Planning models show comparative results

Benders, RMJ; Biesiot, W

Published in:
IEEE Computer Applications in Power

Publication date:
1998

Planning Models Show Comparative Results

R.M.J. Benders*, W. Biesiot*

Electricity supply planning models are built to assist decision-makers in keeping future supply and demand in balance. The planning problem can be approached in different ways. This article focuses on two planning models and compares how they approach and resolve the planning problem.

SEPU is an expert model that can be used for detailed reliability studies, mainly from a short-term perspective. PowerPlan is a planning model for mid-term scenario studies. With PowerPlan, "what if" questions can be answered in an interactive and fast manner.

Although developed with different goals in mind, PowerPlan and SEPU are to a certain degree complementary. The area of overlap is used here for comparison of the performance of the models in simulating a set of scenarios. The points of departure of the scenarios for both models match each other as well as possible in order to get comparable results.

PowerPlan

PowerPlan is a dynamic and interactive simulation model. The model is built from the viewpoint of a central electricity board, in control of the central demand/supply balance in a country or region. Starting from a reference year, the electric power system is simulated. At each planning interval (which can be 1 or more years), investments in decentral capacity and conservation measures are possible. The decentral electricity generated and the conservation measures are treated as a negative demand and subtracted from the total electricity demand to compute the central demand.

PowerPlan can be characterized as a probabilistic production simulation model. The annual demand for electricity is calculated from the load duration curve (LDC) and the simultaneous maximum demand (SMD). Using the merit-order approach, the electricity generated per plant is calculated.

The input data/variables can be divided into three groups:

- Empirical data (i.e., facts that need no further discussion): LDC, technical specifications of power plants already present and those under construction (efficiency, capacity, etc.).
- Scenario variables: the user must make assumptions or make expectations explicit about future developments of crucial time-series (oil price paths). These exogenous variables define the context of the simulation.
- Decision variables (i.e., input data during a simulation): the kind of power plants that should be installed, conservation measures that should be taken, and pollution abatement measures that should be implemented.

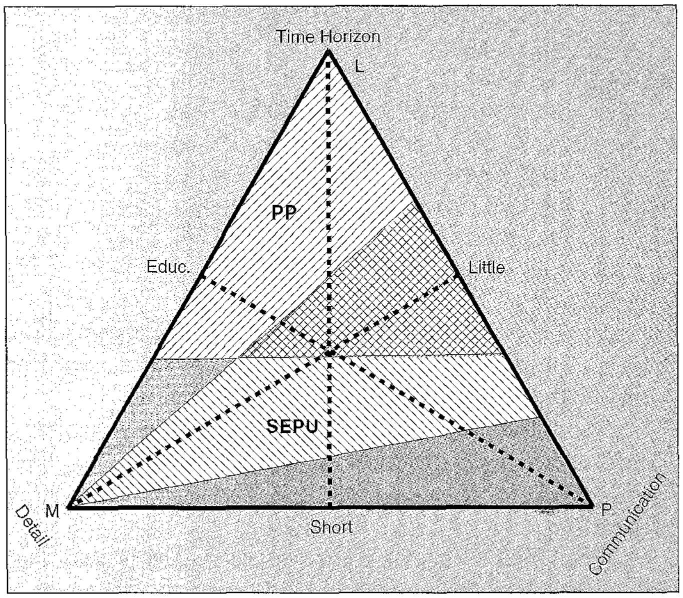

Figure 1. Schematic presentation of the area in which SEPU and PowerPlan operate: time horizon (long...short), goal (planning, scenarios, education), and simulation results (much to little detail)

The system simulation results in scenarios concerning installed capacity, generated electricity, reliability, emissions, solid waste, fuel use and costs. Most of the output can be made available in tables as well as in graphs.

SEPU

The simulation model SEPU was developed at the department of Science, Technology, and Society at Utrecht University, the Netherlands. The model can be

* University of Groningen, the Netherlands

ISSN 0895-0156/98/$10.00©1998 IEEE

characterized as a chronological simulation model. It can be used as a tool to study questions regarding the availability for use, the adjustability and the parameter values of a certain type of power plant within the total electricity production system. The model can also be used to evaluate an electricity supply system on its fuel use, load, variable costs, and NO_x and SO_2 emissions.

