1. General Introduction

This introduction contains a short description of the context and the research aims of this thesis. The history of the development of the PowerPlan tool is given. A brief outline of the thesis is presented.

1.1 Introduction

Electricity plays an important and ever growing role in modern society. During the last decades the contribution of electricity use in production and consumption of goods and services increased strongly and more rapidly than most other key indicators, partly at the expense of other energy carriers or sources. This is illustrated in Figure 1.1, which shows the development of a few general parameters (of the European member states of OECD) during the last three decades. The population growth amounted to about 25%, while the indices for the Gross Domestic Product (GDP) and the Total Primary Energy Supply (TPES) increased to about 160%-180%. Electricity production outgrew the other parameters: an increase of more than 300% since 1960.

![Figure 1.1: Population, Gross Domestic Product (GDP), Total Primary Energy Supply (TPES), and the electricity production; all indexed for the OECD Europe [IEA, 1991a, 1991c, 1992a].](image)

The increase is caused by the strong interplay of developments in the production, distribution and use of electricity, an easy-to-apply energy carrier.
The electricity production system has shown a development from local and rather unreliable electricity generating power plants towards a low-cost, highly reliable, ever expanding and country-wide available system. Electricity demand has grown due to the introduction and large-scale penetration of electricity-driven technologies that became available during the last decades. They were in historic order: washing machines, refrigerators, freezers, central heating pumps, TV/audio appliances (including personal computers, etc.) and air-conditioners.

This successful development has implied a partial substitution from other energy carriers like natural gas and coal, mostly with benign consequences in terms of costs and environmental damage (due to the economies of scale). However, the scale of electricity production and demand has grown such that its impact on the environment has become noticeable:

- gaseous emissions: \( \text{NO}_x \), \( \text{CO}_2 \), \( \text{SO}_2 \) and particles;
- water pollution: thermal pollution;
- solid waste: from nuclear and coal-fired plants and from cleaning equipment;
- space: environmental and social distortion as a consequence of the exploitation of large areas: (pump-)storage hydro and surface mining industry;
- risks: mining industry, nuclear accidents and nuclear proliferation.

Electricity demand and production form a complex system of many interrelated components, which are also continuously subject to change (induced by trends in technology as well as in application). Electricity became an indispensable and vital element in modern society, and by that very process it also contributed to the growth of the set of unsustainable elements in Western society. However this demand/production system itself offers and develops also many options that can be implemented in routes towards a more sustainable society. Some technological improvements are:

- reducing electricity demand by appliances with enhanced efficiencies;
- reducing electricity demand by the shifting to other production processes with lower energy use per unit of product;
- reducing electricity demand from the energy-intensive production of some basic materials by a shift to recycling systems that require less energy (e.g. aluminum);
- reducing the use of fossil fuels by improved efficiencies of power plants;
- reducing the use of fossil fuels by substitutions within the electricity system: the shift to different types of power plants (e.g. from gas-fired plants to wind turbines with no direct fuel consumption);
• reducing specific emissions by internal and/or external improvements of the power plants: higher efficiencies, better combustion technologies like low NOx burners, end-of-pipe technology like Flue Gas Desulphurisation (FGD) processes;

• reducing emissions by fuel substitutions within the electricity system: shift to other fuels (e.g. the shift from coal to gas) to reduce SO2 and CO2 emissions or the shift to different types of power plants (e.g. from gas-fired plants to wind turbines with no direct emissions).

Summarizing, the complexity of the electricity supply/distribution/demand system, its impact on society and environment, and the various (technological, behavioural and institutional) options to change this impact call for research into "electricity futures" that are compatible with sustainable developments. Simulation models are suitable tools for this kind of research if they offer an adequate and reliable representation of the problem at hand, if they give access to the relevant set of options for change and if they can be operated in a fast and user-friendly way. The research described in this thesis started in the mid eighties when no such model was available in the open literature. So, this thesis focuses on the research directed at the development and application of a set of tools (i.e. MEED and PowerPlan) for the interactive exploration of feasible (mid- to long- term) electric power system futures in terms of their technological, socio-economic and environmental impacts.

1.2 Historical overview

The history of the subject of this thesis dates back to the early eighties. Planning models were developed and used by the central utilities, as a result of an increase in complexity of the electric power system (as indicated in section 1.1) and the availability of (main-frame) computers. As a result of oil crises and discussions about the risks of nuclear power, in several countries discussion were started around the central theme of energy. In the Netherlands, a nationwide debate (BMD) on alternative energy futures (high/low growth, nuclear/conservation scenarios took place; cf. [Stuurgroep, 1983]. The Energy Research Unit of the University of Groningen (afdeling Vrije Chemie) developed with BMD funding a mainframe-based electricity planning model: the SCELEC model [Dijk, 1985 and 1988] that served as parallel expertise next to the planning tools used by the electricity power companies. This model has been used for the assessment of the electricity issues inherent in the national energy debate that revolved around the question: "do we need nuclear power or can we meet the electricity demand in another way" [De Vries, 1985a]. SCELEC has also been used for the assessment of the costs of premature
closing of the Borssele nuclear power plant [Oude Lohuis, 1986], a debate that has surfaced a few times in Dutch politics since 1980.

