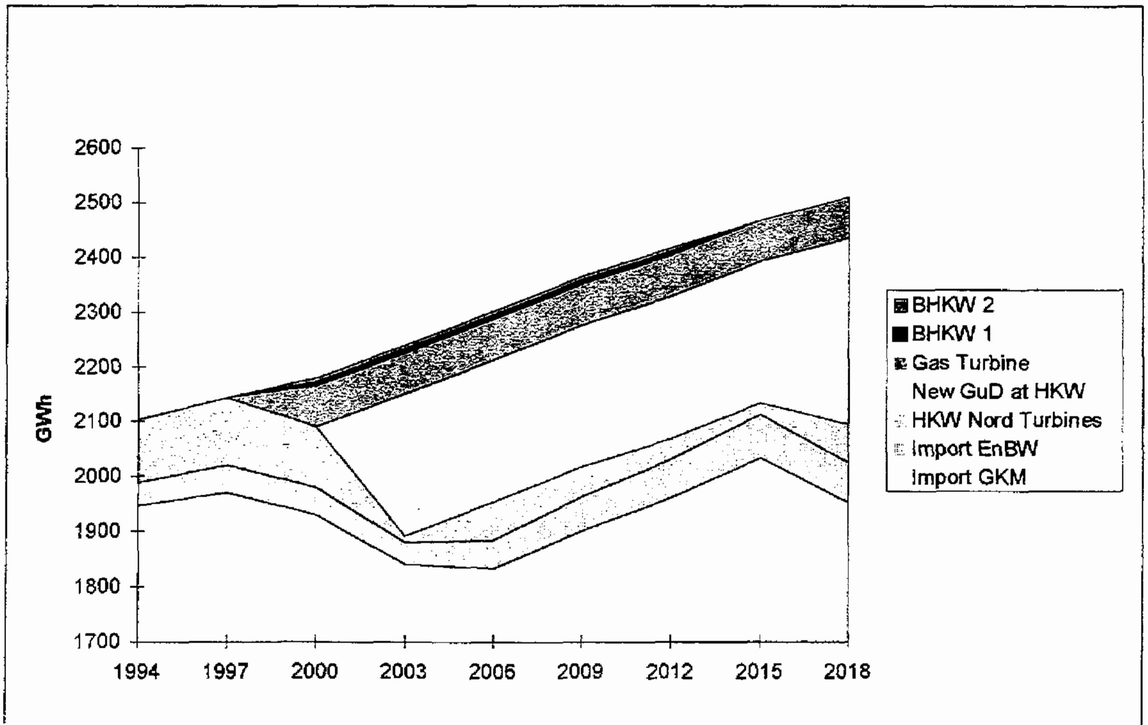


Fig. 5.5-3: Electricity generation in Mannheim according to the reference scenario until 2018

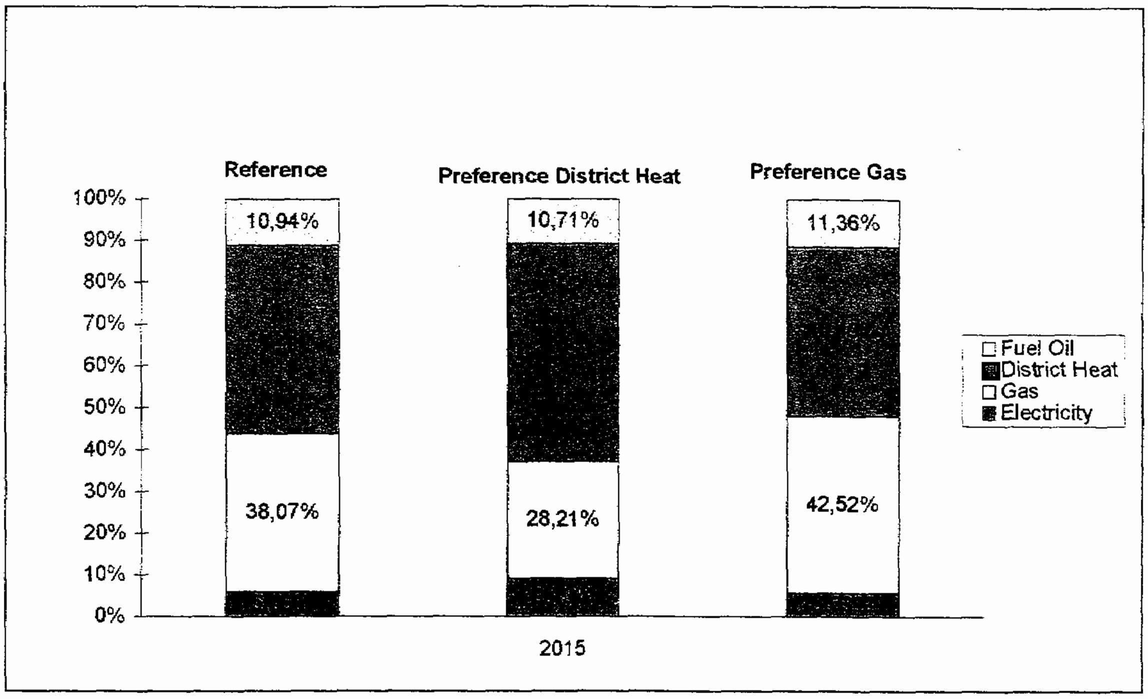


Fig. 5.5-4: Resulting energy carrier structures of the reference scenario and the district-heating and gas supply preference scenarios

A further analysis treated the question of priorisation of either gas supply extension or district heating supply extension in Mannheim. The scenario models display the total system costs for these options and thus provide information on the relative cost-effectiveness of the two options. The result is shown in Fig. 5.5-4.

Despite the quite significant changes in the supply structures of the two scenarios, the resulting total costs differ only by some 0,5 %! Whereas the model reveals some slight economic advantages for a gas strategy, small improvement in the cost structure of district heating would reverse this result. This is a very good example for a case, where the model runs have to be supplemented with a detailed analysis of individual measures, in this case the geographical location of priorisation measures, which cannot be provided by the comprehensive model.

Another very interesting question was the resulting influence of a modest CO_2-tax, according to an existing EU proposal, on energy demand and CO_2-emissions in Mannheim. It was assumed that, as a result, the energy demand for space heating and tap water would drop significantly by almost 10 %. Both district heating and gas supply would be affected equally by this drop. Related to the large proportion of CO_2-emissions from electricity production (43 %), the resulting total reduction of CO_2-emissions would only be 4 % by 2018. Since structural changes in demand will not take place, the conclusion for MVV is that due to decreasing demand, its cost structure should be adjusted, but no structural changes in the supply will be necessary.

MARKAL also includes the marginal costs of the supply system. This allows for an investigation of the development of the marginal costs of electricity supply and a judgement of the future competitiveness of MVV under market conditions. This is shown in fig. 5.5-5.

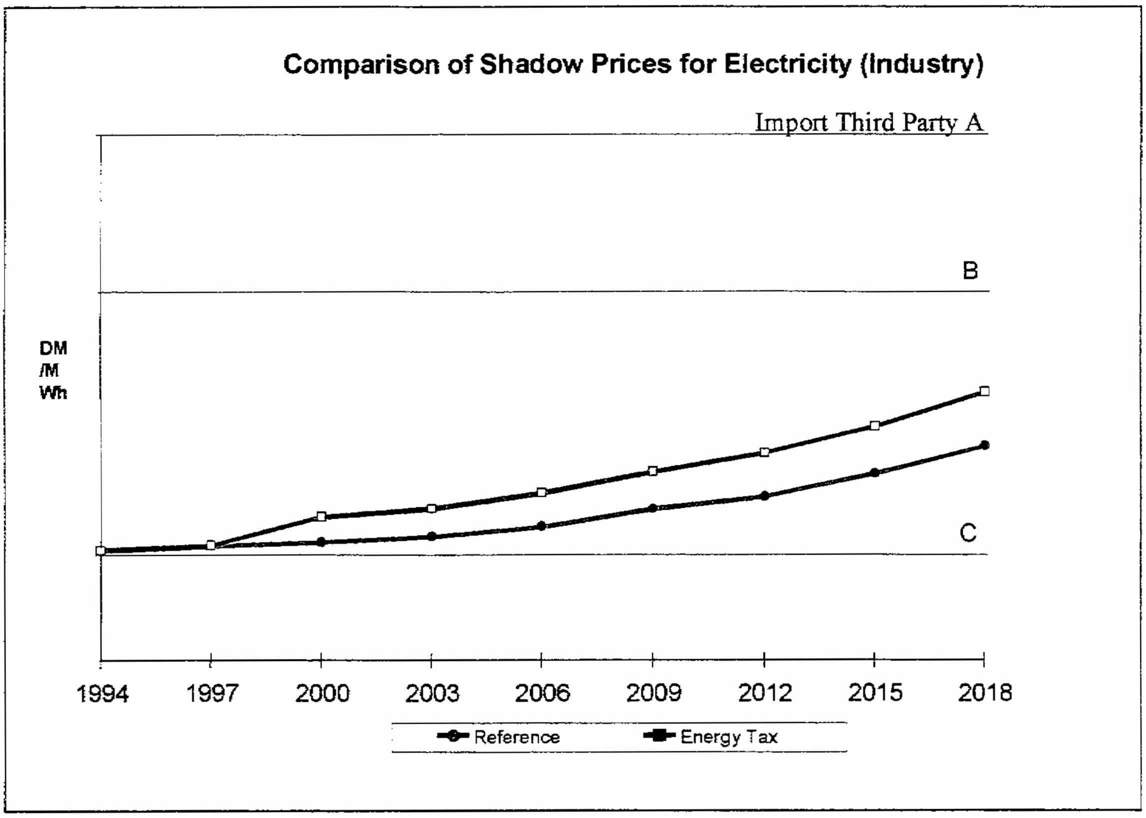


Fig. 5.5-5: Marginal electricity production costs of MVV in the reference and energy tax scenario (the exact values are not shown due to reasons of confidentiality). The line C indicates the present level of electricity import costs from competing utilities. The result indicates a serious cost problem for MVV in the medium-term, which will either drop its margin or its market share in Mannheim.

The possibility of loosing big industrial electricity customers as a result of deregulation will have a significant effect on the production structure of MVV. MARKAL is able to demonstrate this according to the loss of individual big customers and the corresponding effect on the optimal supply structure of the remaining demand. This proves its value as a means of strategic planning for the utility.

Fig. 5.5-6 shows the results of a simulation where some major customers of MVV may have switched to other providers. The reduction of electricity supplied by MVV accordingly drops by approximately 10 % (second graph of Fig. 5.5-6) and by 20 % (the third graph at the bottom), respectively. The reference case is characterised by base-load bought from GKM (Großkraftwerk Mannheim, the big powerstation at the outskirts of Mannheim) and a new CHP plant. In the case of a 10 % loss of demand due to the biggest MVV-customer, the supply structure remains almost unchanged. Only the small gas motors are turned off and in 2003 no electricity is imported by MVV from another utility.

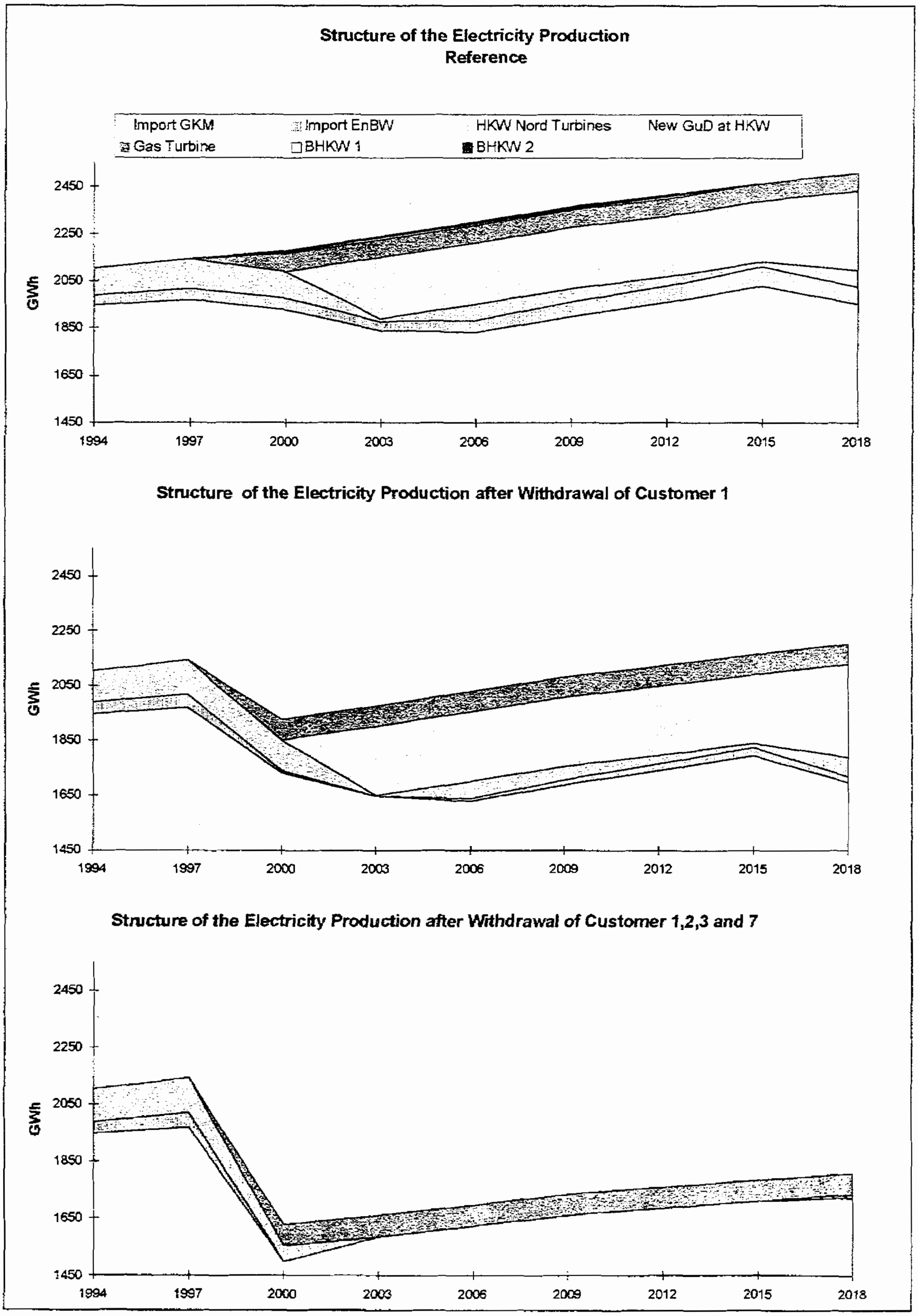


Fig. 5.5-6: Resulting MVV electricity generation structure after loss of key customers (second and third graph) compared to the reference case (first graph)

Fig. 5.5-7 shows the marginal cost of electricity production. In the reference case the marginal costs are caused by electricity imports bought from Badenwerk. This price will fall until 2000 due to liberalisation. In 2003, the marginal costs decrease significantly due to the interruption of this contract caused by the 10% loss in demand. When electricity demand rises with time, the import contract of MVV with Badenwerk will be re-continued.

In reality, such an interruption is rather unlikely. A better representation of the contract conditions and unit commitment in the model should take care of this uncertainty.

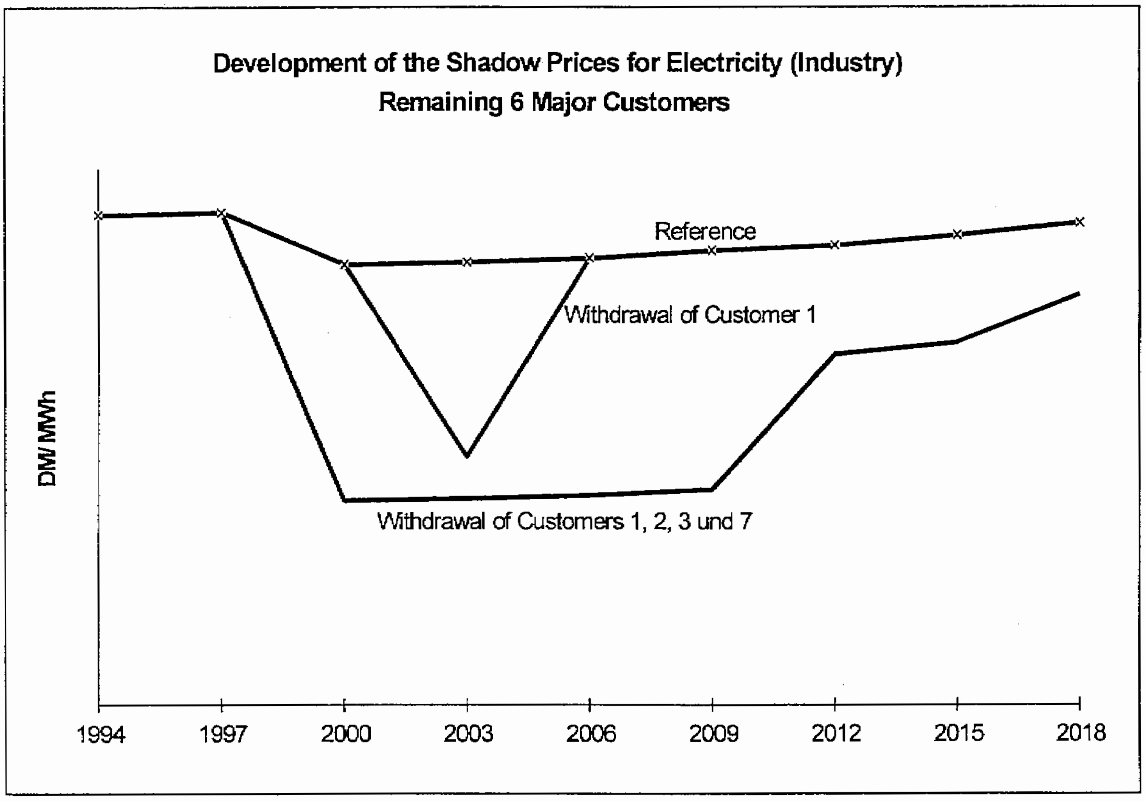


Fig. 5.5-7: Marginal cost for the supply of electricity for the remaining 6 key customers

When additionally three other big customers leave MVV (20 % less demand; see fig. 5.5-6), the supply structure must be adjusted. CHP plant, heating plant (HKW Nord Turbinen) and the Badenwerk supply contract "do not come into the solution" of the model. The marginal costs in fig. 5.5-6 for this case stay at a low level for most of the time. When electricity demand reaches a certain level in 2009, the marginal costs rise to the level of a new peak supply option (hardly noticeable in the figure at the far right side). A new tariff structure for MVV would be necessary to account for the new supply situation; the electricity prices for the remaining customers could be lowered. This example proves the value of the energy system model as a means of strategic planning for the utility.

5.5.6 Demand analysis with the simulation model PLANET

In addition to the MARKAL model, a simulation model (PLANET) was used to analyse the future demand development and additional demand side measures in detail. The supply structure of the PLANET and the MARKAL model are identical to the reference case. The calculated levels of primary energy consumption and CO_2-emissions are very similar. PLANET contains a very detailed description of the housing sector to obtain accurate figures for the future heating and water demand. Four different building types (single family houses, terraced houses, small and large multi-family houses) and four different building age classes for each type were considered. For every building type and age, detailed cost data for improved insulation and heating system retrofit was included in the model. The cost data represents three different levels of insulation measures:

(1) A normal renovation rate with 100 % exchange rate of old windows and a usual rate for other improvements of building and roof. This strategy is included in the reference case of the simulation model.

(2) A strategy for a comprehensive renovation of every building which meets the maximum technical potential. This strategy is named SPAR100 in the model.

(3) Another strategy (SPAR50) achieves 50 % of the potential of the SPAR100 strategy.

Additionally it was assumed for all strategies that the heating systems will be replaced within the next 20 years by highly efficient equipment in every building. The SPAR50 strategy is identical to the forced insulation standard of the MARKAL model.

Figures 5.5-8 and 5.5-9 show results from the cost calculation of the simulation model. The figures show the cost of final energy carriers for households. The costs include the production and transportation cost and also contain an extra cost to account for the profit of the utility. The costs therefore represent market prices. The results shown are calculated for the SPAR50 insulation strategy for buildings. Figure 5.5-8 shows the situation with reference price development. The specific costs for electricity drop considerably due to efficiency measures at the power plants until 2000. The rise in costs for district heat is caused by the reduced consumption as a result of insulation measures. Production costs are constant because the coal price is constant. Costs for gas and oil rise more than district heat. Energy prices for gas and oil rise by 1 % per year.