In SEPU, the chronological approach is chosen instead of a statistical simulation, based on the LDC. The reason for this choice is the importance of chronological data in revision planning and in studying storage systems, wind power, and/or combined heat and power (CHP).

For each (yearly) hour, units for generating electricity demand are determined. For the chosen strategy, many limiting conditions and restrictions (such as warming-up and cooling-down time, minimum load, and unplanned outage for individual plants) are taken into account. Some limiting conditions are taken into account for the system as a whole (such as a revision plan and spinning reserve requirement).

Results of a typical simulation are load, fuel use, and emission per unit.

SEPU and PowerPlan vary in approach and goals, but comparisons can be drawn in their overlap areas of time horizon, level of detail, and communication potential

Comparing Results

Although the models serve different goals and differ on several issues (Table 1), it is possible to compare their results.

In Figure 1, the differences and the overlap on three essential characteristics are presented. Three lines (from angle to base line) represent each one of these characteristics:

- Time horizon: What is the working area of the model (from short-term planning models to long-term scenario studies)?
- Detail level: To what degree can the model produce detailed results (for example, simulation result per power plant versus aggregated results per type of power plant)?
- Communication: To what degree has the model the potential to be used as a tool to communicate? This ranges from low potential (users/experts who interpret the simulation results themselves) to medium potential (scenario studies) to high potential (can be used in an educational context).

PowerPlan (shown as PP in Figure 1) operates mainly in the triangle bound by the long/medium-term time horizon, education/scenarios, and less detailed simulation results. SEPU operates mainly in the triangle bound by scenarios, detailed simulation results, and a simulation time horizon centered around medium term. The overlap lies in the (cross hatched) area, representing medium time horizon, scenarios, and less detailed simulation results. Both models produce general simulation output per year, so it is possible to compare scenario results at this level. The areas in which they are unique can be characterized as educational purposes (PowerPlan) and detailed reliability studies (SEPU).

Scenario Definition

Although the reality of the scenario plays no important role (scenario construction is not the goal of this comparison), an existing supply system is used for these validation simulations. All simulations start in the year 1990 with the situation for The Netherlands based on the Dutch Electricity Plan and end in the year 2020. In this plan, a forecast is made for the electricity demand (central only and total) until the year 2002. For the years beyond 2002, the same trend of electricity demand growth is used. The extension of the supply system (central and decentral, in order to meet the future electricity demand) is also described in this plan. The installed capacity, the capacity under construction, and the capacity planned (central and decentral) are presented. Each scenario takes this supply system as a starting point.

Table 1. Main differences between SEPU and PowerPlan

Features	PowerPlan	SEPU
Chronological calculations	no, cumulant method	yes
Detailed plant output	no	yes
Time horizon	middle (30 years)	short (weeks) - middle
Merit order	more or less fixed	flexible
Revision planning	no, derating of cap.	yes
Minimum simulation period	year	week
Interactive input/output	yes	no, on file
Graphical output	yes	no, indirect yes
Other data-sets available	yes*	no
Typical run time**	3 second	1 hour
User-friendly interface	yes	no

* Data-sets are available for the following countries: Belgium, Germany, France, Denmark, Latvia, Hungary, Maharastra (India), The Netherlands, New Zealand, Portugal and the UK.
** Run-time used for a simulation of 30 years on a 75 MHz pentium MS-DOS PC.

In order to get comparable results, input data for both models should match. The installed capacity for all scenarios is on a plant base and is identical for capacity and unplanned outage in both models. Evidently, simplifications had to be made in PowerPlan, because the