At the annual Balaton Group meeting in 1985 of INRIC\(^1\) the idea was born to develop a strongly simplified electricity planning tool for educational and gaming purposes [De Vries, 1985b], like the STRATAGEM game developed by Meadows [Meadows, 1984]\(^2\). It should be an easily available and accessible model so it was decided to develop a user-friendly model for IBM MS-DOS compatible computers. Initially the model was called **Future Voltage**. I finished my undergraduate courses at IVEM\(^3\) in February 1986 with a report on a first version [Benders, 1986], written in DYNAMO [Forrester, 1968]. At IVEM it was decided to proceed with the development of such a model. In September 1986 a first version (written in Turbo Pascal) was tested at a Workshop in Portugal. An extended version of the Future Voltage model including a manual was finished in 1987 [De Vries, 1987]. This version has been sold and used in various countries (e.g. Belgium, Egypt, Hungary, India and Portugal). The model has been used for educational purposes in a gaming context [Benders, 1989 and De Vries, 1989b], but also for planning purposes (e.g. in the Taiwan 2000 study [De Vries, 1989a and 1990]).

In 1988 it was decided to rebuild the model completely. Different options had to be added and new calculation methods to be implemented [Dijk, 1989]. Even the name was changed into **PowerPlan**. In order to make the model more suitable for application for countries in South-East Asia a cooperation with TERI\(^4\) was started. This collaboration was financially supported by the Dutch Ministry for Development Cooperation. The new PowerPlan model with its manual was finished in May 1991 [De Vries, 1991]. This version is also sold and used in various countries: the Netherlands (several universities and polytechnic schools), Latvia, New Zealand, Denmark and India.

During the process of the development of PowerPlan the results of world-wide

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1 The International Network of Resource Information Centers (INRIC) is an informal network of environmental scientists actively involved in research (including development of tools and training programmes) and policy making concerning sustainable development issues.

2 STRATAGEM is a pc-based management training game on energy-environment interactions. The game has been further developed and revised at IVEM by [Meadows, 1986 and 1995].

3 IVEM (Interfakultaire Vakgroep Energie en Milieukunde)
   Centre for Energy and Environmental Studies of the University of Groningen

4 TERI: Tata Energy Research Institute, New Delhi, India
efforts into end-use oriented energy research\(^5\) became available. This also
served as a stimulus to develop an electricity demand model (MEED); the
results of MEED analyses can be used as input for the electricity planning
modules. The development of the MEED model was stimulated by financial
support in the context of the MARKAL\(^6\) oriented research program at the
Netherlands Energy Research Foundation (ECN). For this programme a case
study into electricity demand forecasts for the European member countries of
OECD has been carried out [Benders, 1993]. The MEED model is also used in
a study at the reduction of CO\(_2\) emissions [Benders, 1994].

### 1.3 Goals and criteria

The origin of both models, as described in the "Historical overview" is different.
The PowerPlan model was primarily developed as an educational model/game
and was a goal in itself whereas the MEED model was developed as a tool for
scenario studies in a specific project [Benders, 1993]. In spite of these different
origins, both models are based on to the same set of general criteria:
interactivity, user friendliness and flexibility. The model-specific goals and
criteria are explained in the next subsections.

#### 1.3.1 Goals and criteria for MEED

The MEED model aims to serve as a tool in scenario studies simulating the
development of electricity demand. To determine the development in electricity
demand, the end-use approach [Johansson, 1990] is used. The resulting
requirements plus a long standing wish to model the electricity demand in more
detail than present in PowerPlan, led to the definition of the following goals and
criteria for the MEED model; cf. Figure 1.2.

The MEED model should be a suitable tool for mid to long term scenario
studies. The model can be used to study scenarios that are too complex for use

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5 The end-use approach starts with an assessment of demand for electricity (or in general: energy)
requiring functions in households or production/service sectors, followed by screening of the
various techniques (available or under development) that can generate those functions at the
required levels. This detailed and systematic procedure is data-intensive and the outcomes are
subject to many assumptions. The overall result is detailed information concerning the demand
for energy carriers like electricity.