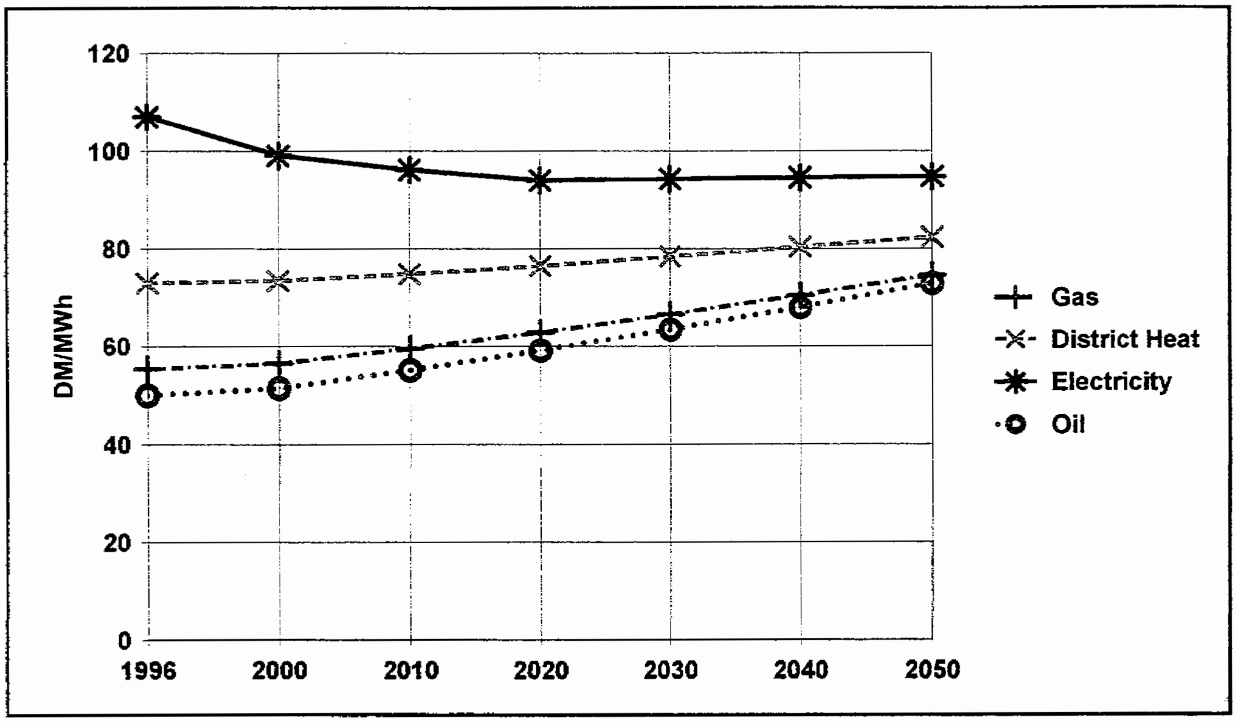


Figure 5.5-8: Energy cost for households. SPAR 50 conservation strategy for insulation and reference price development

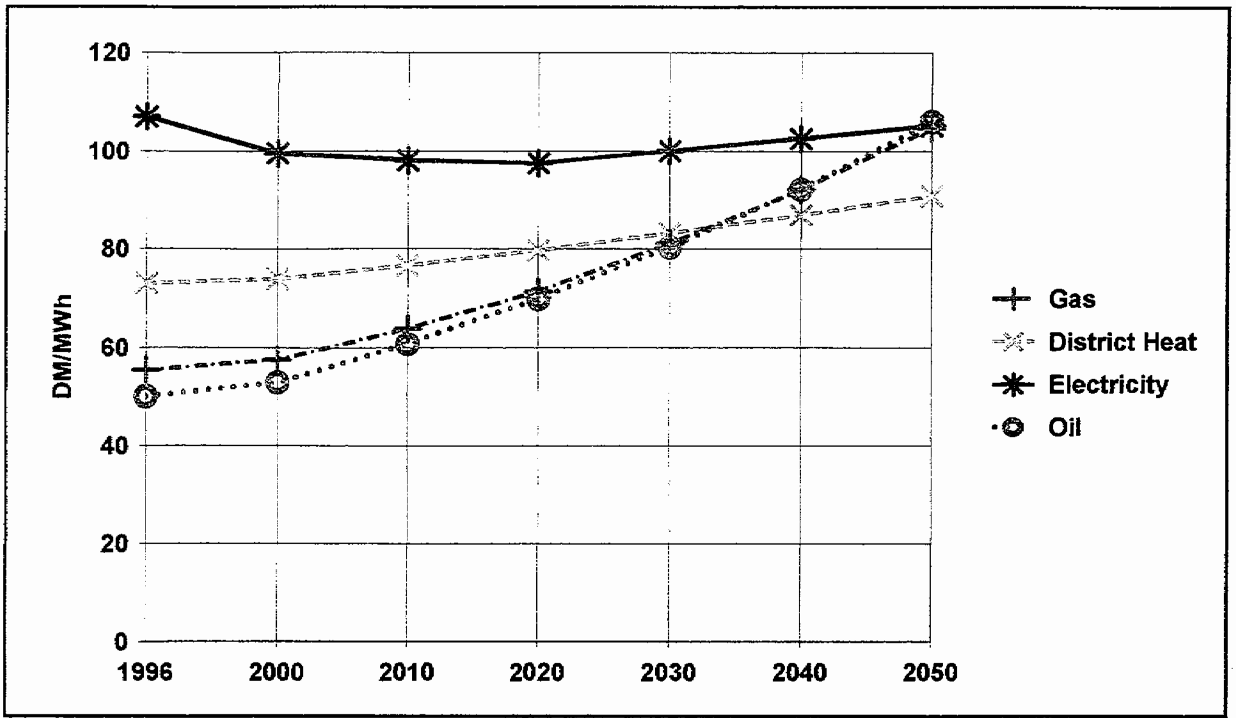


Figure 5.5-9: Energy cost for households. SPAR 50 conservation strategy for insulation and high price development

Figure 5.5-9 shows the same situation, but with high-price development. The rise in price for district heat is much smaller than for gas. Energy prices for coal rises by 1 % per year and by 2 % per year for gas and oil. The calculations show that district heat will become more competitive with gas at a high price level (approximately 2 times the prices today). The model results represent the effects of higher energy prices and higher specific costs due to a reduced demand over the whole modeling period. At the SPAR100 conservation level, the model results show that district heat is less favourable than in the SPAR50 case due to increased specific production costs caused by the lower demand.

Figure 5.5-10 shows a comparison of the costs for room heating for a single family house with gas and district heat. The costs include energy prices and the cost for the heating devices (annual investment and maintenance cost). Only the results for the reference case with the lowest prices and the SPAR100/high price case with the highest price are shown. The additional cost for the heating devices lead to a doubling of the cost for room heating. But the difference in cost is now higher; approximately 30 DM/MWh (25 %). The drop in the costs for gas is caused by improved gas burners. It is cost efficient for the households to invest in new highly efficient gas burners. For a large multi-family house (fig. 5.5-11) the difference in costs is much smaller; approximately 10 DM/MWh (around 10%) at a price level of 95 DM/MWh for district heat and 85 DM/MWh for gas. Increasing gas prices will make district heat more competitive.

These two figures lead to the conclusion to look for cost reduction potential for district heat in single family houses, or to switch to gas supply for these houses. On the other hand, it seems robust to continue the district heat strategy for large multi-family houses. From the point of view of CO_2-emissions, the district heat from co-generation has an advantage compared to gas. The cost to switch to alternative fuels is lower for a district heating system, than for individual gas burner installations.

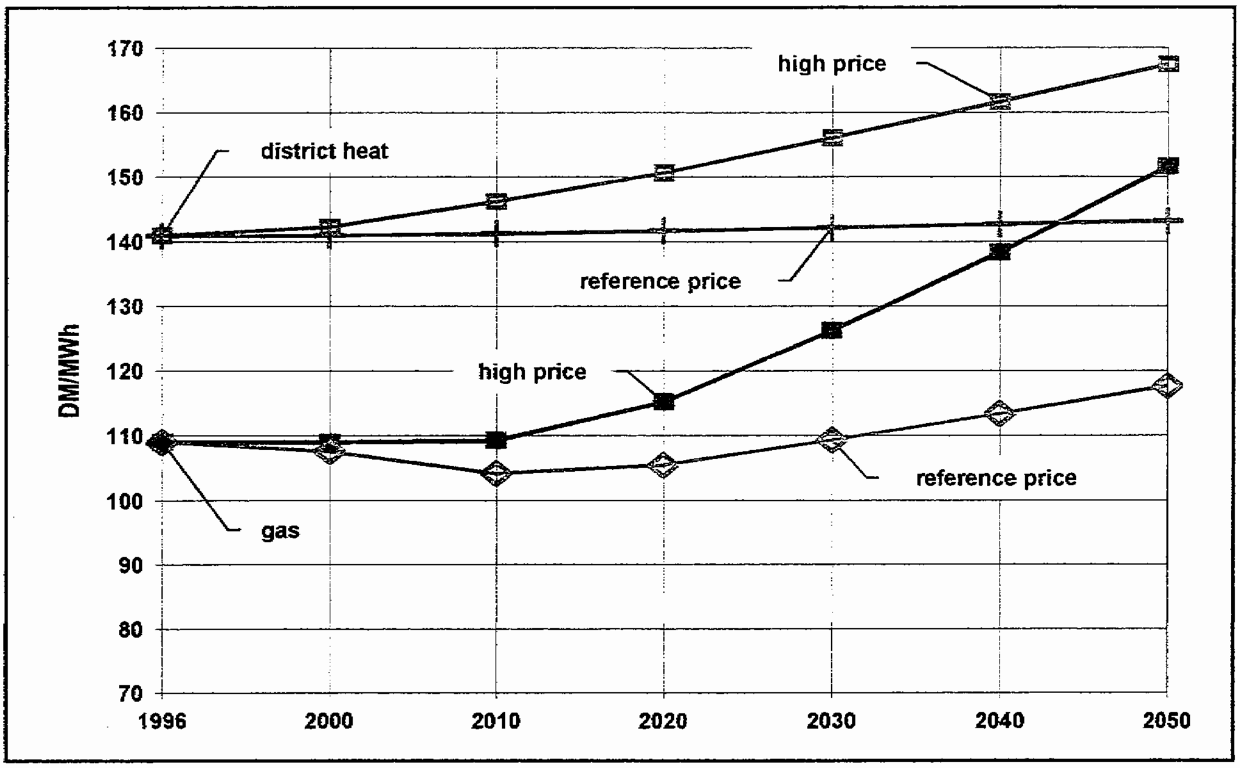


Figure 5.5-10: Comparison of cost for room heating in single family houses with gas and district heat, including costs for heating devices

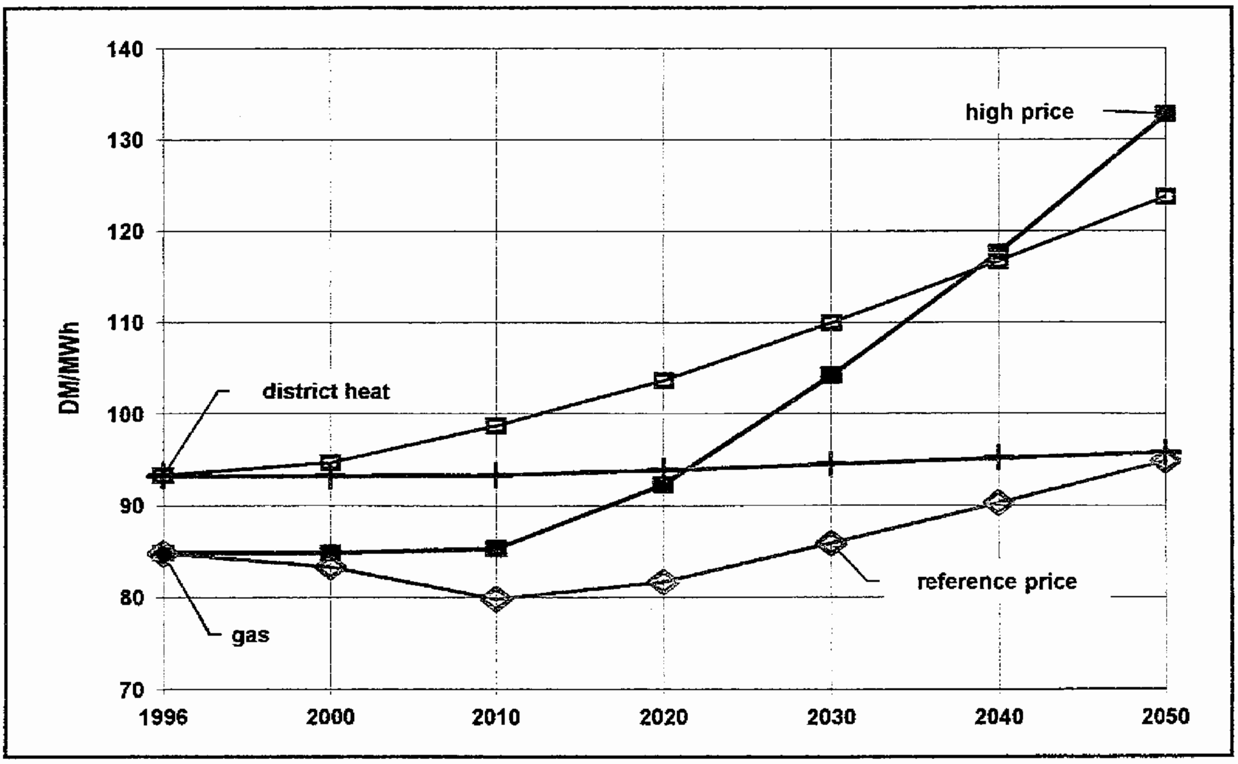


Figure 5.5-11: Comparison of cost for room heating in multi-family houses with gas and district heat, including cost for heating devices

The simulation model answers many important questions which could not be treated by the MARKAL model. The combination of both methods is very powerful.

5.5.6 Evaluation and case study conclusions

As soon as the RES for the comprehensive model is ready for operation, many other scenarios can be investigated very easily. For instance, the electricity price decreased in the German electricity market more rapidly than expected during the case study project. Also, more drastic assumptions on either energy prices or legal CO_2-emission limits could be made and would create interesting results in the systems behaviour and improve its understanding. However, the case study focused on a confirmation of „traditional knowledge", rather than on an exploration of „exotic" developments. This objective has been fully reached within the case study. Further work can – and must – be completed outside the case study by MVV on its own.

The work has also shown that the comprehensive model is able to reveal and quantify sources of future uncertainties, which have to be analyzed in more detail using other tools. The value of a combined strategic and operational approach has been demonstrated.

The work also revealed some weaknesses of the comprehensive model which was used in the Annex 33 case studies. The time parameter provided by MARKAL is unsufficient to allow for a detailed presentation of the annual duration curves of heat or electricity demand. Also, the model provides only cost structures and reveals no information on turnovers or profits. The detailed structures of elecricity contracts gain more importance under market conditions, but MARKAL is at present unable to model this. Thus, in its present version MARKAL is a purely strategic tool which can only be used in combination with other tools.

The user-interface of MARKAL also needs major improvement. At present, the use of the model by utilities is prevented by the need for detailed explanations, which requires continous assistance by system analysts which are fully familiar with the model and with LEP as well. There is a strong need to modernize and simplify the interface and the help tools, (e.g. pre-structured RES) if more widespread use of such energy system models is to be achieved.

All these weaknesses are well known to the model developers and will be improved in the framework of further continous international co-operation with IEA-ETSAP. A close connection to practical applications is necessary to ensure that an improved model will fulfill the existing requirements in practice.

5.6 Energy Supply for Greenhouse Garden Marketing, Delfland

5.6.1 Introduction

Background of the study

In the Netherlands the national energy policy falls within the scope of the Ministry for Economic Affairs. This Ministry has a separate department for energy matters, and one group operating within the department is primarily concerned with energy efficiency issues.

The task of translating Ministry policy into practical applications is performed by a group specially designed for this purpose: the Nederlandse Onderneming voor Energie en Milieu [Netherlands Enterprise for Energy and the Environment] (Novem b.v.). Novem is carrying out a number of programmes for the energy efficiency group of the Ministry for Economic Affairs, and one of these concerns local/regional energy planning.

Novem supports and oversees not only the implementation of the policy of the Ministry for Economic Affairs, but also that of other national and international authorities. One of the international programmes to which Novem contributes is the 'Annex 33' programme of the International Energy Agency (IEA) , part of the OECD (Organisation for Economic Cooperation and Development). The subject of 'Annex 33' is 'Advanced Local Energy Planning' (ALEP).

Novem's contribution to Annex 33 is a study of the possibilities of ALEP in the Netherlands. This study is connected with the Novem programme for local/regional energy planning in the Netherlands. Novem has commissioned G3 Advies to carry out the study.

Aim of the study

The study focuses on possible applications for advanced tools in regional energy planning in the Netherlands. It was assumed that the best place for tools of this kind was in utilities.

Procedure

In the first place, the study focused on the suitability of a specific programme, Markal, for use within an energy distribution company. This was based on a case study. The case, derived from a real situation, was submitted by the energy distribution company Energie Delfland. In the past, this utility commissioned various studies at different scales for a possible energy infrastructure. This meant that the data made available by Energie Delfland could be used for the case study, and that the utility had a point of reference for assessing the results.

The case study investigates whether Markal is suitable for use in carrying out a kind of risk analysis. Relevant factors and risks in selecting an energy system are analysed with Markal in the form of scenario studies. An analysis of this kind might form the initial exploration into a planning process.

Structure of the report

The case will be discussed in greater detail in chapter 2. The specific modelling in Markal of some elements from the case is elaborated in chapter 3, after which scenarios are drawn up in chapter 4. The results of the scenario studies from the case are presented in chapter 5. Chapters 6 and 7 explain the reporting and assessment of the study within the scope of the commission given by Novem.

Developments in the energy market in the Netherlands

In recent years, greater freedom has been introduced into the energy market. This means that the utilities have changed from semi-official agencies to commercial companies. As a result, local authorities and utilities are no longer natural partners. From 2007 onwards, all consumers, including individual households, will be able to decide for themselves which company is to supply them with energy. When a completely free market is assumed, the economic positions of utilities are directly dependent upon prevailing market prices. Utilities have become cautious in investing in new large-scale power supply plants.

The market is not the only uncertain factor, however. The technical possibilities allowing a utility to contribute to a lasting development will increase. As a consequence of this, social pressure on utilities to actually apply new techniques is likely to increase. Public concern about the environment is translated by the authorities into regulations. This is done by directly supporting measures in the form of subsidies, but also by setting requirements through legislation.

In the new legislation, local authorities have an obligation to develop an energy vision which incorporates environmental aims. In this way, the national aims of Kyoto are put into practice in a decentralised manner. On the basis of the energy vision, a local authority can place extra requirements on the energy infrastructure. Apart from environmental aims, the requirements will also tend to protect the public against excessive energy prices.

The study began in a period when the possible consequences of the developments outlined above played only a modest role in the discussions concerning regional energy planning. It was an obvious move to place the regional energy planning within utilities, since, on the basis of concessions, they had a fixed supply area at their disposal. The new freedom in the energy market probably means that an ALEP process will have to be set up differently. A utility will primarily be interested in assistance in commercial decisions. In the future regions will be divided on the basis of local authority boundaries, rather than on the supply areas of utilities. This fact, combined with the legal obligation for local authorities to draw up energy visions, makes local authorities a new target group. However, these considerations did not affect the execution of the study itself. When conclusions are drawn and the results evaluated, we shall return to the question of where ALEP tools can best be accommodated.

5.6.2 The case of Delfland

Introduction

For the study into possible regional applications for Markal in the Netherlands, a case from the energy distribution company Energie Delfland was used. In the supply area of this utility, greenhouse market gardening plays an important part. In the years ahead, the area of cultivation in greeenhouses will be extended by about 450 hectares. In addition, several relatively large new housing estates are being built, with a total of about 25,000 dwellings. To supply the energy for both sectors, investment in new energy production and distribution facilities will be required.

Energy demands in the area

Energy supply for greenhouse market gardening could be combined with the energy supply for new housing in the area. A possibility here could be to produce heat centrally and supply both the market gardening area and new housing estates to be built. A breakdown of the energy demand is shown in figure 5.6-1.

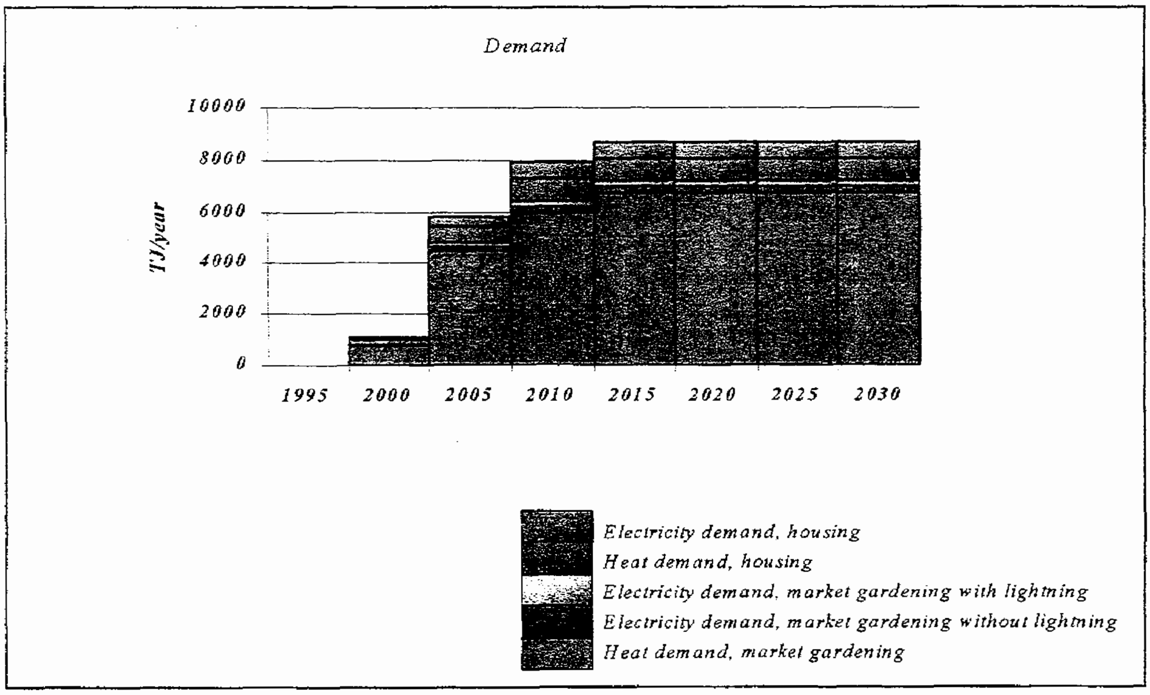


Figure 5.6-1: Schematic composition of energy demand over the planning horizon

Since the energy demand for greenhouse market gardening is dominant, it was decided to focus the case on this issue.

Greenhouse market gardening

In greenhouse market gardening in the Delfland area, the main crops are peppers, cucumbers, tomatoes and flowers. These are grown in greenhouses with a ground area of 1 to 5 hectares. The greenhouses are usually the property of individual growers. To meet the desired productivity and the high product quality requirements, market gardening companies have now developed into modern businesses with high-grade climate control systems (heating, ventilation) and HID lighting. Moreover, companies are equipped with special systems for feeding, humidifying and fertilising the crops with CO_2. This all serves to keep production at high levels of quality and quantity.

The Netherlands have their own extensive natural gas sources and a high-density national gas grid. In recent decades, gas-fired boilers have therefore been used to heat the greenhouses, just as they are used to heat the majority of dwellings in the Netherlands. In recent years, part of the CO_2 released by the burning of natural gas in the boilers used by growers has in most cases been used for fertilising crops. The demand for heat and CO_2 do not always coincide, however. In summer especially, when the sun provides heat in the greenhouses, extra CO_2 is required. So that sufficient productivity is achieved, many companies switch on the boiler even in summer, solely for the production of CO_2. The heat which this produces is released unused. Partly to prevent heat dumping, studies have been performed into other forms of heat and CO_2 supply. Among other things, these studies conside the possibilities of using combined heat and power (CHP). One sector of greenhouse market gardening, electricity (power), also has an important role to play, especially to supply artificial lighting for the crops (HID lighting).