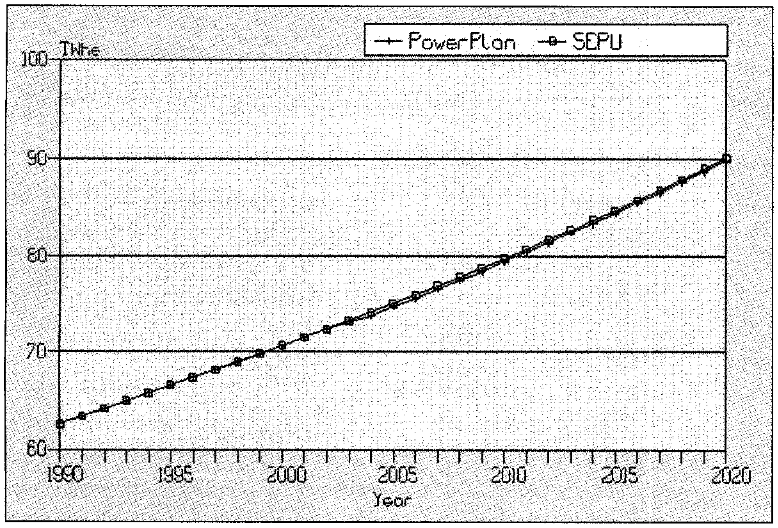

Figure 2. Electricity generated (TWh) for the central coal scenario, 1990-2020

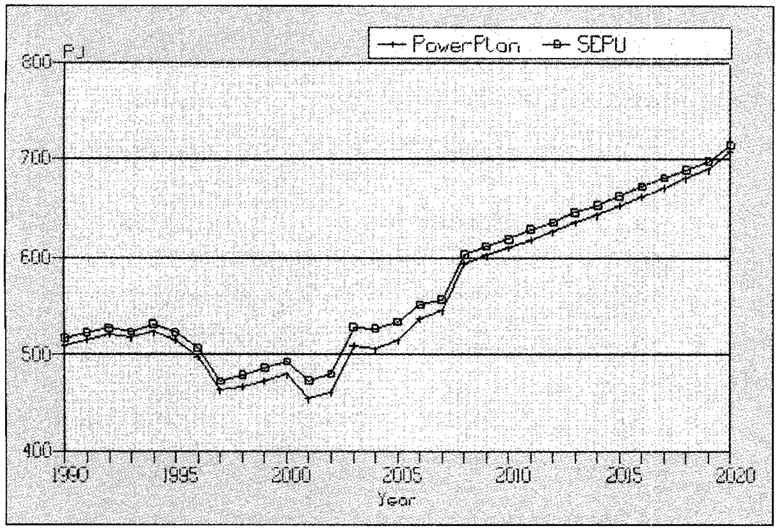

Figure 3. Total fuel use for the central coal scenario, 1990-2020

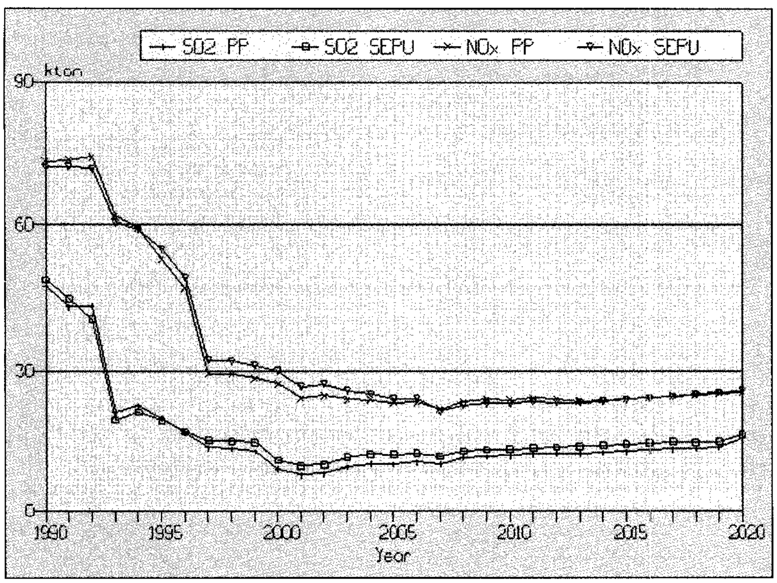

Figure 4. SO_2 and NO_x emissions (kton) for the central coal scenario, 1990-2020

input data for SEPU are more detailed than those for PowerPlan. Some of the most important simplifications/ differences are as follows:

- The 8,760-point chronological demand curve in SEPU is reduced to a 100-point LDC in PowerPlan.
- Efficiency at different plant loads is reduced to one average efficiency (SEPU uses a second order polynomial determined by three fuel-usage coefficients).
- The NO_x emission at different plant loads is reduced to one NO_x emission factor (SEPU uses a second order polynomial, determined by three NO_x emission coefficients).
- The SO_2 emission in PowerPlan is determined from a plant-specific emission reduction factor and the fuel quality. In SEPU, a plant specific emission is used.
- The chronological demand curve based on hourly data for CHP/district heating (SEPU) is reduced to a load factor for central capacity and a three-point LDC curve for decentral capacity.
- A chronological supply curve based on hourly data for wind, etc., is reduced to a three-point LDC curve for decentral capacity.