6 MARKAL is a dynamic, long-term optimization programme for the simulation of a national
energy economy that is mainly used for scenario studies under various degrees of environmental
constraints [Fishbone, 1982].
in an educative or gaming context (cf. Table 1.1).

The simulation model must have an user-friendly and interactive interface. It should be possible to change the initial data read from file, and the user should be able to inspect input and relevant results in tables and graphs.

The criterion of flexibility in particular refers to the definition of the end-use matrix. This matrix represents the economic structure with its production sectors (industry, services, transport but also households) and also the functions required (heating, lighting, cooling etc.) with corresponding appliances. The flexibility guarantees the possibility to use the model for different countries and for isolated sectors within a country. It allows for example the user to focus on a specific part of the economic structure (e.g. households only).

The model should be used as a stand alone model with the possibility to export the necessary data to the supply model PowerPlan.

### 1.3.2 Goals and Criteria for PowerPlan

The main question is: is it possible to develop a tool for electricity supply planning for the mid to long term that is much more accessible, flexible, fast, cheap, interactive, dynamic, educational and still accurate enough for electricity scenario studies than the chronological planning models like SCELEC (cf. section 1.2).

The computer simulation model to be built has to be used for training purposes but also for scenario exercises. The user of the model should not be bothered with a large amount of incomprehensible data to be entered in a highly user-unfriendly environment, characteristic of the old days of huge mainframe planning models. It is thought to be a flexible/open model. This means that it should also be possible to simulate other countries than the Netherlands. Therefore it is necessary that all the data should be imported in the program and
the user should be able to change them. A second requirement concerns the presence of several options for model extensions in order to match the model to the local conditions of the countries studied. One should think of hydropower, different fuel qualities, etc. Because of its interactive character the calculation time per simulation cycle (one or more years) must be a minute at most. To achieve this, simplifications have been made and corresponding detail is lost. In spite of the simplifications the simulation results (year averages/totals) should be accurate within an acceptable range (10%). So PowerPlan is a tool which offers the possibility to explore alternative futures, by combining interactivity with simulation.

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<tr>
<th>Table 1.1: PowerPlan operational modes</th>
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<tr>
<td>simple</td>
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<tr>
<td>education</td>
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<tr>
<td>scenario studies</td>
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As indicated before, PowerPlan has been developed for educational purposes as well as for scenario studies. In educational courses, students can be trained in problems of the generation of electricity. By relatively simple PowerPlan training exercises PowerPlan should also be suitable to serve in more advanced student research projects. In the advanced scenario studies mode PowerPlan can be used to examine relevant electricity futures. In the simple scenario studies mode PowerPlan should be an instrument to communicate with e.g. politicians by showing them alternative scenario outcomes. Table 1.1 shows these four possible operational modes.

Not only technical aspects are important, but also some other dimensions of electricity generation planning, like construction delays, fuel depletion and of course environmental problems as a result of choices made in the past. The latter array of aspects is more important when PowerPlan is used in the simple mode.

When the development of the model started in 1986, a number of criteria was defined which were thought to be important and/or essential. The two main criteria were:

- the results calculated with the model should be an adequate representation of reality, and
- the user interface ought to be user-friendly and interactive (dynamic model).

The educational as well as the management goals are summarized in Figure 1.3.
1.4 Outline of the thesis

As indicated in section 1.1 this thesis aims at the development and application of a set of tools for the interactive exploration of feasible (mid- to long- term) electric power system futures in terms of their social and environmental impacts.

This thesis is not the result of a regular four year Ph.D. study but the outcome of ten years of research experience in modelling in general, focusing on PowerPlan and MEED as the central themes.

The structure of this thesis, is shown schematically in Figure 1.4. The thesis has three parts. The first part containing chapters 2 and 3 is an introduction to the three key words: model, simulation and electricity. Chapter 2 contains general remarks about models and modelling. Items treated briefly are: usefulness, development and validation of models. Electricity, the third key word of this thesis is discussed in chapter 3. Some historical trends concerning electricity demand and supply are given as well as the analysis of the demand and the choices to be made when modelling electricity supply. In chapters 4 and 5, the second part, both models (demand and supply) are described in detail. The last
part, chapters 6 and 7 contains the calibration, analysis and validation of PowerPlan and MEED and application results of both models. Chapter 6 presents the testing on the MEED model and shows some examples of applications: scenario studies with MEED. Chapter 7 contains 3 sets of calibration/analysis/validation exercises with PowerPlan: comparison with an IEEE test system, a historical calibration and (in order to explore the limits of the validity of PowerPlan) a comparison of a set of extreme scenarios versus the outcomes of a more detailed chronological expert model. Chapter 8 contains an illustration of coupling the MEED and PowerPlan models and the final conclusions and reflections. The thesis also contains o.a. appendices in which the interface of both models is presented.