Heat/CO_2 project

Energie Delfland decided a few years ago to offer growers a combined supply of heat and CO_2 . This project has been operational since 1996. Both products come from a CHP STAG (STeam And Gaspower) station which also supplies a large number of dwellings with heat and electricity. The combination of gas and steam turbines in STAG, combined heat and power and utilisation of the CO_2 yields a very efficient form of energy use with as minimal environmental impact as possible. This project means that Energie Delfland can pride itself on being a modern, forward-looking and environmentally friendly utility.

Depending on the climate control in the greenhouse, heat and CO_2 are matched to the actual demand via an advanced control system. Here, the supply of heat is limited to the base load, while conventional gas-fired boilers are used to meet the peak load, these being installed on the grower's own premises. The supply of heat/CO_2 (H/CO_2 for short) can thus be tailored to the existing situation of older market gardening greenhouses. Operation of the control system is monitored remotely (from the main office of Energie Delfland in Delft) and continuous measurements are taken at various points. Measurement data are stored in a database. Along with the monthly bill, the grower also receives an overview with any recommendations for more efficient use of H/CO_2 and reduced operating hours for the boiler. At present, upwards of 140 market gardening companies are supplied with H/CO_2, and current STAG power station is operating at almost full capacity.

Alternatives

The use of decentralised energy generation on the basis of combined heat and power, instead of central generation may also be considered. In this case, gas engines are set up on the growers' premises (Energie Delfland also has experience with this option, as it currently manages a number of such installations for growers). If gas engines are fitted with a special waste gas cleaning system, then it is possible to use the exhaust gases as CO_2 fertilisation.

(Electric) heat pumps are another alternative for meeting the demand for heat. Heat pumps are currently still relatively expensive, but efficiency is very high. With the future possibility of sustainable electricity production, heat pumps make completely sustainable heat supply possible. However, electric heat pumps only provide heat, so a different technology will have to be used for CO_2 fertilisation.

CO_2 may be taken from an industrial area nearby (Botlek). Certain processes in the petrochemical industry release nearly pure CO_2 as a by-product, unlike in the waste gases from CHP in which CO_2 is only one of the components. Utilising a distribution grid, the CO_2 from the industrial area could be transported to the market gardening area.

In the end, it may be that cost effectiveness dictates a preference for gas boilers. This is not desirable for the environment, but alternatives must prove that they can hold their own in a free market and in competition with this conventional technology.

Issue of the case study

The question which must be answered in the Energie Delfland case study, with the aid of MARKAL, is:

Which energy system meets the energy demands of market gardening most efficiently?

The energy demand from market gardening is composed of:

- demand for heat,
- demand for CO_2,
- demand for electricity.

Energie Delfland is faced with the problem of choosing which technologies to use. The sensitivity of the selected system to internal and external factors is examined. Based on an initial understanding of the sensitivities to these factors, the utility can make an initial estimate of the investment risks.

Elements of the case study

The period considered in the case study is 1995 to 2030, with the year 2000 used as the reference year for determining costs. Up to the year 2015, the demand for heat from market gardening will increase as new companies are formed. Assuming that acreage expands by 450 hectares with a heat requirement of 15 TJ per hectare, then this amounts to an ultimate demand for heat of 6750 TJ per year. On the basis of known consumption characteristics, Energie Delfland anticipates a demand for power of 2.4 MW per hectare, which corresponds to a total thermal capacity of 1000 MW or more.

Five different technologies have been included for the choice of an energy system. These technologies and the different types of energy they consume and produce are shown in table 5.6-1.

Table 5.6-1: Technologies, types of energy consumed and supplied

Technology	Consumes	Supplies
CHP-STAG with CO_2	natural gas	heat, CO_2, electricity
CHP-STAG without CO_2	natural gas	heat, electricity
Gas engines	natural gas	heat, CO_2, electricity
Gas boilers	natural gas	heat, CO_2
Electric heat pumps	electricity	heat

It is assumed that heat production always takes place within the region itself. Electricity and CO_2 might be imported from outside the area. Any surplus heat or CO_2 is discharged within the area, while a surplus of electricity can be exported outside the area (fed back into the grid). In general, with regard to the production of the different forms of energy, it can be concluded that a surplus of heat is undesirable (destruction of energy), a surplus of CO_2 seems unavoidable as matters stand (only part of the emissions can be put to good use) and a surplus of electricity could be harnessed to offset costs.

The different options for energy systems in the market gardening area are shown schematically in figure 5.6-2. The energy production technologies form the core of the model. The broken line is the system boundary from which importing and exporting occur.

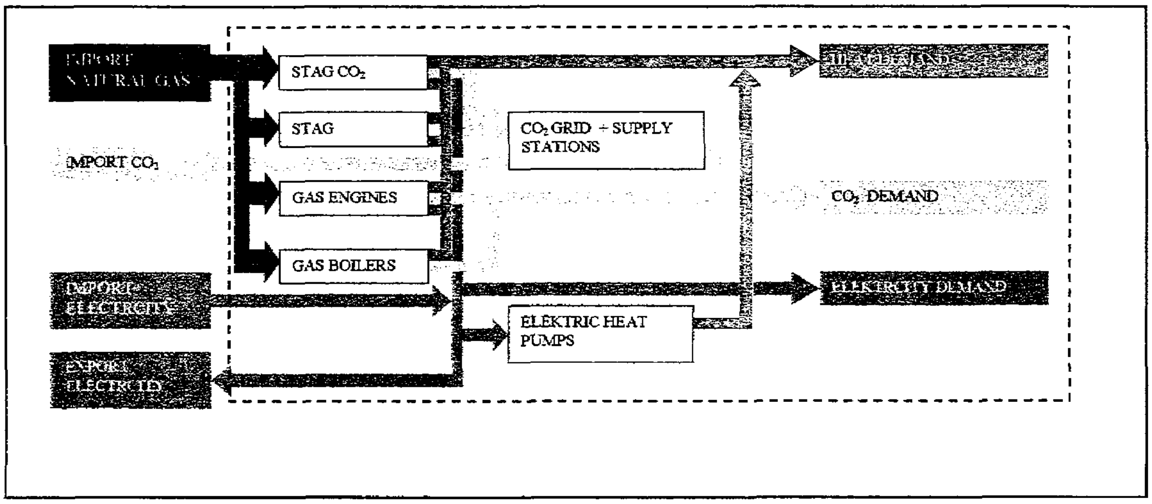


Figure 5.6-2: Schematic representation of energy sources, production and demand

Scenarios

In this case study, three factors are elaborated in more detail in scenarios:

- rates for return supply of electricity,
- internal interest rate for investments,
- CO_2 emission restriction.

Export of electricity is especially important because the export revenue can be used by the utility to offset the relatively high costs of the CHP power technologies. The revenue does however depend on prevailing prices. The level of the export rates is incorporated into the analysis as one of the factors whose influence is investigated.

The internal interest rate is the financial return on investments desired by the utility. By varying the level of this return, the utility can influence the choice of an optimum energy system. The CO_2 emission restriction has been included as an example of an environmental requirement which could be imposed by the local authority (see section 1.3). Chapter 4 considers the structure of the scenarios in more detail.

5.6.3 Tools and methods

Introduction

There are various possible applications for MARKAL. The program is actually a kind of support framework for the real model which the user inputs. Due to the fact that MARKAL itself contains so much freedom of application in the initial situation, the input of the user's model will be simplified if he has carried out a number of exploratory partial calculations. In this way, users get a feeling for the important points (for example, the sector with a predominant demand or investments with high or low costs) of the total model.

In addition, as a consequence of the general structure of MARKAL, in a number of cases must be tailored to specific properties which the user wishes to incorporate in the model. In this section, five examples of adaptions to the Delfland case are examined in more detail. These are:

(1) A special interpretation of cost minimising as a method of optimising
(2) Including revenue within the framework of minimising costs
(3) Modelling a capacity-dependent rate component
(4) Modelling a CHP STAG (with distribution grids)
(5) The CO_2 balance.

The first two issues are connected to general matters of optimising, the last three have to do with specific characteristics of Markal.

Cost minimising as a characteristic of the market

The subject of the study in the Delfland case is not the internal economy of a utility, but rather the position of that utility in the general economy. Finding an optimum energy system using minimisation of costs as the basic assumption is considered an approximation of the free-market, or as the most acceptable way that the choice of an energy infrastructure comes about in reality. The minimisation of costs here is not only the aim of the utility, but is also considered as the basis from which the market prices of products are ultimately determined.

An alternative to market forces is regulation by an authority. The Netherlands energy policy, however, is directed towards using market forces within stated limits in order to achieve maximum efficiency. In Markal it is possible to incorporate limits of this kind as an extra condition, which means that both the market and the official policy can be modelled (in this case the CO_2 emission requirement).

Cost minimisation and revenues

For the Delfland case it is desirable to take into account not only costs, but also revenues. The revenues from the export of electricity outside the area could be used to reduce the total costs within the area. This would make it possible to compensate for the relatively high (investment) cost of the CHP technologies (STAG and gas engines). There are two possibilities for accommodating revenues in the model:

(1) The inclusion of a reference technology (implicit method)
(2) The inclusion of negative costs (explicit method).

In principle, MARKAL operates using costs only. These may be considered indirectly as an indication of revenues. The utility will wish to operate the energy system in such a way so that at minimum the costs are covered. The costs of meeting the energy demand within the area are implicitly the revenues from the sale of this energy*). Any profit margin on the sale price is disregarded in the implicit determination, except in the form of a possible internal interest rate for investments.

For the export of electricity, the value could also be determined implicitly if a reference technology is incorporated within the area, for example a STAG which produces electricity only (E-STAG). The export itself must then also be accommodated within the area in the form of extra demand for electricity. If, when determining the optimum energy system, the E-STAG meets the extra demand for electricity, then this means that the costs of the E-STAG implicitly establish the maximum revenue from the export of electricity (the cheapest technology must cover costs). The disadvantage of this method is that the extent of the export must be established beforehand. Varying the price of electricity would only be possible in this situation by varying the costs of the E-STAG. Moreover, no unequivocal connection with electricity prices can be given. For these reasons, this method was not considered suitable for the Delfland case.

It was decided to use an imposed electricity rate for export in the form of a negative cost component (explicit method). This has the advantage that the revenue from export is subtracted directly from the costs of the CHP options (exactly as in practice). Different prices can then be incorporated in scenario studies and there is no need to incorporate a fictitious extra demand for electricity in the model.

The danger of introducing negative costs is that the total costs may possibly be negative. This danger is especially great in the Delfland case, because the negative costs are connected to the export of electricity, while no limits are imposed beforehand on the extent of this export. This may mean an optimum solution that tends towards an infinitely large CHP capacity (infinitely large electricity export). This can be counteracted by imposing a maximum limit on the capacity of the CHP options.

A closer look at the problem shows in any case that the solution with negative total costs is not acceptable. The explicit method was after all based on the calculation of costs as a consequence of meeting the demand for energy from market gardening, with possible compensation from export revenues. A solution with negative total costs represents a situation in which export alone is already sufficient for installing the relevant energy infrastructure. Energy demand within the area then has no part to play, since the compensation would be greater than 100%.

Rates with a capacity-dependent component

Electricity rates and natural gas prices in the Netherlands have a kWh, plus a kW component. The kW component of the natural gas import is in this case directly set against the capacity-dependent costs of the various technologies. For the kW component of the electricity import, a special (dummy) technology is defined, because it cannot be determined beforehand whether the imported electricity goes first to the heat pumps or directly to the end user (the demand).

With electricity export, incorporation of a dummy technology was not possible, because this would include only negative costs for capacity to be installed. With cost minimising, the capacity of this dummy technology would not be linked to the GJ of electricity exported, but would increase without restriction because each installed kW would be able to contribute to reduction of costs. It was decided to deduct the kW component of electricity exports directly from the capacity-dependent costs of the relevant technologies, as is the case with the kW component of natural gas imports. This makes the model itself clearer and more stable. A disadvantage however, is that the costs and revenues are spread over different places in the model.

STAG and distribution grids

*) In reality, non-financial matters such as scarcity, image and reliability also have an effect on the market value.

It was decided to give the gas engines a fixed ratio between electricity production and heat production. With the STAG, this ratio is variable. In principle it is possible that a STAG is chosen solely for electricity production. To prevent the possibility of an infinitely large amount of STAG capacity being installed, an (arbitrary) maximum of 250 MW is imposed on the electric capacity to be installed, for the STAG with and without CO_2.

The STAG is a central energy generating unit, so for the distribution of heat and CO_2 separate grids must be constructed. In the model, for this case, the properties and costs of the heat grid and the supply stations are incorporated in the 'technology' STAG. This is done because heat grid and heat supply stations are built only in combination with a STAG. Via the CO_2 grid and the CO_2 supply stations, the CO_2 can be imported from the Botlek area. The CO_2 grid and the supply stations are therefore incorporated as a separate technology. Gas engines and gas boilers are set up on site, at the grower's premises, and can therefore supply the CO_2 directly.

A second reason for incorporating the heat grid in the 'technology' STAG is to ensure that the peak capacity for heat in the chain is correctly passed on. This is connected with the manner in which the peak demand has been incorporated in Markal. Peak demand is a demand for capacity without supply (the peak has a duration of 0 seconds). Connecting all heat producing technologies directly to the demand for heat prevents the installation of a heat grid as a cheap stand-alone technology for the 'peak capacity', without the STAG, which is actually coupled to it, being dimensioned for this. In the analyses in this study, the choice of gas boilers for the peak load is effectively based on weighing the costs of e.g. a STAG (including all facilities required) and the gas boilers.

CO_2 - Balance

The CO_2 emissions were derived directly from the natural gas consumption of the technologies. For the export of electricity, in accordance with the regulations in the Netherlands, a reduction in the total CO_2 emissions is taken into consideration. The electricity produced in the area and then exported need not be generated outside the area. The CO_2 emissions avoided outside the area can be deducted within the area.

Other tools

As indicated in the introduction, there is greater confidence in a model in Markal if there is already a feeling for what the critical elements of the model are. This confidence can be developed with a number of approximate calculations. For the Delfland case the simulation models in Excel from G3 Advies were used to carry out static calculations, in particular to gain insight into the revenues from export of electricity. Excel applications for accommodating different costs and revenues into a single technology have also been developed.

5.6.4 Scenarios

Introduction

Before MARKAL can be used in the analysis of an energy system, the issue being examined must be framed in such a way that it can be answered with scenario studies. It was decided to give the scenario studies a different form than similar studies which are purely descriptive in character. The expectations for the future are not the most important results, since this would not leave any room for decisions by the utility. The emphasis of the scenario studies has shifted from future expectation to the robustness of an energy system.

Structure of the scenario studies

The period considered from 1995 to 2030 was divided into blocks of 5 years each. The central question is not which future scenario is considered most suitable and under what circumstances, but:

What influence do different scenarios have on the choice of technology?

Particular attention is given here to sensitivity to parameters and the question as to which technology choice remains stable with various scenarios. The scenarios are characterised by parameters which were derived from the following factors (section 2.7):

- Rates for return supply of electricity,
- Internal rate of interest for investments,
- CO_2 emission restriction.

A limited number of possible values are assigned to the parameters, and these are shown in table 5.6-2.

Table 5.6-2: Possible values for the parameters

Parameters	Values
Electricity rates (% of current rates)	70%, 80%, 90%
Internal rate of interest	high, low
CO_2 emission ceiling (as in base scenario)	not imposed, imposed

The number of possible scenarios corresponds to the number of combinations which can be formed with these parameters. In this case there are twelve.

An interest rate of 5 % is used for investment credit. For a number of technologies, a different internal rate of interest is used. These are installations belonging to the utility. This differing rate is due to the fact that utilities have other costs besides the investment, maintenance and purchase of energy. Examples of other costs include administrative costs and distribution of profits to shareholders. The last aspect reveals something about the financial return. For the internal rate of interest, the values shown in table 5.6-3 are assumed. Gas boilers are the property of the consumers, and therefore no financial return for these are included in the model.

Table 5.6-3: Internal interest rates for three technologies

Technology	Internal interest rate (high)	Internal interest rate (low)
STAG	15%	8%
Gas engines	12%	6%
Heat pumps	12%	6%

In consultation with Energie Delfland, an initial situation or 'base scenario' was set up, characterised by the following assumptions:

- An electricity price of 80% of present-day rates for the return supply of electricity,
- The high financial return on investments,
- No CO_2 reduction restriction.

Next, the consequences of electricity prices of 70% and 90% of present-day rates are considered. In these three scenarios, a relatively high financial return is applied to the technologies which are expected to remain under the control of Energie Delfland. In the fourth study, a lower financial return (halved) and a low electricity price
(70 %) are assumed. Also with a low electricity price, the possible effect of a CO_2 reduction requirement (no higher than the CO_2 emission in the base scenario) is considered. This is the fifth and last scenario. The choices are shown in figure 5.6-3 in a tree structure.

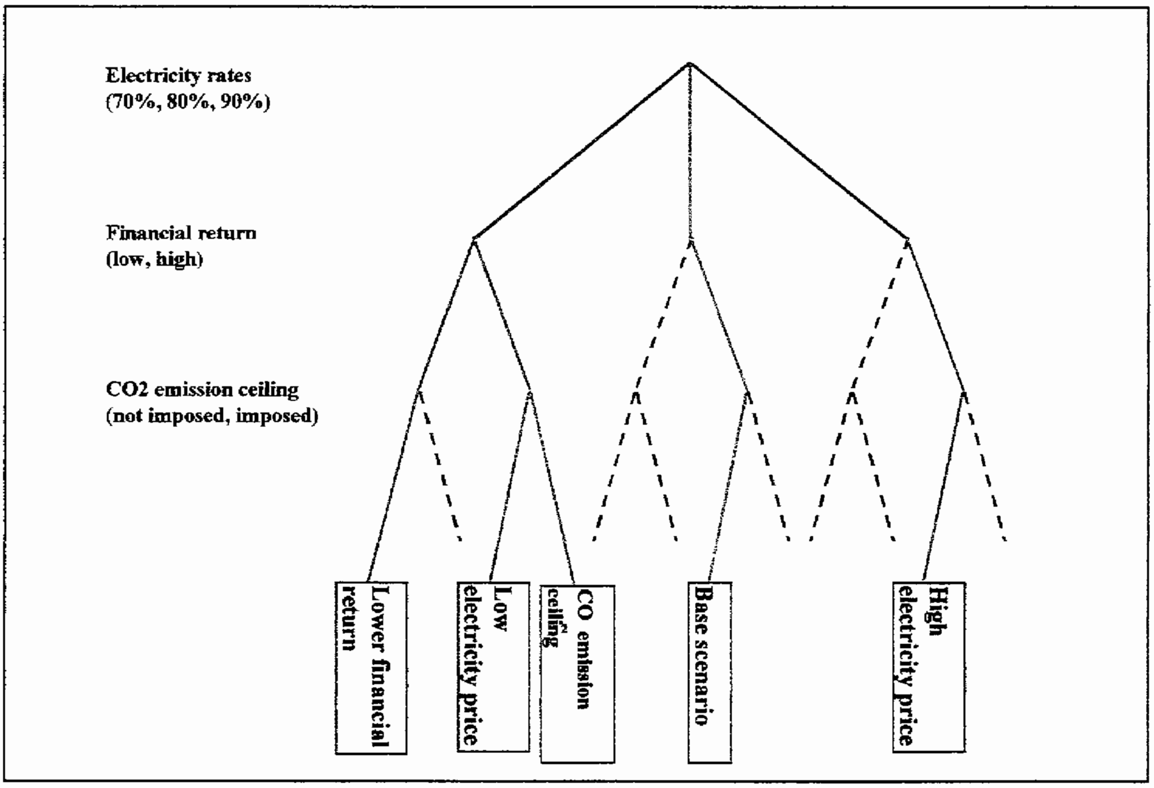


Figure 5.6-3: Tree diagram for the selection of scenarios

The selection of scenarios is partly made with the low electricity price in mind. If a fall in electricity rates means that CHP is no longer cost-effective, the possible effect of two measures is investigated: reduction of the financial return by the utility and an imposed restriction on CO_2 emission. All of this is summarised in figure 5.6-4.

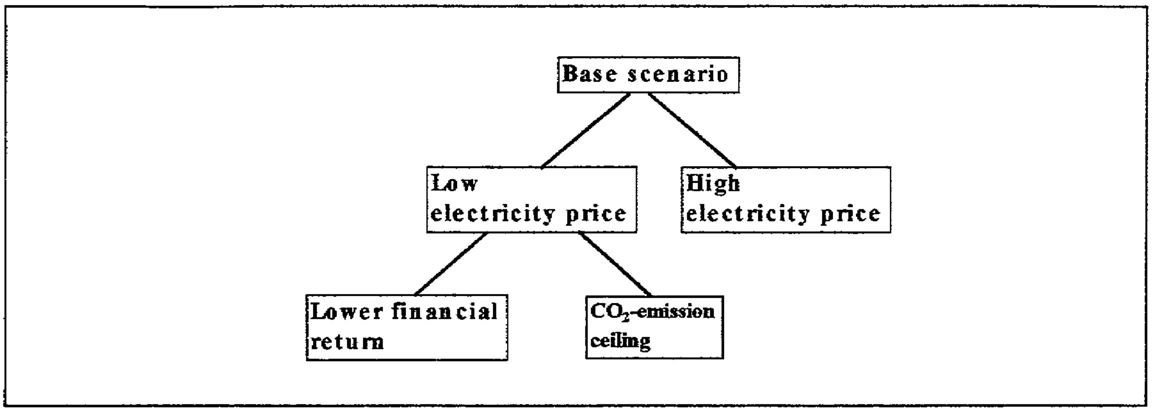


Figure 5.6-4: The connection between the selected scenarios

Risk analysis

Instead of a purely technical analysis or a purely descriptive one, a type of risk analysis is carried out. The analysis in this report, as an example of this type of study, was intended in the first place to provide insight into the *interaction* between different factors. The price of electricity will have an effect on a choice of technology, as will any CO_2 reduction requirement. But how do both factors behave with respect to each other? If a specific choice of technology is found to be robust with respect to variations in both parameters separately and also with respect to the possible interaction between the parameters, then a study such as this one can contribute to a broader basis supporting the final choice. Here it must be remembered that the results are dependent on the parameters chosen and a limited number of parameters cannot describe the complete reality. Rather, a study of this kind may give rise to a more detailed examination of the effect of the most sensitive parameters, or for a feasibility study for the most robust option.