Simulation Results: Central Coal Scenario

The scenarios presented here are a subset of the complete validation of PowerPlan, which also contains a comparison with the IEEE test system and a historical simulation of the Netherlands and Belgium (1960-1990). The reference scenario is characterized by a straightforward electricity supply system, with a moderate growth of the peak demand (1.22 percent per year). The present base and middle load units are replaced during the simulation by typical base load units: coal gasification steam and gas-turbine (CG STAG). The present gas-turbines and the central district heating (DH Centr.) units and those under construction are replaced by similar units with updated specifications (higher efficiency, lower emissions). The other conventional units, import and nuclear power stations are replaced by modern CG STAG units. This results in a 73 percent installed CG STAG capacity in the year 2020). These units are responsible for 72 percent of the electricity generated by the central supply system.

Figure 2 shows the amount of electricity generated. As expected, the electricity generated fits well (less than 0.6 percent deviation). Figures 3 and 4 show other simulation results: fuel use (characterized by a decrease in fuel use in the period 1997-2006, due to higher efficiencies) and SO_2 and NO_x emissions. Most of the differences can be explained from two simplifications in PowerPlan:

- Less detailed merit-order
- Absence of fuel use for preheating of (mainly slow) starting base-load units and for keeping the base-load units standby.

SEPU has a more detailed merit-order than PowerPlan, for example:

- Can handle more than the 10 different types of power stations allowed in PowerPlan.
- Can handle partial loads, so some types of power stations (nuclear, STAG NG, etc.) can first run on a partial load of say 40 percent and then be geared up in one step to 100 percent. In PowerPlan, a unit runs on the full prespecified capacity or not, and a given type of power station will come completely in operation followed by the next type in the merit order.

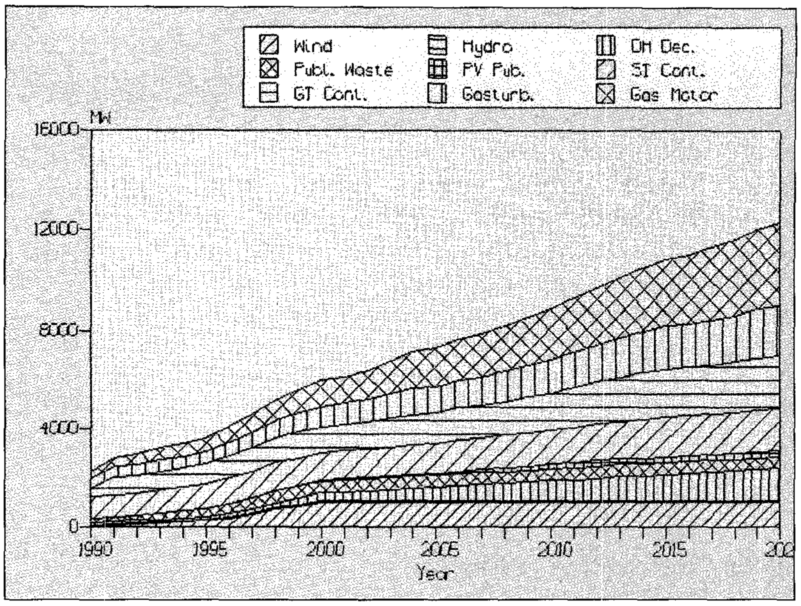

Figure 5. Decentrally installed capacity (MW) used in SEPU and PowerPlan for the combined CHP scenario, 1990-2020

The differences in the results caused by the merit order approach can be explained by the second option (partial load). Conventional coal units in SEPU have a higher load than the more advanced CG STAG units.

The origins of the deviations between the two models can be divided into five groups:

- Deviation in electricity generation, less electricity generated by PowerPlan causes an underestimation of fuel use and emissions.
- Deficiency in PowerPlan concerning standby and preheating cause an underestimation of fuel use and emissions.
- Approximation with a single average efficiency can cause either a positive or negative deviation in fuel use and emissions.
- Differences in the merit order can cause a positive or negative difference in fuel use and emissions.
- Difference in implementation of the specific emissions.