5.6.5 Results

Introduction

The scenarios as drawn up in chapter 4 were calculated with Markal. In the results, attention was mainly given to the choice of technology. For the final assessment, the total costs and the CO_2 emissions of each scenario were also considered.

Base scenario

The capacity and the annual supply of the technologies in the base scenario are shown in figure 5.6-5. For the CHP installations, the electricity capacity is given as a measure of the capacity to be installed (in Markal, heat is considered a by-product). The other options supply only heat, and the thermal capacity is given for these.

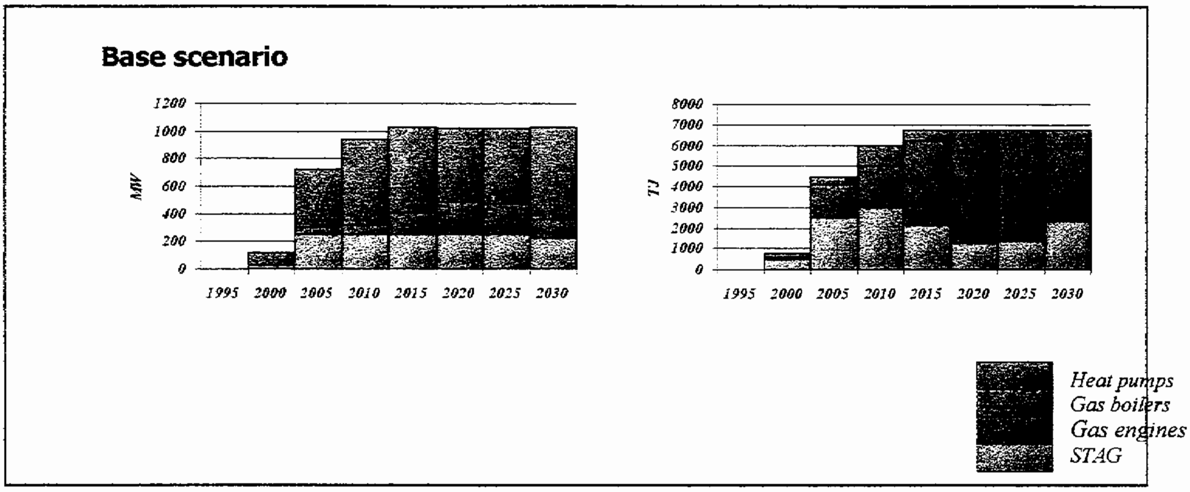


Figure 5.6-5: Total capacity and annual heat supply in the base scenario.

In the base scenario the optimum energy system consists of:

- STAG, without CO_2 supply,
- Gas engines,
- Gas boilers.

From 2005 onwards, the maximum (electrical) capacity of the STAG is installed (250 MW). The STAG supplies both electricity and heat. Although a relatively large capacity of gas boilers is also installed, this is hardly used. The investment costs for gas boilers are relatively low and therefore gas boilers will be installed for peak load and spare capacity. Gas engines are used for the supply of heat and CO_2. Heat pumps are not used. The STAG produces a relatively large amount of electricity which is subsequently exported.

The choice of CHP stands out clearly. The maximum STAG capacity is installed, so that in any case 250 MW could be installed and possibly more, if no maximum is set. Part of the total market gardening area is provided with heat by gas engines. All CO_2 required for the greenhouses is supplied by the gas engines. In practice, this may give rise to a technical or logistic difficulty, since in this case all growers must obtain both a gas engine (approx. 0.5 MW/ha, or on average a 1 MW engine per individual enterprise) and also a connection to the heat grid. Further investigation should show whether it is feasible to connect all market gardening companies to a STAG, possibly with supply of CO_2 . To be able to meet the peak load, it is in any case desirable that the growers shoul have their own boilers.

Effect of the price of electricity

The result of the high electricity price scenario is shown in figure 5.6-6 Two points stand out: there is an overproduction of heat and although the maximum capacity for the STAG has already been installed starting in the first period, there is little or no heat produced. The STAG is installed solely for the production of electricity. The revenues from the export of electricity are in any case so large that the production of electricity is the driving force even, with gas engines. This means that a surplus of heat is produced.

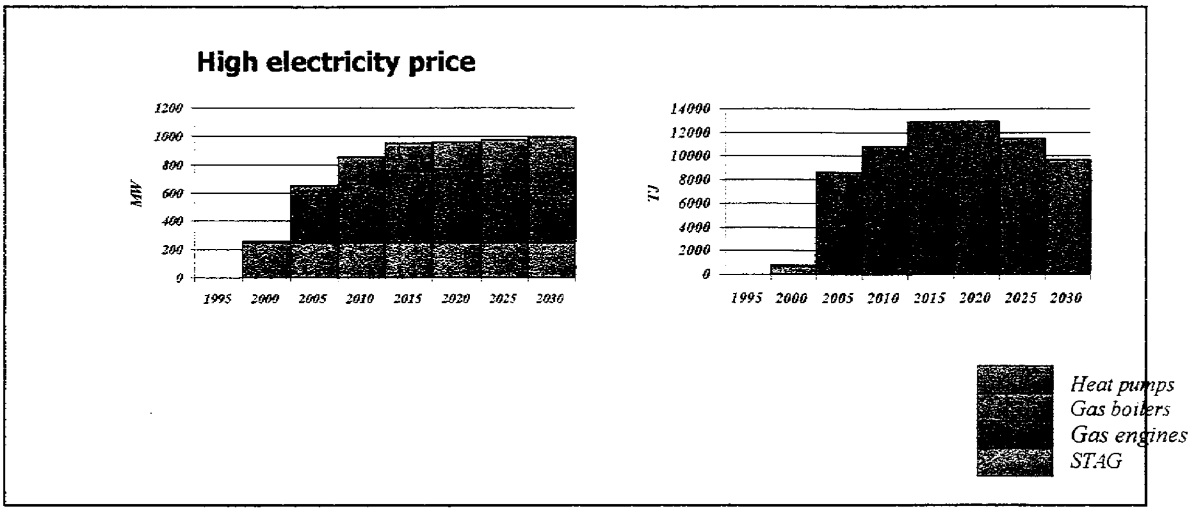


Figure 5.6-6: Total capacity and annual heat supply in scenarios with high and low electricity price.

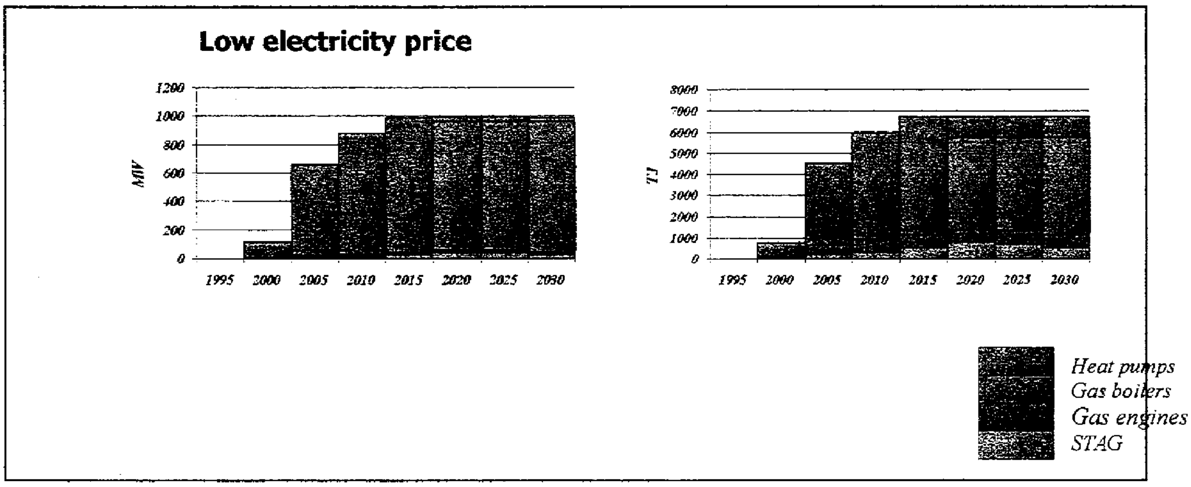


Figure 5.6-7: Total capacity and annual heat supply in scenarios with high and low electricity price.

The gas engines are partly dimensioned for peak load in the demand for heat, and run continuously throughout the year for the sale of electricity. This implies that more heat is supplied than there is a demand for. In practice this would amount to a waste of heat.

The total costs which are minimised when the choice of technologies is made on the basis of cost minimisation, also give an indication of the difference in the costs of the options compared with one another. The sale of electricity at 90% of the electricity price ensures that the total costs (in respect to production of heat) are 50% lower than the costs of the base scenario. The CO_2 emissions are almost 80% higher, however.

The low rate scenario is shown in figure 5.6-7. The most important result of this calculation is that the CHP options are no longer relevant. At 70%, the return supply rate is found to be too low to compete with the gas boilers. From 2020 onwards, the selection requires that some of the gas boilers be replaced with electric heat pumps. The electricity for the heat pumps is obtained from the small CHP capacity which is already installed. No electricity is imported for the heat pumps. The total costs turn out to be about 20% higher than in the base scenario. CO_2 emissions are 85% higher. This can be attributed partly to the gas boilers. And since there is now no combined generation of heat and electricity, there is no export of electricity for which the CO_2 emissions avoided are deducted

Effect of lowering the internal interest rate or the CO_2 emission ceiling

The result derived from the scenario with a lower financial return (with low electricity rates) is shown in figure 5.4. The solution Markal gives in this case resembles the base scenario from section 5.1, in which 80% of the export rates and a high internal rate of interest are assumed. The emphasis is now on CHP and the full available capacity for the STAG is installed. The use of gas boilers is limited to the peak load and spare capacity. Although the operation of heat pumps has become more economical compared with the initial situation (due to a lower internal rate of interest and lower electricity rates), this technology is not chosen at the expense of the gas boilers. CHP is able to meet the demand for heat. The total costs are 5% lower than in the base scenario (because a lower return is required), for 5% lower CO_2 emissions. The latter case is explained by a lower production of heat by gas boilers.

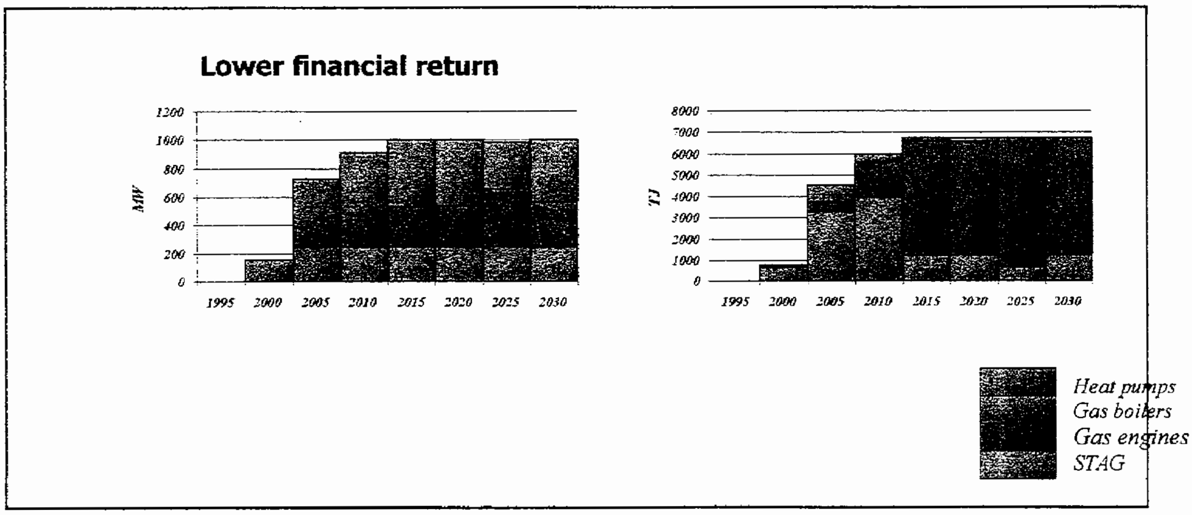


Figure 5.6-8: Total capacity and annual supply of heat in the scenario with lower financial return (and low electricity price).

The results derived from the scenario with a CO_2 emission ceiling are given in figure 5.6-9. The CO_2 emissions can be limited by using heat pumps. This leads to 25% higher costs compared to the base scenario. A STAG of about 100 MW is installed. The CO_2 is produced by the gas boilers and gas engines. For spare capacity for the peak load, investments in gas boilers are made.

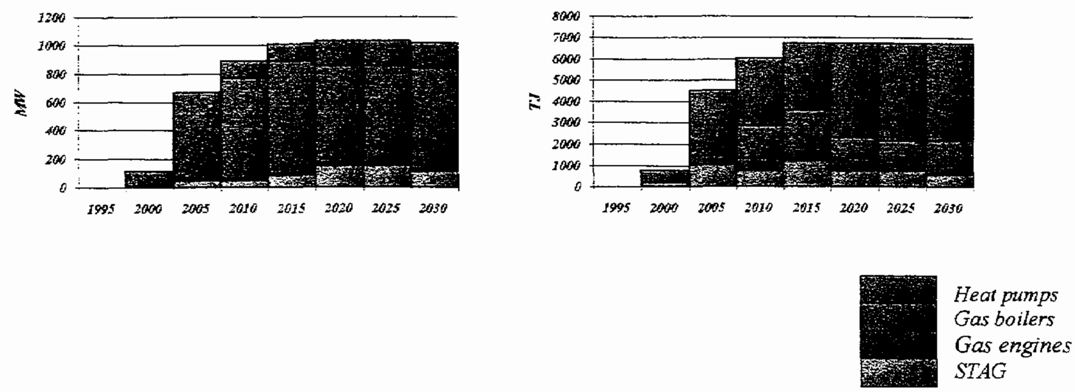


Figure 5.6-9: Total capacity and annual heat supply in a scenario with CO_2 emission ceiling (and low electricity price).

Conclusions regarding the results of the case study

The results are summarised in figures 5.6-10 and 5.6-11 (next page). Because this is a relatively global analysis, no absolute conclusions can be made from the figures. A trend can be seen, however. In both the base scenario and the low rate scenario with lower internal interest rates, the optimum energy supply was from combined heat and power installations, with optimum use of the STAG. This option results in relatively low CO_2 emissions. Moreover, it appears that the CHP option can be retained if a lower financial return can be accepted from a fall in electrcity rates. To summarise, it may be stated that with reference to this global investigation, there are sufficient reasons to focus a detailed follow-up study on the use of CHP.

To reach a more precise conclusion regarding the choice of technology, it is recommended to

- Consider more factors in the sensitivity analysis,
- Examine more closely the cause of any sensitivity of the results of specific factors which may be revealed.

Conclusions regarding possible applications for advanced tools

This study has demonstrated that it is possible to use analytical tools such as Markal to obtain insight into:

- The extent to which different factors influence the choice of technology,
- The interaction between these factors (for example the internal interest rate on the price of electricity).

A tool of this kind is suitable for carrying out a global exploratory analysis with respect to the possible options and any risks.

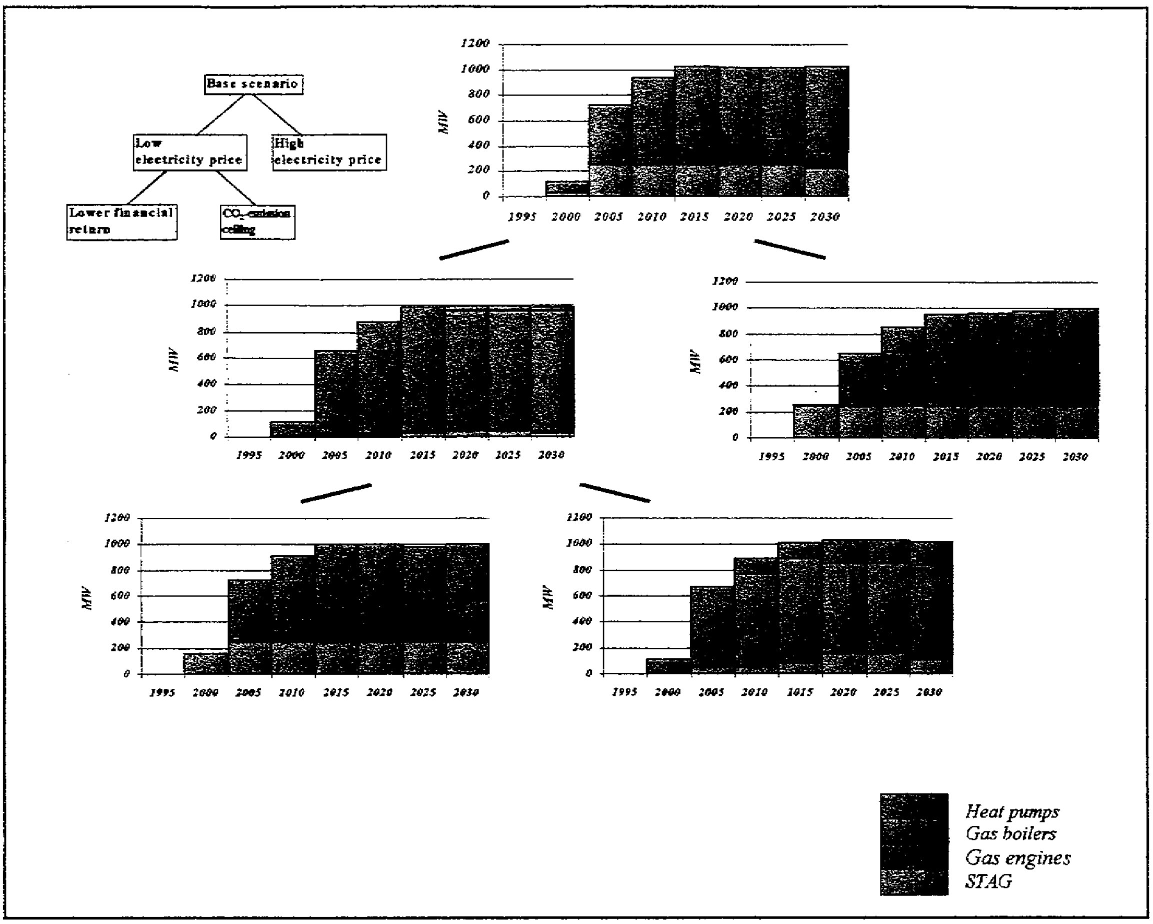


Figure 5.6-10: The choices of technology (total installed capacity) in each scenario.

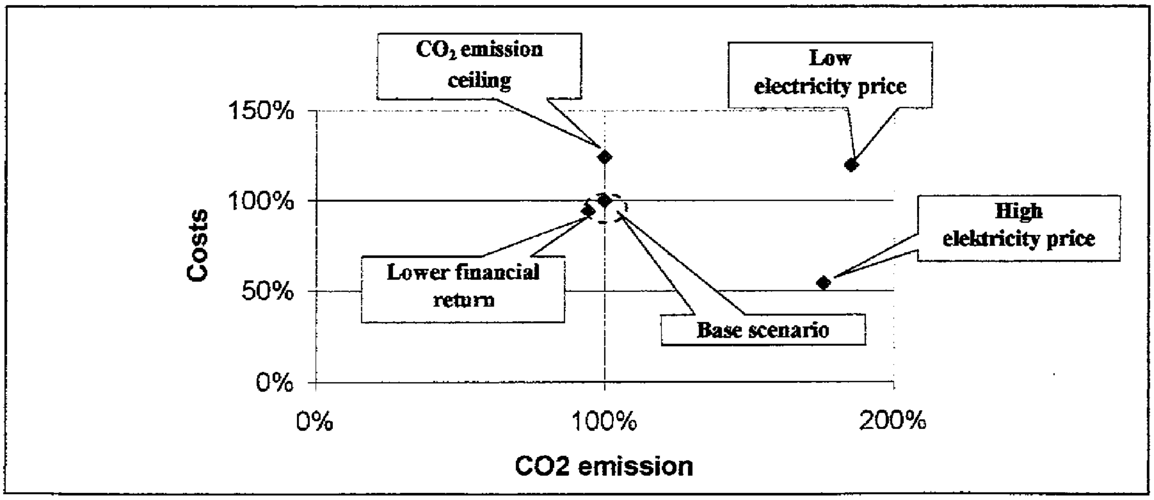


Figure 5.6-11: Costs plotted against CO_2 emissions for each scenario.

5.6.6 Exchange of information between the groups concerned

In the first chapter, it has already been indicated that the study was commissioned by Novem. The case study derived from an actual situation, but in assessing the results, the first consideration was whether the type of information would be usable for utilities. In addition, when using MARKAL, the question of whether the programme could eventually be implemented within a utility did play a part in the assessment. The utility Energie Delfland made the information available and at the request of G3 Advies supplemented it in a number of points. There have been discussions concerning the input and the interim results. In addition, at the request of Energie Delfland, the method of calculation of MARKAL was examined in more detail, so that they were better able to assess the extent of influence of the results. Collaboration on these points went well. Concerning the (interim) results, regular reports were given both to Novem and to Energie Delfland.

5.6.7 Evaluation

This study may be seen as a first step in an implementation process in which the evaluation has a bearing on the follow-up process. It has been found that working with Markal does require a certain specialist expertise. It will have to be considered whether the investment by a utility in the training of a specialist is worth the anticipated results. Moreover, an important point is whether analytical tools play a part in the appraisal of commercial risks, because at the moment the attention of many utilities is focused primarily on the consequences of this increased freedom for their own internal organisation.

For the follow-up process, a number of suggestions have been made. Consideration may be given to shifting the focus on the energy vision to be set up by local authorities. In that case the local authority must have technical and economic knowledge related to energy supply, if it wishes to make an appraisal of the possibilities independently from utilities. This knowledge can be obtained from an external consultant. Markal could then also be used exclusively by consultants.

It is possible to involve several utilities in drawing up the energy vision of the local authority. This consultation could become an ALEP process in which requirements and possibilities could be matched to each other at an early stage, as a kind of preparation for a possible tendering procedure. In this process, the local authority could also be supported by a consultant using MARKAL.

APPENDIX:

ALEP Modelling Tools

Whereas the guidebook has frequently used the term "comprehensive models" as a means of ALEP in the main part of this guidebook, no explanations where provided so far for energy system models and their mathematics. This is done in the Appendix by the following three parts:

A.1 Modelling the Energy System
A.2 The MARKAL model: A Comprehensive Tool for ALEP
A.3 Fundamentals of Linear Programming

The purpose of this part of the guidebook is to provide the reader with an overview of existing models and the methods for simultaneous optimization. The interested reader is referred to textbooks on Operations Research for further information (see end of A.3). In addition, references to actual literature are provided in A.1 and A.2.

A.1 MODELLING THE ENERGY SYSTEM

A.1.1 Introduction

Large-scale energy systems are highly complex structures in which energy and materials flows are connected by articulate networks of technologies, with equally complex single components. Energy-environmental planning pursues different objectives, such as: minimising goods and services costs, pollutant emissions, fuel imports; achieving either a strategic or detailed planning result; and involving different demand sectors (residential, industry, transportation, services, etc.).

At the same time, uncertainties affect many aspects of energy systems modelling: changeable future development of energy and socio-economic scenarios, physical boundary conditions, availability of resources and technologies, prices of fuels, or new issues from technology development or scientific findings.

Thus, a large amount of information is required to describe such complex systems, and several tools are necessary to analyse different issues and achieve a variety of results that are needed for the planning process. Therefore, even if developing, learning and applying computer models is a time-consuming effort, it becomes an essential step of the planning process in order to deal with the *complexity* and *uncertainty* of energy systems development.

The ALEP approach is based on the use of *comprehensive tools* for modelling the whole energy system The aim of modelling is to provide an optimal allocation of resources in compliance with existing and superimposed technical, social, economic and environmental constraints. Furthermore, the modelling procedure must be iterated with respect to new issues arising from the decision framework and from the analysis of intermediate results. Such an iterative procedure must be set up to regularly update the model database, to analyse and compare different development scenarios, and to perform a sensitivity analysis which allows the users to identify the key-parameters of the case studies and to point out the effects of their variation.

In this framework, energy-technology comprehensive models, such as MARKAL, can take into account the above-mentioned points and are therefore powerful tools for the ALEP purpose. In fact, their high flexibility makes them suitable for analysing and optimising energy systems characterised by different boundaries, different spatial and time scales and with varying levels of detail.

Besides this comprehensive model, other auxiliary tools are necessary to integrate and support the planning process. Taking into account the planning goals, the comprehensive model gets information from auxiliary models and from a dynamic database, which is interfaced with a Geographical Information System (GIS). Furthermore, the results obtained by the comprehensive model support the definition of the planning strategies for updating the database and, eventually, correcting the planning goals. In this phase, GIS is helpful for data analysis and presentation, allowing the user to visualise the impacts related to different strategies. These relationships are described by figure A.1-1 in a slight variation of figure 1-1, chapter 1.

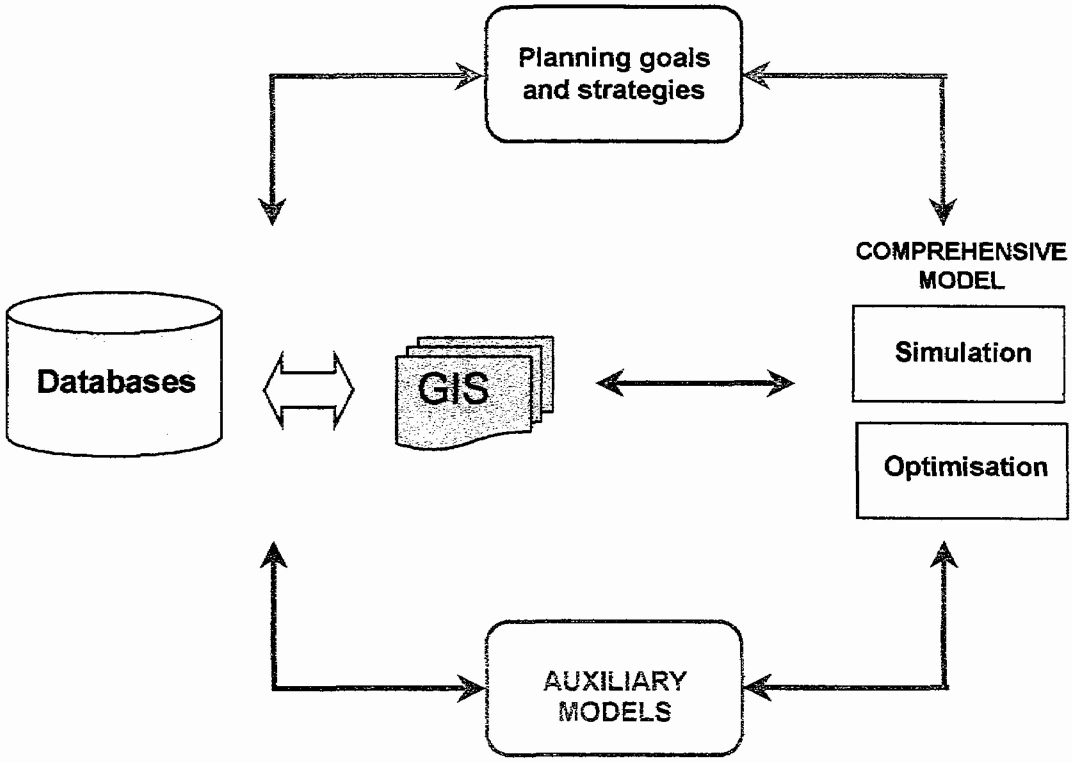


Figure A.1-1: Flow chart of the integrated comprehensive approach.

Optimisation and simulation models used for the analysis of the anthropogenic activities system can be classified by two kinds of approach: the *technical* and the *macroeconomic* approach. In the first case, the features of the aggregate demand are built up from a specific and detailed description of the technological and social-economic environment, whereas in the macroeconomic approach the focus is directed rather on the behaviour of aggregate economic variables, than on specific details of end-use demands and technologies. The two classes of models tend to generate quite different estimates of costs, due to the different approach and to the different definition of costs (UNEP, 1992).

Model inventories, as provided in this appendix, use a growing number of tools for the analysis of local energy systems. Therefore it becomes important to assess the applicability of a model in a particular planning situation. Relative to their different features, models can be classified as follows:

- *Comparative static* models, which compare in great detail one year to another without representing their development, and *multi-period dynamic* models, which represent the development of systems over a medium or long-term horizon;
- *Energy specific* and *economy wide* models: the former represent the energy sector in detail whereas the latter focuses on the whole economy, with the energy sector as one part;
- Depending on the time scale, *short-term*, *medium-term* and *long-term* models can be distinguished.

Other distinctions refer to the *level of disaggregation* and the *geographical scope*, which depend on the aim and the characteristics of the model.

Technological models, which are of importance to the ALEP planning process, can be divided into three categories:

- *Subsystem models*: computer software which can be used to simulate energy supply and/or demand, either for one year of operation or development over several years. They provide data on the technical characteristics of the energy system and related financial or direct costs (investment, O&M, and fuel costs);

- *Integrated energy system simulation models*: they may be used to represent complex energy demand and supply systems in which end-use, conversion and production technologies are included at a highly disaggregated level, allowing for a very detailed analysis both of economic characteristics and of options for emissions abatement, such as CO_2. The main limitations and possible drawbacks are the following: the checking of system consistency is often left to the model-user, the result of a scenario simulation does not indicate whether a system optimum has been achieved, the high level of detail requires a thorough knowledge of the system both in the data-input and in the interpretation of results. An example of such a model is MESAP/Planet.

- *Energy system optimisation models*: in general they use the linear programming approach, determining the optimum mix of energy supply which corresponds to the minimum discounted cost over a long-term period, constrained by a number of infrastructure and policy parameters. The main limitations are the following: the linear representation can only describe constant return to scale, small variations in input parameters can cause large variation of results so that many constraints must be introduced to reduce the degrees of freedom of the problem; the most attractive technologies are generally implemented first, whereas in reality they are introduced gradually and in parallel. Models of this category are EFOM, MESSAGE and in particular the IEA-MARKAL and TIMES developments. A drawback of this class of models is that conventional planners are hardly ever familiar with them, since they have been used so far by systems analysts rather than by planners working in the field of local energy planning.

In general, technological models ignore the existence of hidden costs for technologies and transaction costs for the implementation of policy measures (e.g. information campaigns, normative setting, R&D). Moreover they do not take into account that market imperfections and other economic barriers can obstruct the potential implementation.

To help environmental and energy planners in the choice of supporting tools for ALEP, criteria for the model choice and an overview of representative models with their main features are provided in the following paragraphs.

A.1.2 Scope and detail of models

As discussed in chapter 4 two conflicting pairs of requirements govern the modelling of energy systems: Strategic vs. operative planning and subsystem vs. comprehensive analysis. The requirements can be expressed by the time span covered by the planning task, and the consideration of interdependencies between subsystems and influences of socio-economic developments:

- Operative and strategic planning are distinguished by the time span considered and by other factors related to the energy, technological and socio-economic framework. Operative planning looks at short-term optimisation from minutes to days, and an otherwise fixed technical energy system and socio-economic framework. Strategic planning tries to include long-term technological and socio-economic developments.

- Subsystem and comprehensive analyses are distinguished by the extent of their system boundaries. Subsystem analysis is restricted to a limited number of subsystems within the whole technical energy system. Influences from other subsystems are considered in a simplified manner. A comprehensive analysis, on the other hand, tries to treat all important subsystems and their interdependencies within one model.

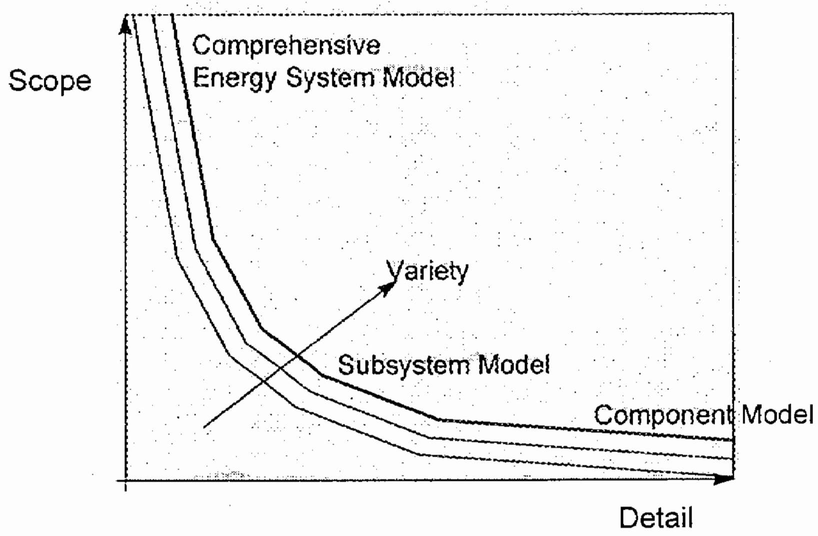


Figure A.1-2: Scope and detail of models

Operative planning requires a large amount of detail within the subsystems, because high accuracy is required. In strategic planning, too much detail in the subsystems can often obstruct the view of the total system behaviour for long-term developments. Instead it is more important to consider the interdependencies between the large number of subsystems. A planner can not control too many details at the same time, since he has only limited resources to collect the necessary data and to build a model, which helps him to understand the complex interdependencies. Additionally there are restrictions to the ability of the tools to handle complexity and to process the data required for very large models (often consisting of more than 1000 equations) in reasonable time. As a result, operative planning is carried out on a subsystem level with a limited time horizon and little consideration of comprehensive aspects. Strategic planning, on the other hand, is done in a comprehensive analysis with a long time horizon and little detail on the subsystem's level.

Figure A.1-2 expresses the connection between detail and scope of models in a qualitative way.

The scope of a model is defined by the number of different processes and flows that are described in the model, the number of subsystems, the time frame and time steps. The detail of a model is defined by the complexity of the mathematical description of the processes and flows and their system dynamics. A component model (for example, a model for a heat exchanger or a combustion chamber of a power plant or a building) may contain a very complex description of the thermodynamic behaviour, but it describes only one or two processes and the time span is either stationary or describes, for example, the behaviour of a transition from cold to hot. Therefore, a component model has a high degree of detail but a "narrow scope". A comprehensive energy system model, on the other hand, uses simple descriptions for the processes and flows, but contains many objects and uses a complex description of the system behaviour over time. Therefore, a comprehensive energy system model has a wide scope but a low degree of detail. A model with large variety, that means wide scope and high degree of detail is faced by a combinatorial avalanche. Figure A.1-2 expresses this connection for a set of models which are assumed to have the same amount of variety. The fat line indicates the maximum variety which can be handled by models today because of the limitations of the computer software and solution algorithms. Considering the limitations of a model and the abilities of a modeller to set up such a model and to understand the results, a choice between scope and detail has to be made. Both aspects must therefore be addressed by different models.

A.1.3 Choice of model and modelling method

In order to decide on the use of one specific model, it is important to explain the differences between model structure, data and modelling method. A model is a simplified abstraction of a real technical energy system. The structure of the model is defined by processes and the energy and material flows between the processes (some models can also distinguish different regions and economic sectors). A model needs technical and economic data to describe processes and flows (see also the RES figure in Chapter 4). A model also needs a set of mathematical equations to describe the behaviour of the system. The mathematical description of the processes and flows follows a certain methodology. Examples of methods are simulation, linear optimisation or non-linear optimisation. Hence a model consists of the description of the structure, the data and the equations.

The term *energy system model* refers to a software tool, a so-called model generator. This means that the user can build his own model representation of any technical energy system. He starts from scratch or from a suited example, and adds processes and flows to build the structure of his model. Then he has to enter the input data. From the structural definition of the model and the model data, the software tool (model generator) creates an equation system using certain methodology like linear optimisation.

The purpose of using an energy system model is to calculate the implications of certain policy strategies on the energy system, the economy and the environment. Models can be distinguished by the aggregation of the energy system, as well as by their spatial and time resolution. Models are made for specific purposes like investment calculation, operation planning for power plants or strategic energy system planning for whole energy systems. Questions, objectives and availability of data determine the selection of a method (e.g. simulation or optimisation) and the construction of a model (processes, flows, boundary conditions). The main consideration for the selection of a tool is the method (e.g. simulation or optimisation). Optimisation is especially suited to calculate least cost strategies under certain boundary conditions. Simulation is better suited for energy demand analyses or explorative analyses. As a general rule simulation is easier to understand and to apply. The interpretation of the results is straightforward. Optimisation is more complex and it takes more time to get meaningful results. Interpretation of results and error detection requires much experience. The results are sometimes unexpected, but give new insights into the system behaviour. It is easy to see the influence of new restrictions. A combination of both methods can be very effective.

Other considerations for the selection of a model are the possible time horizon, limitations on the number of possible processes and flows allowed by the modeller, cost and hardware requirements of the software and the necessary engineering skills and computer literacy of users (influenced by the user interface that is available for different models).

At present, only a limited number of well documented and user friendly model generators for comprehensive energy system models are available. Energy system models for the comprehensive analysis like MESSAGE, EFOM, MARKAL and MESAP-PlaNet all use the "RES" representation for energy systems, whether they are flow oriented models like EFOM, or process oriented models like MARKAL, MESSAGE and MESAP -PlaNet. (MESAP -PlaNet is a simulation tool and MESSAGE, EFOM and MARKAL are optimisation tools.)

A summary of models actually used in energy-environmental planning is given (in alphabetic order) in Table A.1-1.

MODEL NAME	ORIGIN	TYPE OF MODEL	OTHER INFORMATION
AIDAIR	CUEH[1]	GIS based decision support system	It is composed of three interconnected modules: EGIS (Energy GIS), TAP (Traffic and Air Pollution) and APPH (Air Pollution and Public Health), in ***French***
BALANCE	IAEA, US-DOE[2]	Energy supply and energy system model	A model for the *simulation* of energy supply, belongs to the ENPEP family, in ***English***
CAPLEP	LAME[3]	Design of district heating network	In ***Italian***
CO2DB	IIASA[4]	Energy information system	CO_2 database, in ***English***
DECPAC/DECADES	IAEA[5]	Energy information system	Database and technology chain analysis, in ***English***
E³Net	IER[6]	Energy supply and Energy system model	Optimisation model, in ***German***
EFOM-ENV	EU	Energy supply and Energy system model	**E**nergy **F**lows **O**ptimisation **M**odel, in ***English***
EM	World Bank, GTZ[7]	Model for life-cycle assessment of power systems	**E**nvironmental **M**anual: a *simulation* model based on the GEMIS-model, in ***English***
ENERPLAN	UNDTCD[8]	Modular planning instrument	It couples a macroeconomic model with a simulation model of energy sectors, in ***English***
ENIS	IER	Energy information system	Database in ***German*** and ***English***
ENPEP	IAEA, US-DOE	Modular planning instrument	**E**nergy and **P**ower **E**valuation **P**rogram, in ***English***
ETA-MACRO	EPRI[9]	Energy-economic model	Dynamic model which couples the macroeconomic MACRO with the aggregated energy system model ETA (**E**nergy **T**echnology **A**ssessment), in ***English***
ETB	ERL	Modular planning instrument	**E**nergy **T**ool**b**ox for developing countries, in ***English***
GEM-E3, E3ME	EU	Energy-economic model	Computable **G**eneral **E**quilibrium **M**odel for studying economy-energy-environment interactions, in ***English***
GLOBAL 2100, GREEN, 12RT	OECD[10]	Energy-economic model	Dynamic models based on ETA with 5 (*GLOBAL 2100*) or 12 (*GREEN, 12RT*) world regions, in ***English***.
GOMBIS	VSE Saarbrücken	Model for simulation of complex cogeneration plants	In ***German***

[1] Centre Universitaire d'Ecologie Humaine et des sciences de l'environnement, University of Genève (Switzerland)
[2] USA Department of Energy
[3] Laboratorio di Analisi e Modelli Energetici, Polytechnic of Turin, Italy
[4] International Institute for Applied Systems Analysis, Laxenburg (Austria)
[5] International Atomic Energy Agency
[6] Institut für Energiewirtschaft und Rationelle Energieanwendung, University of Stuttgart (Germany)
[7] Gesellschaft für Technische Zusammenarbeit mbH
[8] United Nations, Department of Technical Co-operation for Development
[9] Electric Power Research Institute, Palo Alto (California, USA)
[10] Organisation for Economic Co-operation and Development, Paris (France)

HERMES	EU	Macroeconomic model	Sector model in ***English***
HOVA	PROFU	Model for the analysis of energy conservation potential	An Excel-based model, database in ***Swedish***
IKARUS Technical data-base	KFA[11], BMBF[12]	Energy information system	Database in ***German***
IKARUS Models	KFA, BMBF	Modular planning instrument	A model system to reduce energy-related greenhouse gas emissions in Germany, in ***German***
LEAP	TELLUS	Modular planning instrument	**L**ong-Range **E**nergy **A**lternatives **P**lan-ning, simulation model for developing countries, in ***English***
MACRO	IIASA	Macroeconomic model	Sector model in ***English***
MADE	IKE[13]	Model for the analysis of energy demand	**M**odel for the **A**nalysis of the **D**emand of **E**nergy, in ***English***
MAED	IAEA, US-DOE	Model for the analysis of energy demand	**M**odel for the **A**nalysis of **E**nergy **D**e-mand, a module of the ENPEP planning tool, in ***English***
MARKAL	ETSAP[14], IEA	Energy supply and Energy system model	**MARK**et **Al**location model with an User Support System (MUSS), in ***English***
MARKAL-MACRO	BNL[15]	Energy-economic model	Linked models for energy-economy analysis, in ***English***
MARTES	PROFU[16]	District heating model	A *simulation* model for district heating production, database in ***Swedish***
MEDEE	IEJE[17]	Model for the analysis of energy demand	**M**odèle d'**E**valuation de la **D**emand **E**n **E**nergie, bottom-up model, in ***English*** and ***French***
MESAP	IER	Modular planning instrument	**M**odular **E**nergy **S**ystem **A**nalysis and **P**lanning, in ***English***
MESSAGE	IIASA	Energy supply and Energy system model	*Optimisation* **M**odel for **E**nergy **S**upply **S**ystems and **T**heir **G**eneral **E**nviron-mental Impact, in ***English***
MICRO-MELODIE	CEA[18]	Energy-economic model	Energy-economy interaction model for long-term planning, in ***French***
MIDAS	EU	Energy supply and Energy system model	A modular *simulation* model, in ***English***
MIS-IKARUS	KFA, BMBF[11]	Macroeconomic model	Dynamic I-O model, in ***German***
MODEST	IKP[19]	Energy system optimisation model	Minimisation of capital and operation costs of energy supply and demand side management, in ***Swedish***
NEMS	US-DOE	Energy-economic model	**N**ational **E**nergy **M**odeling **S**ystem, in ***English***
NEWAGE	IER	Energy-economic model	Quasi-dynamic model with an hybrid representation (*bottom-up* and *top-down*) of the technologies of the indus-

[11] Forschungszentrum Jülich (Germany)
[12] Bundesministerium für Bildung und Forschung, Bonn
[13] Institut für Kernenergetik und Energiesysteme, University of Stuttgart (Germany)
[14] Energy Technology System Analysis Project
[15] Brookhaven National Laboratory
[16] Projektinriktad Forskning och utveckling-PROFU, Göteborg (Sweden)
[17] Institut Economique et Juridique d'Energie
[18] Commissariat pour l'Energie Atomique
[19] IKP Energy systems Institute of Technology, Linköping (Sweden)

			try sector, in ***German*** and ***English***
PERSEUS	IIT[20]	Energy and material flow model; energy system model	Program package for emission reduction strategies in energy use and supply - integrated resource planning, in ***German***
PLANET	IER, University of Stuttgart	Energy supply and Energy system model	Long-term energy system simulation, in ***English***
POLES	EU	Energy supply and Energy system model	**P**rospective **O**utlook on **L**ong-term **E**nergy **S**ystems, *simulation* model in ***English***
PRIMES	EU	Energy-economic model	A computable Price-Driven Partial Equilibrium Model of the Energy System and Markets for Europe, in ***English***
SAFIRE	EU	Technology assessment model	**S**trategic **A**ssessment **F**ramework for the **I**mplementation of **R**ational **E**nergy. *Simulation* model for power and heat supply at the local and regional level for European countries, in ***English***
SESAM	Aalborg University	Modular planning instrument	The **S**ustainable **E**nergy **S**ystems **A**nalysis **M**odel for energy systems planning at local and regional scale, in ***English***, ***Danish*** and ***German***
SUPER/OLADE-IDB	OLADE-IDB	Modular planning instrument	Special tool for Ecuador, **O**rganizacion **La**tinoamericana **de E**nergia, in ***English***
TEESE	TERI[21], India	Modular planning instrument	**TE**RI **E**nergy **E**conomy **S**imulation and **E**valuation model, in ***English***
TIMES	ETSAP[22], IEA	Energy supply and Energy system model *(under work)*	The **I**ntegrated **M**ARKAL-**E**FOM **S**ystem, in ***English***
TEMIS/GEMIS	ÖKO-Institut, Freiburg/Darmstadt	Energy system model	Calculates CO_2-emission balances and pollutants of mixed supply systems (based on GEMIS), in ***German*** and ***English***
WASP	IAEA, US-DOE	Electricity supply model	**W**ien **A**utomatic **S**ystem **P**lanning, *optimization* model, in ***English***
WINGRAF	LAME	Energy system model	Simulation software, in ***Italian***.