It is assumed here that these five origins of deviation are independent, which is not necessarily the case.

The stand-by/preheating and the differences in the merit order are the major contributors to the deviation between the two models. For the emissions, the difference in implementation plays an important role in explaining the deviations between the models.

Simulation Results: Combined CHP Scenario

The combined CHP scenario, shown in Figure 5, is characterized by a major shift to CHP, central (84 percent) as well as decentral capacity (85 percent, inclusive district heating)..

The PowerPlan simulation is expected to result in an overestimation of the contribution of decentral capacity to the total amount of electricity generated. This combined CHP scenario contains a large extension of decentral capacity. The already planned capacity of 5,647 MW increases to 12,247 MW in the year 2020. Because of these large amounts of capacity, the simulation results are expected to show differences as a consequence of the differences in the merit order approach. In the SEPU model, some central units are placed higher in the merit order (e.g., nuclear at minimum load) than the decentral units. This is not the case in PowerPlan, where all decentral units are highest in the merit order as a consequence of the method used for the incorporation of decentral capacity.

The amount of electricity generated by the decentral units (58 TWh, 53 percent) exceeds centrally generated electricity (52 TWh, 47 percent) in the year 2020. As expected, the decentrally generated electricity in PowerPlan is slightly higher (less than 1.1 percent deviation) due to effects described previously, as shown in Figure 6. For the central units, the opposite is true (less than 2.0 percent deviation).

The deviation in the total amount of electricity generated is caused by an underestimation of the production by heat demand following units in PowerPlan. This effect is also reflected in fuel use, as shown in Figure 7. The fuel deficit for the central units in the CHP central scenario in PowerPlan is larger here because of the lower amount of electricity generated in the PowerPlan simulation. The maximum deviation in the fuel use increases from 6 percent in CHP central to 10 percent in CHP total.

Inspection of the sources of the deviation in central fuel use shows that the merit order is not the major contributor it was in the central coal scenario. The reason for this is rather trivial: from the year 2008, 75 percent of electricity generated from central units stems from one power station type (CHP). In both models, this type of power station is at the same place in the merit order.

The difference in fuel use between SEPU and PowerPlan is explained by the reduction of the electricity generated by wind turbines in the SEPU simulation. In the year 2000 1,702 GWh (of a total supply of 1933 GWh) is used, generated by 100 MW of wind turbines. The utilization of wind power is thus 88 percent compared to the theoretical maximum in SEPU. In 2020, this utilization is reduced to 33 percent, all with a constant capacity (1,000 MW) of wind power, so the electricity from wind turbines is "dumped." The reason for this is the over-production of electricity from decentral (heat following) units, during base load hours, which is the consequence of the difference in merit order between both models. This explains the surplus of fuel use in SEPU simulations.

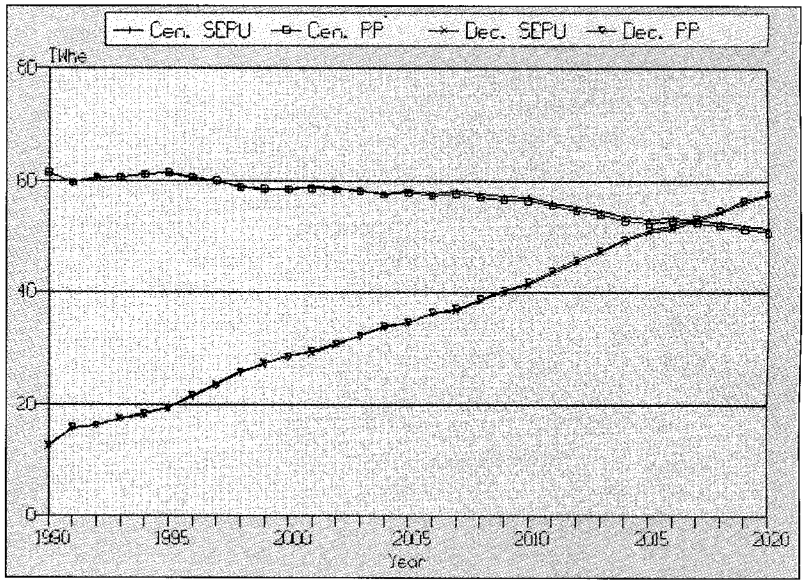

Figure 6. Electricity generated (TWh) by central and decentral capacity for the combined CHP scenario, 1990-2020