Table A.1-1: List of models used in energy-environmental planning (partially extracted from Schlenzig, 1992).

Table A.1-1 shows that a large number of models with different degrees of scope and detail are currently available. Some of them are discussed in more detail below.

A.1.4 Energy system modelling

The analysis of technical energy systems can be supported by several tools designed to analyse the entire energy system or its subsystems, i.e. large-scale energy conversion (e.g. cogeneration plants), energy distribution (e.g. electricity or district heating), energy supply and conservation in buildings, energy demand simulation and energy conservation options. The following paragraphs give a brief de-

[20] IIP, Institut für Industriebetriebslehre und Industrielle Produktion, University of Karlsruhe (Germany).
[21] Tata Energy Research Institute
[22] The principal architects are Gary Goldstain (International Resources Group, Ltd., USA), Amit Kanudia and Richard Loulou (GERARD, Canada), Denise van Regemorter (KUL, Belgium), Peter Schaumann and Uwe Remme (IER, Germany), and GianCarlo Tosato (ENEA, Italy)

scription of simulation and optimisation models that today are frequently used in energy system analysis, although many other tools are available or in the process of development.

A.1.4.1 Optimisation models

MARKAL is one of the most widespread models used in energy-environmental planning. It was used throughout the case studies of Annex 33. Among the several implementations of MARKAL model now available there is RMARKAL which allows the user multi-regional analysis. Therefore for each region a model is created and can be optimized as in a usual MARKAL application; moreover different regions can be linked together by the way of commodities exchanges (energy carriers, materials, etc) or CO_2 permits trades and the whole system can be dynamically solved. RMARKAL is widely used to analyze possible co-operation in emission abatement and CO_2 permits trades between countries, while at local level (for instance municipalities, counties, etc) can be used to enhance local peculiarities and investigate energy flows.
For a more detailed description of MARKAL model refer to Chapter A.2.

MODEST is a *static* model based on linear programming developed in 1992 and used in several Swedish energy planning projects. Contrary to the MARKAL model, the optimisation of the energy system refers to a single year instead of a multi-year period. On the other hand it provides a very detailed time resolution for load curves.

IKARUS arose out of a 1990 German project aimed at the exploration of "Instruments to Reduce Energy-Induced Greenhouse-Gas Emissions". The model consists of simulation and optimisation tools, as well as a database and technology information system which provides well documented and generally accepted data.

The **MESAP** (Modular Energy System Analysis and Planning) software is a decision support system for energy and environmental management at the local, regional or global scale. It has been designed at IER / University of Stuttgart according to professional software engineering standards. MESAP can be applied for demand analysis, integrated resource planning, demand-side management, and the simulation or optimisation of energy supply systems. It can also be used to set up statistical information systems in order to regularly produce energy balances and emission inventories. The core of MESAP is a standardised database and information management system with interfaces to different energy models with Windows user-interface, built-in scenario management and unit conversion. The current version MESAP 3.1 contains the following modules: *PlaNet* - the simulation model for energy systems, *ENIS* - the energy information system, *Analyst* - the report generator, and *Manager* - the MESAP system administration tool. An extension to TIMES is being worked on.

MESSAGE (a **M**odel for **E**nergy **S**upply **S**trategy **A**lternatives and their **G**eneral **E**nvironmental Impact) is a dynamic linear programming model developed by IIASA - International Institute for Applied Systems Analysis (Austria). In its usual application the model is used for the optimisation of energy systems at the national level, but any other problem dealing with flows of commodities (where specified demands are to be met by a given set of supply options) could also be modelled. The latest version, MESSAGE IV, adds the option of multi-regional model definition to the formulation and can also be used to optimise mixed integer programming models, defining investment variables as integers and using adequate solution algorithms (e.g. CPLEX, OSL). In 1996 a new integrated MESSAGE -MACRO model was developed to simplify the entire modeling approach by adding a macroeconomic module to the systems-engineering model.

EFOM (**E**nergy **F**low **O**ptimization **M**odel) is an energy supply model commissioned by the Commission of the European Community / General Directorate XII during an early EU-research program on energy and environment. It simulates or optimises the primary energy requirements and the related investments in energy production and end-use equipment necessary to satisfy an exogenously determined consumption of final energy. The technical-economic information is stored in a database (the EDB - European Energy Data Base) designed to enable the user to build specific structures of energy systems. The energy system is represented by an oriented network in which the primary energy flows is gradually transformed into secondary and final energy. It has a multi-periodic structure which allows the user to cover a study time span of up to 40 years, divided into sub-periods.

The **PERSEUS** program family (IIP / University of Karlsruhe) is based on the energy system model EFOM. It was developed into a multi-period, mixed integer linear optimisation program for energy planning, technology assessment, development of climate protection strategies, integrated resource planning and energy supply program optimisation. As with MARKAL and TIMES, PERSEUS also uses the programming language GAMS for the mathematical description of the energy system. The energy system is modelled as a link node structure representing the energy flows and transformation processes. The main features of the model, which is intended for use by regional and local utilities, are:

- utilisation of realistic and detailed load curves with diurnal and seasonal variations,
- flexible definition of model structure and level of detail,
- integration of supply side and demand side alternatives,
    - power plant management and optimisation,
    - power plant expansion planning,
    - optimisation of buy and sell options and energy trade including spot markets,
    - demand-side management programs,
    - contracting projects
- calculation of short-term and long-term production costs,
- calculation of costs and proceeds from individual customers or customer groups,
- calculation of overall investment costs and proceeds.

PERSEUS can be used as a decision support system in the energy industry for both strategic and short term planning under competitive market conditions.

TIMES (The **I**ntegrated **M**ARKAL-**E**FOM **S**ystem) is an optimising model that produces least-cost solutions subject to a set of constraints, such as emission limits. It is intended to replace MARKAL which has its origin in the late 70ies and no longer meets modern requirements and possibilities of up-to-date software engineering.

The increased flexibility of TIMES as compared to MARKAL enables it to be used for a wider variety of problems. The main features of TIMES include:

- *Flexibility in time*, the user can select an unlimited number of time periods of variable length, according to the goals of the study. 'Time slices' provide flexible handling of divisions of the year into a four-level hierarchy: annual, seasonal, weekly and day-night.
- *Improved representation of technology* permits a more realistic representation of technological change, innovation and diffusion. A distinction is made between the technical life of a technology and the "real" life time used for economic calculations.
- *Interregional commodity flows* may be used to evaluate the effects of international carbon emission permit trading and, within countries, the infrastructure requirements for electrical grids and natural gas pipelines.

Moreover, TIMES provides better linkages of the reference energy system with the outside through elastic demand curves, regionalization, import/export variables, trade variables for any pair of regions, state-of-the-world index (for stochastic or multi-case runs), monetary flows, taxes and subsidies. Before TIMES can be widely used, however, a user-friendly 'shell' needs to be developed such as is currently available for MARKAL by ABARE[23].

[23] ANSWER is a Windows-based user interface for the MARKAL family developed by ABARE, Canberra (Australia).

A.1.4.2 Simulation models

LEAP (Long-range Energy Alternatives Planning) is a computer-based accounting and simulation tool. It is used to project the energy supply and demand situation and to assess the likely impacts of energy policies. LEAP is structured as a series of integrated programs. Energy scenarios are set up employing a bottom-up approach which makes predictions more detailed and less uncertain. The energy system is simulated by resources, production, transformation, transmission and distribution, and end-use of energy.

MARTES has been largely used in Sweden for the operation of large-scale energy conversion plants. It provides a detailed simulation of district heating production (day-by-day for up to ten years) and uses marginal cost ordering to select the most appropriate operating strategy and calculate the economic and environmental consequences.

HOVA is a Swedish EXCEL-based model for the analysis of energy conservation potentials in the building stock. Based on data for individual measures and the structure (age and numbers) of buildings it is possible to calculate aggregated conservation costs and potentials. Measures can also be aggregated in "packages" to facilitate use in other models, e.g. MARKAL.

The **GOMBIS** subsystem model was developed under commission of a German utility to simulate and optimise cogeneration plants and their integrated operation with a peak load facility (with or without thermal storage). It allows a detailed cost/benefit analysis which includes the financial balances of the utility and effects of tariff structures and eco-taxation.

MESAP /PLANET is a model for long-term energy system simulation developed by IER/Stuttgart (Germany). It uses a flexible time scale, regional scale and technological aggregation, and allows for the analysis of energy demand, the analysis of the impacts of policy strategies on energy and emission balances (with the detailed analysis of environmental impacts) and the overall energy system costs.

The **CAPLEP** (**C**omputer **A**ided **P**rocedure for **LEP**) software is aimed at the design of district heating networks in terms of plant siting, network layout, dimensioning and cost evaluation, pollution estimation and comparison, etc. It was developed by the Energy Department of the Postgraduate Technical College of Torino, Italy (L.A.M.E. – Laboratorio di Analisi e Modelli Energetici).

WINGRAF is a simulation software also developed by L.A.M.E. (Torino, Italy) in order to describe energy and material flows in complex systems and to evaluate costs and environmental impacts.

A.1.5 Models for waste management

Energy-environmental planning, which until now has focused primarily on energy and productive systems, also deals with waste management problems. Here it has to deal with the feedback of energy and material flows from the waste disposal system into the energy and production system. To fulfill these requirements energy models have been expanded to also include waste and material flows. The terminology "integrated waste management models" comprises a wide variety of modelling approaches which can be classified according to their objectives. The two major objectives regard cost minimisation of the waste management system and mapping of environmental impacts of the waste processing strategies. In some models such objectives are combined.

The following list describes the main models used for waste management planning (Swedish Environmental Protection Agency, 1998).

The main ***optimisation models*** used for waste management are :

- The **WAMMM**, **WA**ste **M**anagement **MARKAL M**odel (INFM - National Institute for Physics of Matter), used in a local scale case study (Basilicata Region, Southern Italy) to estimate the environmental impact of the waste processing technologies in the context of the whole production system.
- The **MIMES/Waste** model (Chalmers University of Technology, Göteborg), a non-linear optimising model for the strategic planning of municipal waste management systems, which is being applied in several systems both in Sweden and abroad.
- **EUGENE,** a mixed integer linear programming model developed in Canada (École des Hautes Études Commerciales, Montréal) to help the regional decision makers in the long-term planning of the solid waste management activities.

Moreover, environmental planners can refer to the following ***simulation*** models:

- The **SWIM** model, an interactive computer package developed in EXCEL by the University of Melbourne (RMIT) to provide a structure for systems analysis of solid waste management problems at the municipal level. Also based on EXCEL spreadsheets is **HMA** (**H**elsinki **M**etropolitan **A**rea), a static and linear simulation model, which was developed in Finland for the calculation of recovery rates and waste streams and for the assessment of system costs and emissions.
- The *'model for the collection and processing of waste streams'* developed at **TNO-MEP** (The Netherlands) is set up with three separate modules which allow the user to describe the organisation of the *collection* system, the *processing* phase and the *transport/logistic* step .
- Other models were developed for specific purposes, such as to estimate the needs and costs for collection and recycling, and the cost impact of adding beverage cartons to a future programme (**ERRA** model, by TETRA-PAK International); to assess the effects of thermal and material recycling of plastic waste on the waste management system (system dynamic modelling software **POWERSIM**); to investigate changes in costs, energy-utilisation and material flows, depending on changes in waste input for municipal solid waste incineration (**ECOSOLVER**).

A.1.6 Applications of GIS

Geographic Information Systems (GIS) technologies are rapidly finding applications in different areas including risk assessment, pollution control and environmental planning. There have been several attempts to integrate GIS with other tools, following two main pathways: a *full integration* approach, in which models are developed directly within GIS using GIS -based programming language, and a *soft linking* approach, which allows models and GIS to complement each other in iterative steps. To handle the large amount of technical and environmental data which have to be taken into account in the ALEP phases, GIS -instruments are increasingly used to provide the graphical representation and visualisation of this information.

The **AIDAIR** system is an Information and Decision Support System (IDSS) designed to help decision-makers in their assessment of public policies and strategies concerning urban air quality policy. This system is composed of three interconnected modules: EGIS (Energy GIS), TAP (Traffic and Air Pollution) and APPH (Air Pollution and Public Health). The structure of the IDSS and the relationship between the three modules are represented in figure A.1-3.

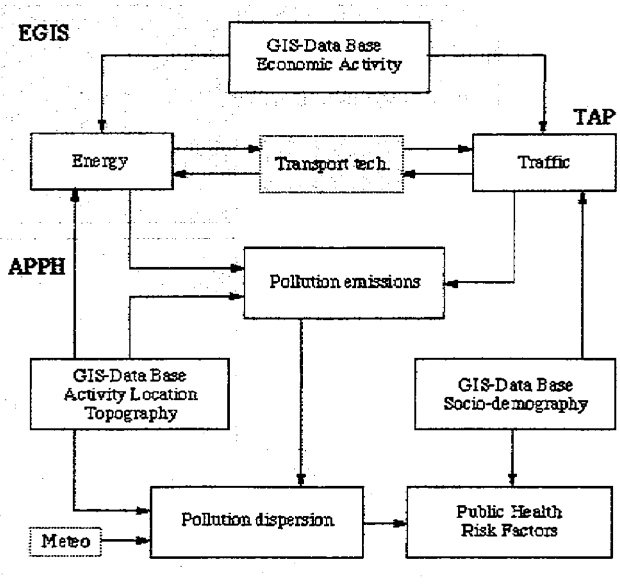


Figure A.1-3: The AIDAIR system

The novelty of the AIDAIR IDSS lies in the dynamic integration on a common platform of GIS and different models (e.g. a traffic equilibrium model, an energy/technology choice model, a pollution dispersion model and a health impact model). The system permits an integration of many meteorological, physical-chemical, technological, economic and medical parameters. AIDAIR was implemented for the Geneva region as a case study. Figure A.1-4 shows a display of pollution plumes over Geneva due to the 16 most important NOx emitters in the canton, illustrating also AIDAIR's graphical user interface. Different analyses can be triggered by clicking the command buttons.

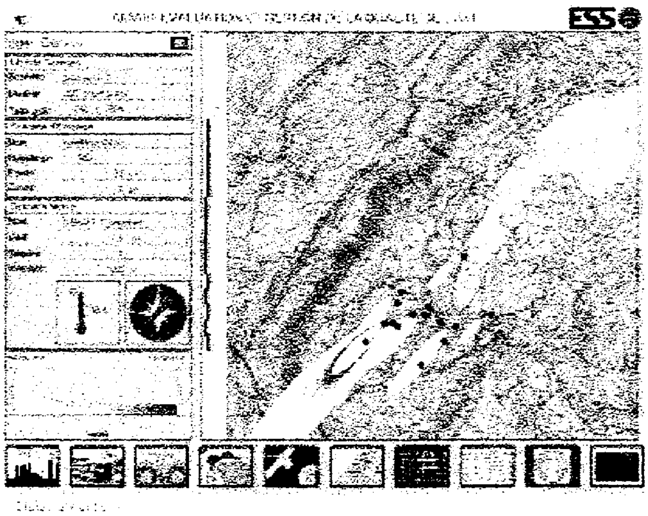


Figure A.1-4: NOx pollution plumes over Geneva

Other models containing a GIS-system include the following (Jank *et al.*, 1994):

- **NIPS,** an alphanumeric database with technical information on electricity, gas, district heating and water-grid facilities, other than customer information (contracts, house connections, installation, etc.). It is used in Germany to provide the basic data for the calculation and optimisation of the gas and district heating network, their expansion and the grid-facilities maintenance.

- **BETRIS,** a German information system on energy supply facilities, which integrates marketing and energy distribution information and communicates with external mapping tools. Different modules refer to the market information system, facility information system and strategic planning.
- **PEGASUS,** a PC-based design tool for gas networks with a GIS-interface. It is frequently used by German gas distributors.
- Several energy distribution models are used in Sweden: **SWEDNET,** a model for the technical-economic planning of the electricity network at high and low voltage levels. **LICHEAT** and **TBMENY,** tools for the design of district heating networks and the calculation of costs and heat losses. **EASYNET** and **GASENOK,** models for dimensioning gas networks in a municipality or conurbation; in particular they can be used to optimise the routes for laying the gas network on the basis of market demand.

In the waste management sector, as well as in the energy sector a big effort is made to combine databases, methods and GIS systems to help decision-makers in defining suitable strategies for the local case. In particular GIS systems may be used to characterise waste handling (localisation of processing technologies, both in terms of the site and the ecological footprint related to different alternatives). An example of such an integration is **GISMAM** (GIS for reduced waste) provided by two Swedish universities (Linköping and Mälardalen University) which combines a relational database system with GIS functions. Such an IT-GIS tool, complementing other optimisation and simulation tools, may be used to support the systems analysis of waste flows both for environmental waste management planning and in Life-Cycle Analysis (LCA).

Another interesting application of GIS based tools is the investigation of the diffusion of atmospheric pollutants in industrial areas. Here, one of the main issues is represented by the necessity of improving the monitoring networks, to support in real-time emergency situations, and to describe more completely the environmental impact of industrial plants. In this framework air pollutant diffusion models are useful to predict the transport, the spatial distribution and the emmission concentrations of pollutants. Their handling by a GIS allows the user to visualise the effects of pollution on the territory, connecting emission sources, pollutant concentrations and land use. The general relationships between diffusion models and a Geographical Information System are shown in figure A.1-5.

A GIS was utilised in the project of the monitoring network of the industrial area of S.Nicola di Melfi (Basilicata Region, Southern Italy), a zone close to an agricultural area, in which a big automotive plant (the FIAT-SATA) and an integrated platform for waste incineration (the FENICE) are located.
In this application, all the information relative to the site characterisation were georeferenced and translated into informative layers of a Geographical Information System, based on the ARC/INFO software (produced by the Environmental Systems Research Institute). Moreover, the Industrial Source Complex (ISC) - a Gaussian plume model developed by the Environmental Protection Agency (US-EPA, 1995) - was used to study the diffusion of pollutant emissions. The analysed area spans 15 km around FIAT-SATA plant.

As a first step the orography data-input of the ISC model was set up, utilising a Digital Terrain Model (DTM) of the Northern Basilicata elaborated by the GIS ARC/INFO software. In the successive steps, taking into account the punctual concentration values estimated by the diffusion model, a G.I.S. - ISC interface was realised to obtain georeferenced pollutant iso-concentration layers. Figure A.1-6 shows the impact map obtained for NOx.

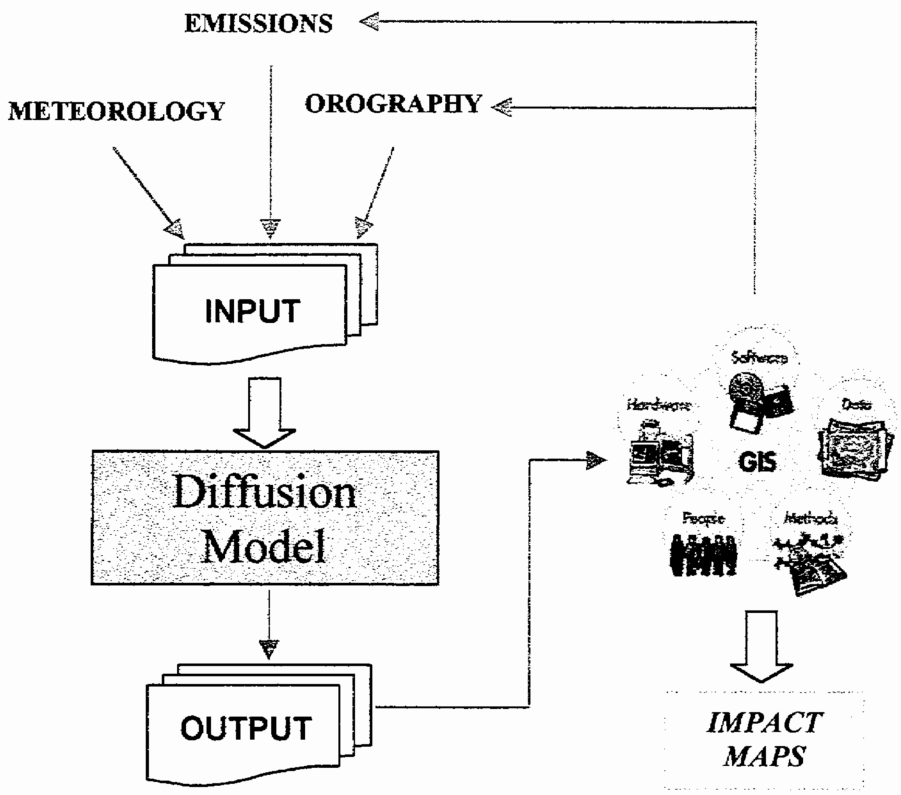


Figure A.1-5: An example of integration among GIS and diffusion models

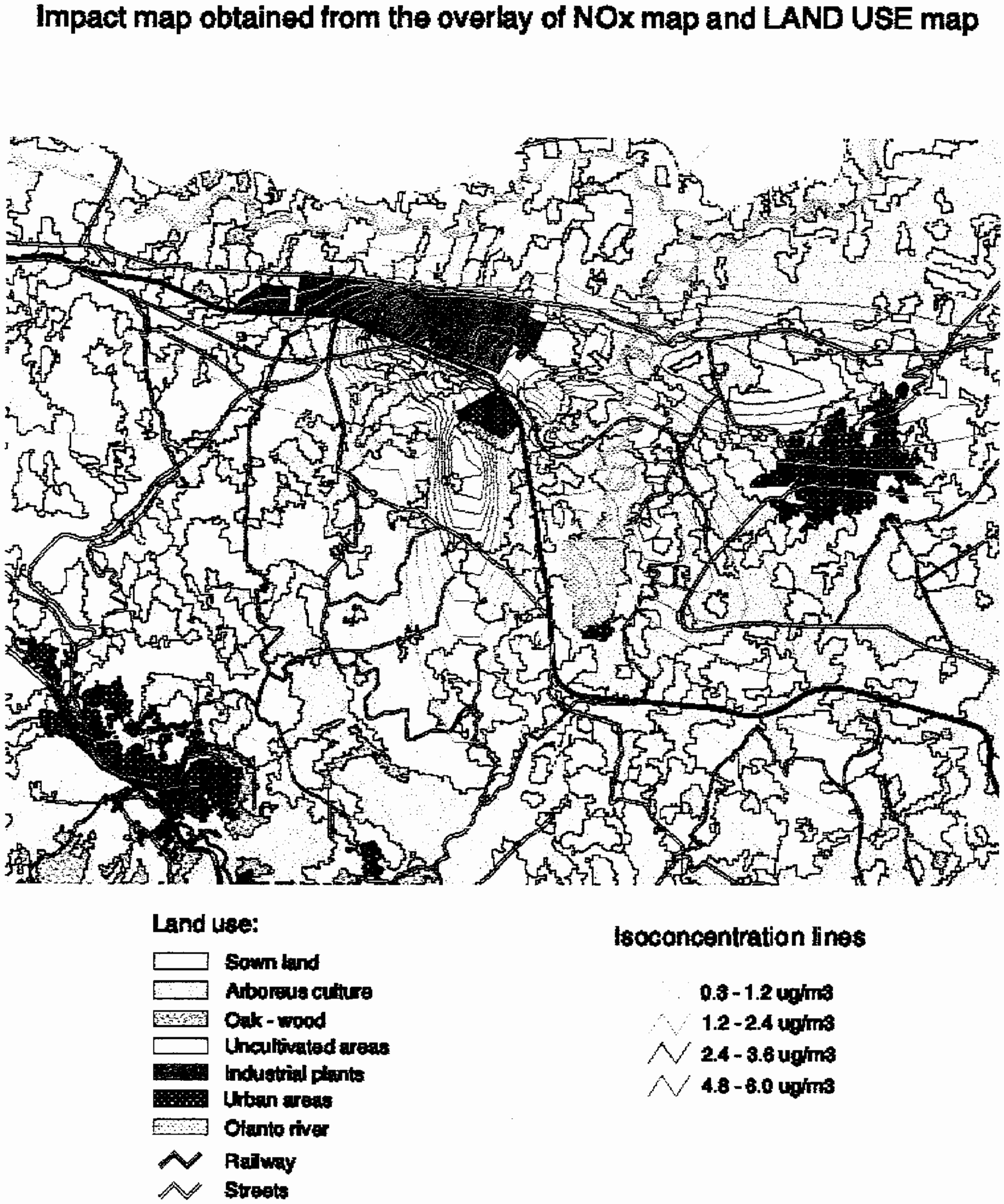


Figure A.1-6: An NOx impact map for an industrial area in Basilicata region as an example

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A.2 The MARKAL Model: A Comprehensive Modelling Tool for ALEP

A.2.1 Introduction

Unlike LEP, Advanced Local Energy Planning (ALEP) is, as decribed in chapter 1, always based on some consistent assumptions of boundary conditions and the behaviour of the (whole) local energy system under consideration, which can be briefly summarised in the following:

a) The energy supply is driven by the demand for goods and services;
b) ALEP uses energy system models rather than isolated component models: in other words its main goal is to identify, on the basis of a given technological, economic and social background, the optimal pathways to achieve some objectives (i.e. to carry out the least cost solutions) satisfying, at the same time, the boundary conditions, as well as other additional constraints;
c) ALEP takes into account all the existing constraints and their relationships. A comprehensive approach is therefore necessary to describe the anthropogenic activities' system, in order to allocate resources (raw materials, technology, energy and financial resources) in the best possible way;
d) ALEP is based on a multi-period dynamic approach: this requirement allows the user to easily add new processes, technologies and resources to the original set of data; to perform the analysis of the energy system over a longer time horizon than the average lifetime of technologies included in the model; and to take into account depreciation times and costs, and to evaluate the potential effects of technology development;
e) ALEP is technology and energy demand oriented in order to include technology development and supply evolution throughout the time horizon. This requirement, in addition to the multi-period structure, allows the user to find the processes that can satisfy the end energy demand, while also having the lowest environmental impact. In any case it is necessary to assess the environmental impact in order to evaluate the necessity of changing the end use demand, or fostering technology innovation to include supply technologies with an acceptable environmental impact. Moreover, technology oriented modelling allows the user to describe the anthropogenic activities in terms of efficiency, average lifetime, availability and depreciation of technologies, pointing out their respective investment costs, operating and maintenance costs and fuel costs. This approach allows the representation of the life cycles of technologies and products either from an economic or from an environmental point of view (emissions of pollutants, land use, waste generated, etc.);
f) ALEP includes a sensitivity analysis to investigate the robustness of solutions to variations of the boundary conditions and of the superimposed constraints. This feature is particularly important for analysing the structure of the end-energy demand, changes in resources availability and effects of increased environmental constraints.

A.2.2 The MARKAL model

A.2.2.1 Background

Among the current available models, as listed in A.1, **MARKAL** (an acronym for **MARK**et **Al**location) is an optimising model based on linear programming techniques. It uses the "revised simplex algorithm" as developed in Operations Research (Fishbone L.G. and Abilock H., (1981)). It is able to satisfy all these requirements better than most other models available. MARKAL was originally developed at the end of the 1970s by Brookhaven Laboratory and KFA Jülich, under an implementing agreement of IEA, addressed to energy planning at the national and supranational scale. So far it has been widely used by OECD member countries in different applications (e.g. E. Fragniere E. and Haurie A. 1996; Johnsson *et al.* 1992; Josefsson *et al.* 1996; Kanudia A. and Loulou R. 1998; Kipreos S. 1992; Kram T. and Hill D. 1996). Recently, also proved to be very useful in environmental planning at local scale.

A full description of the MARKAL model can be found in the *User's guide for MarkAl (BNL/KFA version 2.0)* (Fishbone L.G. *et al.* 1983); in this appendix we summarise its main features in order to discuss the reasons why it can be considered as one of the main tools for ALEP available today (and therefore used for all case studies of Annex 33).

MARKAL is a comprehensive model for energy-environmental planning which allows the user to get a holistic view of the system, by integrating data coming from different sources. In particular, energy, socio-economic and environmental constraints can be combined and taken into account simultaneously to determine the optimal future configuration of the anthropogenic activities' system which achieves the desired targets.

The model is demand-driven and technology oriented (figure A.2-1). These features are essential in order to include technology development and to achieve solutions that match the demand of consumers, also integrating the consequences of demand-side management options.

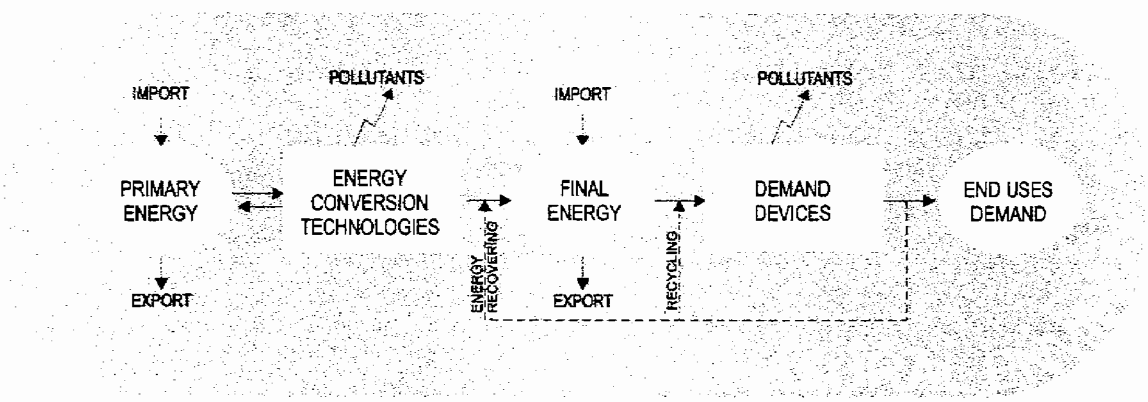

Figure A.2-1: Energy and materials flows in the MARKAL model

No extrapolation model is used to project the past trends into the future, because MARKAL is based on a multi-period structure made up of input data tables with consistent basic structure, containing information on technologies and resource availability elaborated by the actual user. Such a model makes it possible to examine the evolution of the energy system over a time period (divided into several time periods of fixed length) which is based on the knowledge or projection of technology development, economic resources and environmental constraints.

A.2.2.2 Linear Programming Principles

In the following, a short description of the mathematical approach used by MARKAL for systems optimisation is provided (for more details on LP see A.2.4).

A bottom-up linear programming approach is utilised to build up a cost function C (the total discounted cost of the "anthropogenic activities system", such as a total municipal energy system):

$$C = \mathbf{c}\,\mathbf{X}$$

which represents the objective function of the ***"primal problem"*** (to be minimised), where **X** is the vector of the anthropogenic activities and **c** is the vector of the activities' costs per unit of activity. In this structure, the productive activities are characterised by the fuels and the technologies utilised, by the pollutants emitted and by the waste produced. All the costs are actualised to a base year (usually the middle year of the first time period), allowing the user to compare the investments made in different time periods and with different return rates.

Many linear relationships (which represent the "primal constraints' system") are set up to model the system's boundaries, the non-negativity of activities and other physical limitations on resources:

$$\mathbf{AX} \leq \mathbf{B}$$
$$\mathbf{X} \geq \mathbf{0}$$

A, a [n, m] matrix, contains all the coefficients necessary to define the constraints of the local energy system environment, while **B** is the vector of the exogenous constraints. The most important equations concern the fulfillment of end-use demand, the availability of technologies and fuels, and the maximum levels of emissions allowed.

In the optimising procedure, the best allocation of activities identifies the fuel mix and the set of technologies which are able to satisfy the constraints imposed on the system at the minimum feasible cost.

A reference model database can be set to describe the existing energy system and the "natural" trends of supply and end-energy demand (*"Reference Energy System"* – RES). Starting from this RES, changes on the same database can be set up, to model a different evolution of the boundary conditions ("scenarios"). In this way, sensitivity analyses can be performed to investigate the stability of the solutions given by the model to the changes of exogenous or endogenous parameters (energy prices, discount rates, technology efficiency, supply, goods and services demand, emission restrictions, etc.).

For example, it may be interesting to examine the consequences of discount rate variations on the system configuration. This exogenous parameter strongly influences the rate of substitution of technologies (in fact, a higher discount rate usually prevents investments in new technologies, so that the implementation rate of a more efficient technological configuration is slowed down). A sensitivity analysis of the market allocation of fuels and technologies as a function of the discount rate values can be performed in this example to quantify the role that monetary incentives could have in promoting the penetration of technological innovation into the market.

More generally, to analyze different objectives it is possible to minimise the primary objective function (the total discounted cost of the energy system) by varying stepwise the other parameters of interest (for example, the allowed emissions levels), which act as a secondary objective function (Goicoechea A. and Harris T.R., 1988). The optimal solutions found for each value of the investigated parameter can be represented by trade-off curves, which allows the user to visualise the behavior of the primary objective function versus the investigated parameter.

As an example let us consider the abatement of NO_x emissions in the case study of the Basilicata region energy system (Macchiato et al 1994). The environmental constraints scenario can be set by fixing the amount of allowed NO_x emissions and decreasing this limit stepwise to a minimum value for which there still exists a feasible solution. For each scenario a minimal cost solution of the total system is determined by MARKAL. The graphical representation of the set of the optimal solutions, i.e. of the cost variations due to the increasing environmental constraint, establishes a trade-off curve (figure A.2-2).

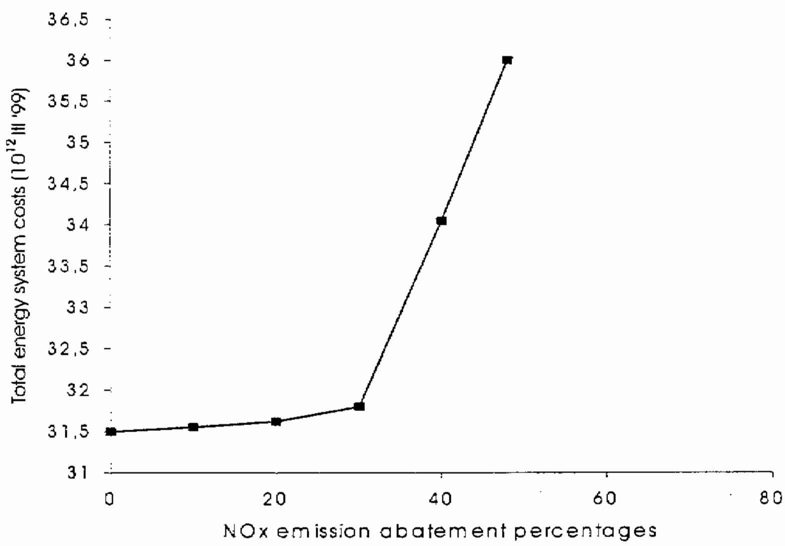

Figure A.2-2: Trade-off curve for NOx constraint scenarios (discount rate 2%)

This trade-off curve provides the average unit abatement costs within the whole time frame considered, enabling the user or any decision-maker to fix the optimal level of emission abatement relative to a feasible economic expenditure.

More useful insights can also be drawn from the solutions of the ***"dual problem"***, which is automatically built up by the model, utilising the same coefficients of the primal problem. The dual solutions emphasise the economic consequences caused by changes in resource utilisation and are useful for defining operative recovery strategies.

A utility function P (the dual objective function, to be maximised) is built up by multiplying the total amount of resources **b** by their respective marginal costs **Y** (which are determined by the exogenous constraints – e.g. procurement prices of fuels, resource availability, limits to the emissions):

$$P = \mathbf{b}\,\mathbf{Y}$$

Similar to the primal problem, a (dual) constraints' system can be set to assure that profits from end energy sales will not be lower than production costs:

$$\mathbf{Y}\,\mathbf{A}^{T} \geq \mathbf{c}$$

where $\mathbf{A}^T$ is the transposed value of the primal constraints matrix **A** as defined above. The optimal dual solution represents the maximum feasible benefit which satisfies all the superimposed constraints.

By exploiting the relationship between primal and dual variables a subsequent cost analysis can be performed to evaluate the economic competitiveness of technologies and the role of the different cost components (investments in new technologies, operating and maintenance expenditures, environmental costs) in order to identify the most effective economic strategies for achieving the prefixed targets (Finnis M. *et al.* 1984).

The most interesting information is given by the so-called *shadow prices* and *reduced costs*. The shadow prices Y_j of resources (the dual values determined by the optimal solution)

$$Y_j = \partial\,(\mathbf{c}\,\mathbf{x}) / \partial\, b_j$$

represent the variations of the prices of resources due to any change in the boundary conditions and are graphically represented by the derivatives of the trade-off curves. In particular, the shadow prices of the constrained pollutants define the monetary equivalent of the emissions avoided and can, for example, be used to set the value of an environmental tax.

Still referring to the Basilicata case study, the figure A.2-3 shows the behavior of NOx shadow prices corresponding to the trade-off curve of figure A.2-2.

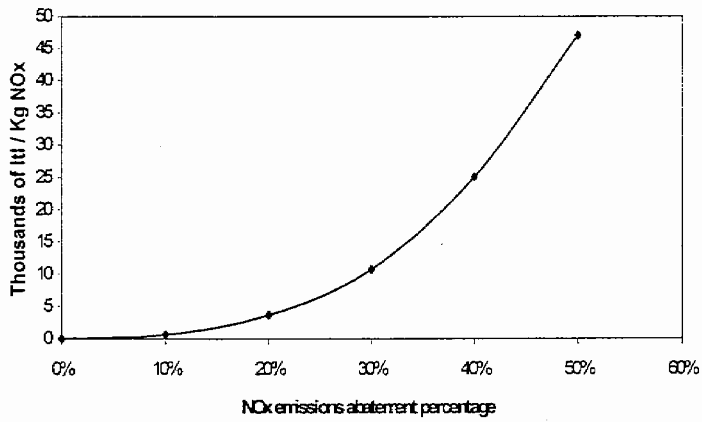

Figure A.2-3: Shadow prices of NO_x (discount rate 2%) (Cosmi et al. 1999)

The reduced costs **r**, as defined by the relationship

$$\mathbf{YA}^T = (\mathbf{c} - \mathbf{r}),$$

originate from the non-marginal resources and point out the price difference between competing technologies which produce the same commodities. They take into account the technology's availability and the market boundaries, obviously being zero for the marginal technologies, and positive or negative for the others according to the values of activity variables. In particular, the reduced costs are negative for the upper bounded resources which are utilised up to the maximum (the model would like to use it over the limit), they are positive for the resource not utilised or lower bounded (the technologies that are not feasible).

It is also possible to single out the different components linked to the investments (which emphasise the marginal cost reduction necessary to make the purchase of the considered technology competitive), the cost difference relative to the operating and maintenance expenditures and the emission penalties (figures A.2-4 a, A.2-4b).

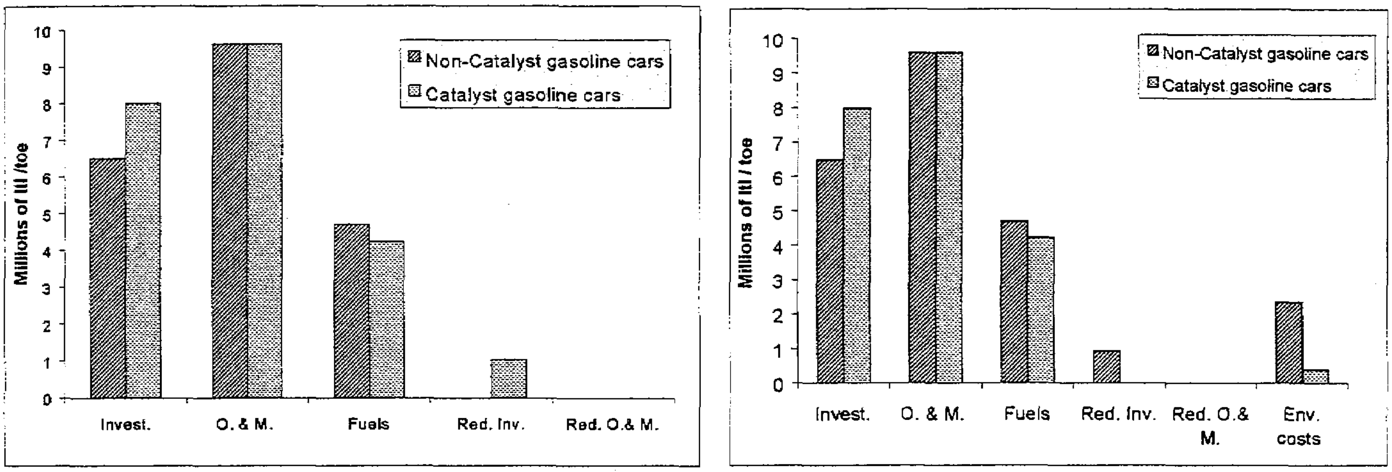

Figure A.2-4: Reduced cost of gasoline cars: a) baseline scenario; b) NOx-50 scenario. (Cosmi et al. 1999)

In the example shown, which refers to the borderline environmentally constrained scenario of figures A.2-2 and A.2-3, we discuss the effect on technology choice caused by a 50% reduction of actual NO_x emissions. The most relevant contribution to NO_x emissions is caused by transportation and, in particular, by urban traffic. Therefore, the technologies that are most involved in NO_x reduction are private cars. To show the variations of costs induced by the NO_x emission constraints we compare the reduced costs of catalyst and non-catalyst gasoline cars.

Figure A.2-4a shows the behavior of the reduced costs in the baseline scenario: the higher investments for the purchase of a catalyst car are not fully compensated by its lower fuel costs, and differences in operating and maintenance expenditures are not relevant. The environmental constraint, as shown in Figure A.2-4b, determines high environmental costs for the non-catalyst equipment (which are about six times higher than environmental costs of catalyst engines) induced by the high shadow price of NO_x emissions. Also the fuel cost difference in the environmentally constrained scenario is not sufficient to induce a technology substitution: besides promulgating restrictive policies it can be useful to subsidize investments in new cars. These results agree with the policies carried out by most of the automotive corporations which offer lower selling prices if a new car substitutes an old one.

More generally, the analysis of shadow price trends and reduced costs is even capable of suggesting operative economic strategies that are suited to push the reference anthropogenic activity system towards its optimal configuration. As mentioned before, the shadow prices of resources can be used to define a tax-rate on commodities or on pollutant emissions. In this context, a comparison between shadow prices of fuels and shadow prices of pollutants can be useful for defining more punctual strategies. Besides this, the analysis of the reduced costs of technologies allows the user to define economic strategies to foster technology innovation. For example, if the difference of the marginal technology is due mainly to emissions penalties, it may be useful to raise fuel costs and, to move that difference to the input costs of the technology chains which use or produce the dirty fuels. On the other hand, if the difference in marginality is due to the investments, it may be useful to provide money incentives for the purchase of new technologies. Moreover, if the difference is due to operating and maintenance costs, it may be useful to subsidise labor costs, which are an important component of the operating and maintenance expenditures.

Anyway, it is worthwhile to note that recovery policies based only on tariff changes may not be satisfactory (or politically acceptable), because they charge the costs of environmental protection only to final users. A better choice may be to adopt a more mild approach, mixing higher prices for commodities, caused by environmental taxes, with subsidies for conservation investments, for example. In any case, the chosen strategies must be accompanied by a set of actions which foster motivation and behavioral changes, technology development and monitoring and dissemination of results.

A.2.3 Successor to MARKAL: TIMES

MARKAL has been developed and used over the past 20 years. It has proven to have a high flexibility and problem solution capacity in many different local, regional and global applications all over the world. Its widespread use and familiarity by many systems analysis working groups in many countries has made MARKAL the most successful energy model. However, MARKAL is based on a concept and a programming structure which is becoming more and more outdated, with higher requirements for systems analysis on the model and with a much different software and hardware environment as compared to the eighties.