Strengths and Weaknesses

This article focuses on the area of overlap in using both models, and thus relates only partially to the performance in their respective specific areas of application. The scenario comparison exercise shows that PowerPlan is capable of reproducing the SEPU outcomes in qualitative and, in most cases, also in quantitative terms. Differences show up where they are expected: structural underestimation of fuel use and associated emissions in PowerPlan due to differences in treatment of fuel consumption for standby and preheating, in merit order details, and in calculation of emissions.

Unexpectedly, PowerPlan turns out to be capable of reliably simulating scenarios with high growth rates in decentral capacity. The three-point LDC used in PowerPlan for decentral units can thus be regarded sufficiently accurate for its purposes.

Some PowerPlan shortcomings can be corrected relatively easily by changes in software and input data. This does not hold for those related to the absence of chronological information in PowerPlan, the basic distinctive feature in this comparison. Remedy requires more input data and calculation time. Decisions concerning these improvements have to be seen in the light of the permanent question in modeling: What is the balance between insights due to more details and insights due to simplicity?

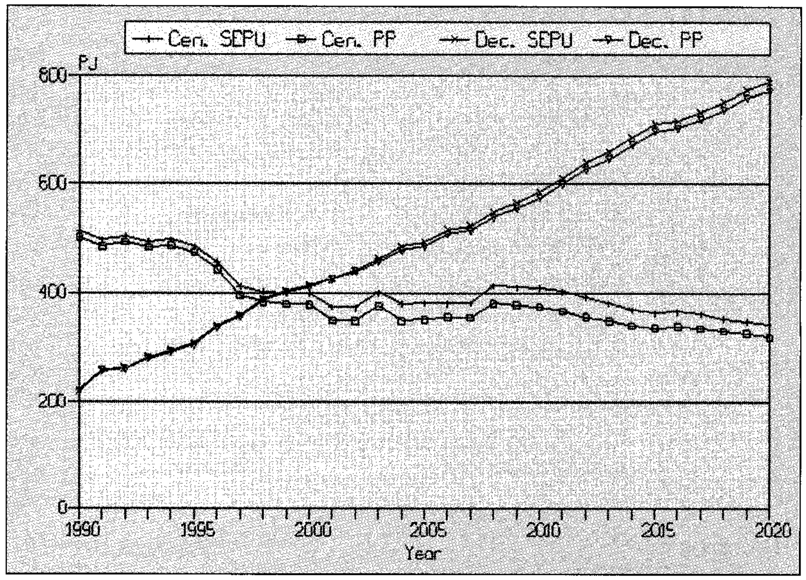

Figure 7. Fuel use in central and decentral units for the CHP total scenario

Acknowledgments

The authors thank S. Fockens and A. van Wijk of the Department of Science, Technology and Society, Utrecht Universityfor running the SEPU model with the scenarios described in this article.

The PowerPlan software package can be obtained from R. Benders, E-mail R.M.J.Benders@fwn.rug.nl.

For Further Reading

R.M.J. Benders, H.J.M. de Vries, "Electric Power Planning in a Gaming Context," *Simulation & Games*, 1989, Volume 20, Number 3, pages 227-244.

R.M.J. Benders, *Interactive Simulation of Electricity Demand and Production.* PhD Thesis, University of Groningen, 1996.

B. de Vries "Energy and Environmental Consequences and Prospects: Taiwan's Miracle," *Energy Policy*, December 1990, pages 949-961.

"IEEE Reliability Test System," committee report, *IEEE Transactions on Power Apparatus and Systems*, Volume PAS-98, Number 6.

Biographies

René M.J. Benders is a staff member of the Center for Energy and Environmental Studies at Groningen University and specialized in the modeling of mid- to long-term energy and environmental issues. He has a PhD in energy and environment from Groningen University.

Wouter Biesiot is associate professor and head of the Energy and Materials department of the Center for Energy and Environmental Studies at Groningen University. He has a PhD in nuclear engineering from Groningen University.