The successor to MARKAL is already under work by some working groups within the ETSAP community. It is named TIMES and will provide enhanced flexibility with respect to time resolution, cost structures of technologies (input) and energy systems (output), regional resolution, inclusion of „flexible instruments" like emissions trading from the Kyoto protocol, as well as possibilities to link to other models and data bases. This enhanced power of the new model requires a new user interface to create the necessary user friendliness (which is a serious weakness of MARKAL).

Whereas work on the new model has already proceeded quite far - in fact, a functioning version have been announced for the middle of the year 2000, and validating tests with MARKAL runs have already been carried out successfully - the important work on the interface is still to be completed. This will be the pre-condition to increased use of the new model outside the scientific community. It was experienced from the work on the Annex 33 case studies, that only a transparent model software complying with modern interface standards will be accepted by potential users in the field of local energy planning.

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A.3 Fundamentals of Linear Programming

A.3.1 Introductory remark

Linear Programming (**LP**), a branch of Operations Research, is mainly used to determine the optimal sharing of resources for obtaining simultaneously the least feasible production costs and the largest benefits.

In particular, linear optimization is aimed to find the optimal value (maximal or minimal value, depending on the problem) of a linear function of a certain number of variables (usually labeled x1, x2, ...xn), given a set of m linear constraints on these variables (equalities or inequalities).

Even if it may seem quite theoretical in a first approach, linear optimization has a lot of practical applications in real problems. As a matter of fact, the minimizazion of objectives functions (that can be production costs, numbers of employees to hire, quantity of polluants relessed) given a set of constraints (availability of workers, of machines, ...) is often used in industry, governmental organizations, ecological sciences and to solve complex problems in resource management.

There has been a proliferation of linear programming solver software since 1980 (ex : CPLEX, LINGO, MINOS, etc). Each solver implements different algorithms (Simplex method, Interior-Point method, etc) and offers different options (sensititvity analysis, basic certificates, etc). Depending on the problem to be solved, some solvers can be more or less efficient than other in terms of speed, accuracy, number of iterations and available options.

A.3.2 An example

Let us consider the manufacturing of two products with different production costs and different profits, which requires the utilisation of the same fuels and raw materials. At first glance it may seem appropriate to produce only the product which assures the maximum benefit, but this choice may use up resources faster, while mixed production of both the goods may assure better utilisation of resources. The definition of the best production program can be made by utilising linear programming techniques, which are based on some fundamental principles of algebra and geometry, and allow the user to represent the relationships between energy resources, raw materials and products by means of linear inequalities.

The general mathematical formulation of a linear programming problem is the following.
A linear form (the objective function)

$$F(\mathbf{x}) = c_1x_1 + c_2x_2 + ...+c_px_p$$

is minimised (or maximised) under the linear constraints:

$$a_{i1}x_1 + a_{i2}x_2.....+a_{ip}x_p \leq b_i \qquad \text{for } i = 1,....,m_1$$
$$a_{i1}x_1 + a_{i2}x_2.....+a_{ip}x_p \geq b_i \qquad \text{for } i = m_1 +1,....,m_2$$
$$a_{i1}x_1 + a_{i2}x_2.....+a_{ip}x_p = b_i \qquad \text{for } i = m_2+1,....,m$$

$$x_j \geq 0 \qquad \text{for } j = 1,...,p$$

This set of equalities and inequalities is called constraints' system: the first set represents the boundary conditions (upper and lower limits to resource use, other exogenous constraints) while the last inequalities stem from the non-negativity of resources. The solution is given by the vector

$$\mathbf{x} = (x_1,...,x_p)$$

with p – components, which is a solution of the constraints' system and minimises (maximises) the objective function.
The solution can be defined by utilising a graphical representation or the computational analysis, in particular the simplex algorithm.

Graphic solution of a LP problem.

To show the usefulness of the graphic method, let us consider a two-variables example. Let us consider, for instance, the boilers P_1 and P_2 which are produced utilising the technologies M_1, M_2 and M_3. To produce P_1, M_1 is utilised for 5 minutes, M_2 for 3 minutes and M_3 for 4 minutes, while to produce P_2, M_1 is utilised for 1 minute, M_2 for 4 minutes and M_3 for 3 minutes. The net profit is 150 Euro/unit P_1 and 100 Euro/unit P_2. The aim is to determine the maximum achievable profit, utilising the three technologies for an hour.
In this case the objective function – to be maximised – is given by:

$$F(\mathbf{x}) = 150\, x_1 + 100\, x_2$$

Where x_1 and x_2 are the optimal quantities of the products P_1 and P_2 to be determined.
The constraints' system is constructed by taking into account the time of utilisation of each machine for the two products and the non- negativity of resources:

$$\begin{array}{ll} 5\,x_1 + 1\,x_2 \leq 60 & \text{for } M_1 \\ 3\,x_1 + 4\,x_2 \leq 60 & \text{for } M_2 \\ 4\,x_1 + 3\,x_2 \leq 60 & \text{for } M_3 \\ x_i \geq 0 & \text{for } i = 1, 2 \end{array}$$

In the plan $x_1 x_2$, the objective function is represented by the family of parallel lines:

$$150\, x_1 + 100\, x_2 = K$$

while the constraints are represented by the lines corresponding to the respective equalities and limit the zone S of the plan in which the feasible solutions are located (figure A.2-5).

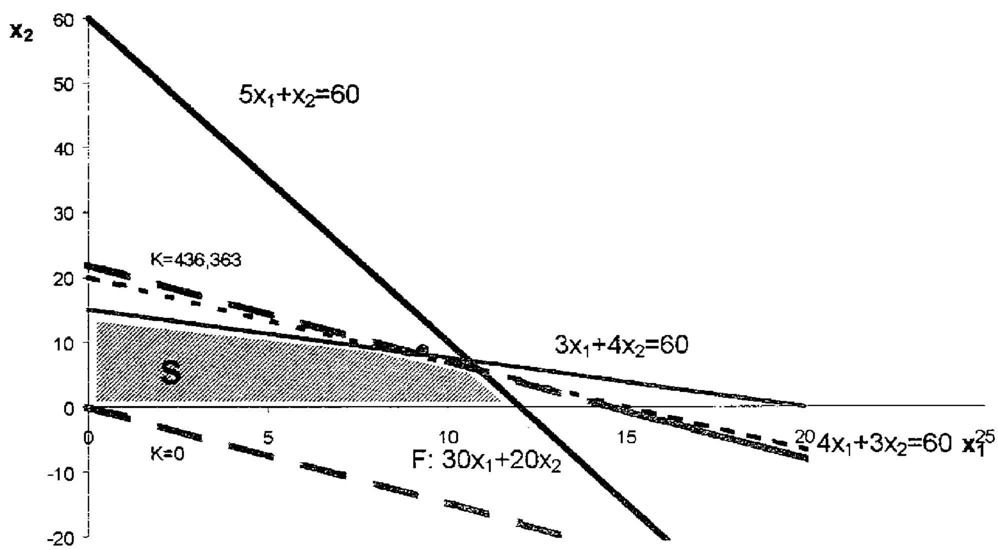

***Figure* A.2-5:** *Graphical representation of the region of feasible solutions in the two variables example.*

The optimal solution is represented by the point P* which maximises the area of the polyhedron S. The corresponding value of the parameter K in this case is 21,818 Euro.

Normal form of an LP problem

Let us consider the minimisation[1]:

$$\min F(x_1,\dots, x_p) = \Sigma^p_{j=1} c_j x_j$$

with the constraints:

$$\Sigma^p_{j=1} a_{ij} x_j \le b_i \qquad \text{for } i = 1,\dots,m$$
$$x_{ij} \ge 0 \qquad \text{for } j = 1,\dots,p$$

This problem can be set in "normal form", transforming the inequalities

$$a_{i1}x_1 + a_{i2}x_2 \dots\dots + a_{ip}x_p \le b_i \qquad \text{for } i = 1,\dots,m$$

of the constraints' system into equalities, by utilising some auxiliary variables (the "so-called" **slack variables**):

$$a_{i1}x_1 + a_{i2}x_2 \dots\dots + a_{ip}x_p = b_i - a_{ip+1}x_{p+1} - \dots\dots - a_{in}x_n \qquad \text{for } i = 1,\dots,m$$

these equations can be rewritten as follows:

$$a_{i1}x_1 + a_{i2}x_2 \dots\dots + a_{ip}x_p + a_{ip+1}x_{p+1} + \dots\dots + a_{iq}x_q = b_i \qquad \text{for } i = 1,\dots,m_1$$

The slack variables can also be inserted into the objective function with null coefficients:

$$F(x_1,\dots, x_n) = \Sigma^p_{j=1} c_j x_j + \Sigma^n_{j=p+1} 0\, x_j = \Sigma^n_{j=1} c_j x_j$$

In a vector notation, the problem can be rewritten as follows:

$$\text{Min } F(\mathbf{x}) = \mathbf{c}^T \mathbf{x}$$

Under the constraints:

$$\mathbf{Ax} = \mathbf{b}$$
$$\mathbf{x} \ge \mathbf{0}$$

where **c** and **x** are n-dimensional vectors, **b** is a m-dimensional vector and **A** is a [m, n] matrix. In particular, the choice:

$$\mathbf{b} \ge 0 \; ; \quad c = (c_1, \dots, c_{n-m}, 0,..,0) \text{ and } A = \begin{pmatrix} a_{11,\dots}, a_{1,n-m}, & 1,..0 \\ \dots\dots\dots\dots & \\ a_{m1},\dots, a_{m,n-m}, & 0,..1 \end{pmatrix}$$

represents the canonical form of an LP problem.

Primal and dual formulation of a LP problem: shadow prices

A linear programming problem consists of two parts: the primal problem and the dual problem, which are defined simultaneously and have the same numerical solution, but different meanings, both useful in real applications. More details on the theory of duality can be found in every text of linear programming (e.g. Strang), but it is useful to recall some fundamental information to better understand the significance of primal and dual solutions.

[1] A minimum problem can be transformed into a maximum problem by multiplying each term of the objective function by −1. In the same way the constraints can be transformed from ≤ to ≥.

The dual problem can be formulated utilising the same coefficients as follows:

$$\max P(\mathbf{Y}) = \mathbf{b}\,\mathbf{Y}$$

where the dual variables Yj (the "so-called" shadow prices) are represented by the m–dimensional vector **Y** whose (positive) components are defined by the differential equations:

$$\partial\,(\mathbf{c}\,\mathbf{x})/\,\partial\,bj = Yj$$

that represent the changes of the objective function caused by the marginal variations of the resource availability.

The dual constraints' system is:

$$\mathbf{Y}\,\mathbf{A}^T \geq \mathbf{c}$$

where $\mathbf{A}^T$ is the transposed value of the primal constraints matrix **A.**

The following example can be useful to show the relationships between a primal and dual problem in a two-variables application.

The good P_1 is produced utilising 2 units of the resource x_1 and 1 unit of the resource x_2, while the good P_2 is produced utilising 5 units of x_1 and 3 units of x_2. The demand for each product is respectively 6 units for P_1 and 7 units for P_2, while the costs of the resources are 1$ /unit x_1 and 4$/unit x_2.

The LP problem can be formulated as follows:

Primal problem

The cost function is:

$$F(x)= x_1+ 4x_2$$

The primal constraints' system is determined by fulfillment of the demands of G_1 and G_2 and the non-negativity of resources:

$$2x_1 + x_2 \geq 6$$
$$5x_1 + 3x_2 \geq 7$$
$$x_i \geq 0$$

Utilising the graphical method, the region of feasible solutions in the plan x_1x_2 is unlimited; the first constraint, represented by the family of parallel lines:

$$2x_1 + x_2 +k = 6$$

includes the second and assures the non-negativity of resources, so that the optimal (minimum) solution is graphically represented by the point P*(3,0) that is the intersection of the line:

$$2x_1 + x_2 = 6$$

with the axis x_1 x_2 which minimise the area S (figure A.2-6).

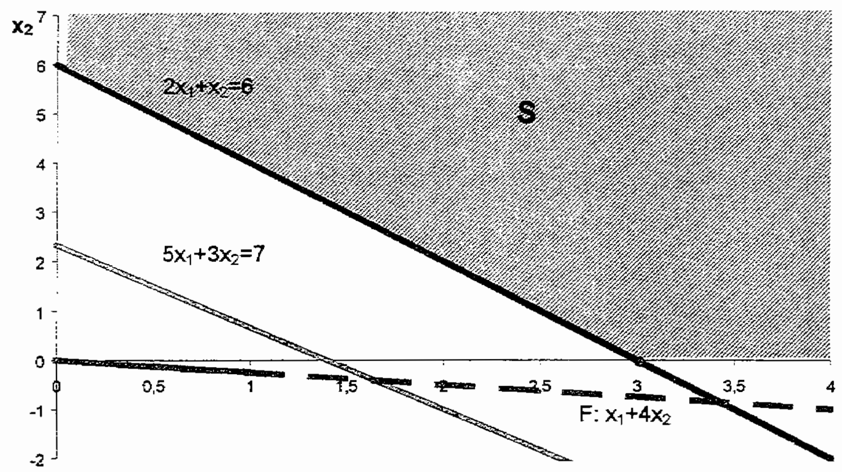

***Figure* A.2-6:** *Graphical representation of the region of feasible solutions in the two variables example.*

Dual problem

The utility function is:

$$P(y) = 6\,y_1 + 7y_2$$

The dual constraints' system, which assures that the selling prices are higher than the production costs, is given by:

$$2y_1 + 5\,y_2 \leq 1$$
$$y_1 + 3\,y_2 \leq 4$$
$$y_j \geq 0$$

The value of the objective function is given by the point P*(0.5;0), which maximises the area of the polyhedron S, represented in figure A.2-7.

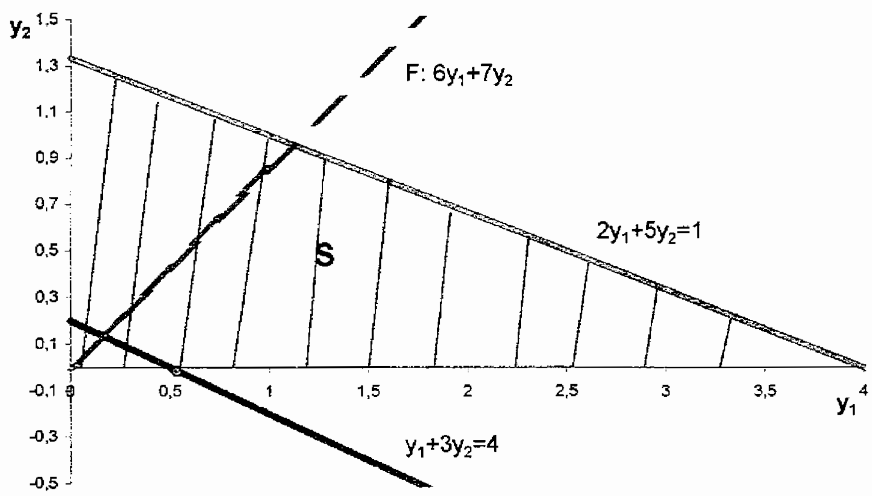

***Figure* A.2-7:** *Graphical representation of the region of feasible solutions in the two variables example.*

Alternative formulation of a LP problem and its solution: reduced costs

The solution of this LP problem is a solution of the constraints' system which minimise the linear function F(**x**).
A fundamental theorem of linear algebra assures that, *m* being the rank of matrix A, there exists a unique solution for each choice of a set of *n-m* variables. In particular, the **basis** solutions (which includes the solution of the LP problem) assign a null value to each set of *n-m* free variables. This implies that the LP problem can be rewritten in term of **free variables** $\mathbf{x}_f$ and of **basis variables** $\mathbf{x}_b$ (the set of variables which define the set of linear independent equations of the constraints' system):

$$F(\mathbf{x}) = \mathbf{c}_b \mathbf{x}_b + \mathbf{c}_f \mathbf{x}_f$$

where $\mathbf{c}_b$ and $\mathbf{c}_f$ are the coefficients of the basis variables and of the free variables, respectively. Analogously, the constraints' system is:

$$\mathbf{Ax} = \mathbf{Bx}_b + \mathbf{Fx}_f$$

where **B** and **F** are the sub-matrices of the coefficients of the basis variables and of the free variables, respectively.
In real applications the free variables represent the non-marginal resources, while the basis variables are the marginal resources.

Making use of the weak slackness theorem and of some algebra, the dual constraints may also be written in a more useful way:

$$\mathbf{Y}\,\mathbf{A}^T = (\mathbf{c} - \mathbf{r})$$

where:

$$\mathbf{r} = \mathbf{c}_f - (\mathbf{B}^{-1}\,\mathbf{b}\,\mathbf{F})$$

is the reduced costs vector. The optimal solution determines the values of the reduced cost: they are zero for the marginal resources, positive for the resources not utilised (whose activity is zero) and negative for the upper bounded resources.

The shadow prices **Y** (dual prices of the marginal resources), in terms of the new coefficients $\mathbf{c}_b$ and **B**, can be written as follows:

$$\mathbf{Y} = \mathbf{c}_b\,\mathbf{B}^T$$

So that the cost function becomes:

$$\mathbf{c}\,\mathbf{X} = \mathbf{Y}\,\mathbf{b} + \mathbf{r}\,\mathbf{X}_f$$

emphasising the role of the shadow prices and the reduced costs in the definition of the production costs.

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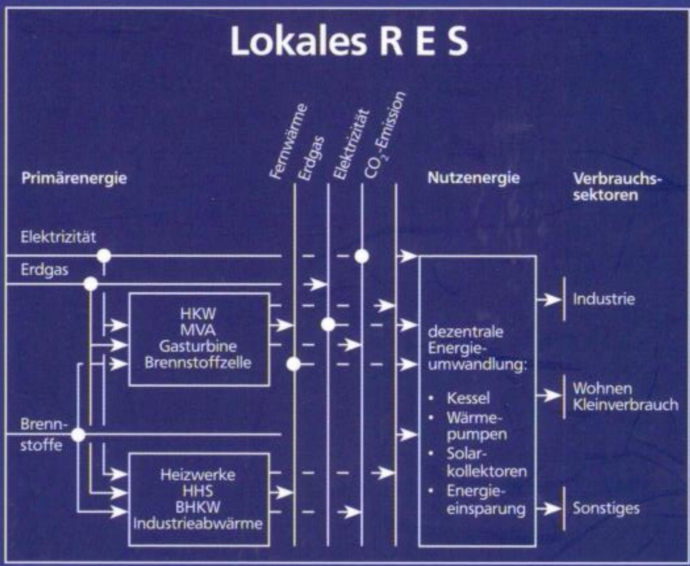
List of Contributors to Annex 33:

Participating Countries	Authors		Contributing Organisations
Germany	Reinhard Jank (Operating Agent)	Klimaschutz- und Energieagentur Baden-Württemberg GmbH Griesbachstr. 10 D-76125 Karlsruhe	• Federal Ministry for Education and Research (BMBF), Bonn • Research Center Jülich (FZJ) • MVV - Energie AG, Mannheim
	Thomas Steidle Christoph Schlenzig	Universität Stuttgart, IER - Institut für Energiewirtschaft und Rationelle Energieanwendung Hessbrühlstr. 49a D-70550 Stuttgart	
	Thomas Kilthau	MVV - Energie AG Luisenring 49 D-68031 Mannheim	
	Stefan Rath-Nagel Dieter Wilde Wolfgang Krüger	IC Consult GmbH Theaterstr. 50 D-52062 Aachen	
Italy	Prof. Vincenzo Cuomo Prof. Maria Macchiato (Co-ordinators) Monica Salvia Lucia Mangiamele Carmelina Cosmi	IMAAA-CNR - Institute of Advanced Methodologies for Environmental Analysis - National Research Council C. da S. Loja I-85050 Tito Salo (PZ) INFM – National Institute for Physics of Matter DIFA – Dept. of Environmental Engineering and Physics, University of Basilicata C. da Macchia Romana	• Basilicata Regional Authority • INFM - National Institute for Physics of Matter • IMAAA - CNR Institute of Advanced Methodologies for Environmental Analysis - National Research Council
	Prof. Evasio Lavagno Chiara Codegone Daniela Scaramuccia Angelo Venezia Giuliano Zoppo	Politecnico di Torino Energy Department Corso Duca degli Abruzzi 24 I-10129 Torino	
Sweden	Bo Rydèn Håkan Skoldberg	Profu AB Gotaforsliden 13 S-43134 Mölndal	• Swedish Council for Buildings Research • Göteborg Energi AB
	Jan-Olof Berghe	Göteborg Energi AB Box 53 S-40120 Göteborg	
	Prof. Clas-Otto Wene David Weiner Daniel Stridsman	Chalmers University of Technology, Dept. of Energy Systems S-41296 Göteborg	
The Netherlands	Roland van Driel Sander Willemsen Frank Spruit Wilbert Grevers	G3 Advies b.v. Markt 1 NL-4112 Beusichem	• NOVEM b.v.

Within the IEA (International Energy Agency) program on Energy Conservation in Buildings and Community Systems four countries have co-operated to apply the approach of "Advanced Local Energy Planning" (ALEP) to three big cities and three regions in Germany, Italy, Sweden and The Netherlands, using Markal as a comprehensive energy model.



This Guidebook on Advanced Local Energy Planning contains the results of these case studies, a presentation of the "ALEP philosophy" and a discussion of the potential benefits of energy system models in the context of strategic local energy planning, compared to conventional planning approaches. It has been shown that the results of the energy model could be verified with conventional tools and that the model, once established, allows for much more comprehensive analyses and optimization and thus is better suited to develop a fully consistent long-term energy strategy than conventional means. Although capable of modeling a complex local energy system, there are deficits in user-friendliness which represent a major barrier for wider distribution. Therefore, further development is necessary. By Annex 33, a specification of the needs of practical Local Energy Planning to future energy system models that are at present under development was provided.

Klimaschutz- und Energieagentur
Baden-Württemberg GmbH,
Karlsruhe

Forschungszentrum Jülich GmbH
Projektträger Biologie,
Energie, Ökologie des BMWi

Distribution:
Fachinst. Gebäude-Klima e.V.
Danziger Str. 20
D-74321 Bietigheim-Bissingen
Facsimile: ++49-7142-61298
e-mail: fgk-ev@t-online.de

KEA
Klimaschutz- und Energieagentur
Baden-Württemberg GmbH