SINTEF

CASE STUDY 1

PLANNING NEW ENERGY INFRASTRUCTURE

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1 INTRODUCTION

This is an example of a typical planning problem in many regions/towns in Norway. The forecasted demographic development of the region under study triggered the need for planning of new energy distribution infrastructure that will supply the increase in the local energy demand and connect new customers.

The decision maker in this case is the local energy distribution company that is planning to increase the capacity of supply of an existing energy distribution system[1].

The increase in the local energy demand can be supplied by different energy carriers such as electricity, gas, hot water/district heating or biomass. In the area of interest (AI), electricity is the traditional and most common used energy carrier and therefore the use of a new resource (gas for example) would require that the local energy company will invest in new energy distribution infrastructure (gas or district heating). The material presented here is based on [1-4].

2 PROBLEM STRUCTURING

2.1 System boundaries

Primarily, system's boundaries have been drawn geographically, in order to include the area where an increase in energy demand has been forecasted.

The main increase in energy consumption comes from a large area where new residential buildings (over 2000 households) will be constructed in the near future. In addition, a potential for heat demand has been identified at an industrial site. This industry has a large demand of heat (for special industrial processes) that is currently supplied by a local heat generation facility (an oil-fired boiler). However because the boiler is almost reaching it's optimal life time, and because of increased oil prices, the management of the company is searching for solutions to replace it. One alternative will be to buy the heat form the local distribution company if the costs and other criteria are better that building a new boiler in it's backyard.

The energy system analysed in this case study consists of the existing electricity distribution system and a new district heating system, providing that the end consumers will be supplied with both electricity and heat.

Gas and electricity are 'imported' at system boundary. The electricity import is in terms of quantity of energy imported (with its daily variations) with associated marginal cost (price) at system boundary and emissions. It has been assumed that the electricity import triggers marginal changes in the global CO_2 emissions and that the price of electricity at system border does not include taxes (for CO_2 or other local emissions). The gas import is taken into consideration only in terms of quantity and price.

The system analysed can be schematically represented as in Figure 1.

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[1] Although the case-study is based on a real planning problem, no reference to company's name or details about the region will be given here.

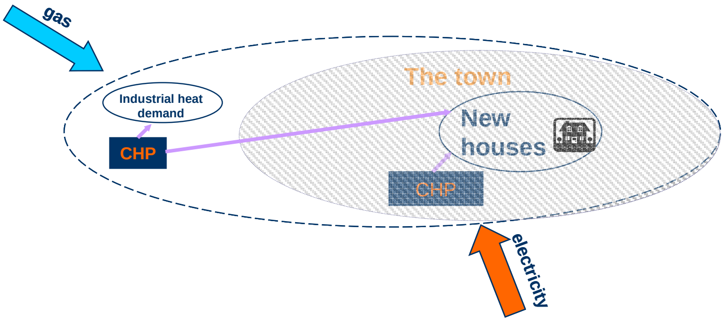

Figure 1 A schematic representation of system boundaries

2.2 Identification of alternatives

Four investment alternatives have been identified for further investigation. The planning approach to increase the capacity of the local electricity distribution system - in order to be able to accommodate new customers, is compared with the approach of using gas as local energy source and hot water as energy carrier in a new, parallel district heating infrastructure.

The first alternative consists of reinforcing the electricity grid with a new supply line to the area, so that one can continue to rely on electricity to supply the local stationary energy demand. A district heating network and a CHP plant is built in the other three alternatives, to serve the heat demand for the customers in the residential area. In addition, a gas boiler is built to meet the peak demand for district heating.

In the second alternative, the district heating network also covers the industrial site outside the residential area. The CHP plant is placed at the industrial site, and can also meet the heat demand there – this demand is currently covered by an old diesel boiler.

In alternatives 3 and 4 the CHP plant is placed nearby the residential area. The only difference between these alternatives is the size of the CHP plant. The larger CHP plant in alternative 4 facilitates generation of more electricity, which can be sold to the electricity market when it is profitable to do so. A consequence of higher electricity generation might be excess heat from the CHP plant, which must be dumped to the local surroundings.

The following table summarises the four alternatives.

Alternative	*New el line*	*DH network*	*CHP plant*	*Gas boiler*
1	yes	no	no	no
2	no	large	3.6 MW	5.0 MW
3	no	small	3.6 MW	5.0 MW
4	no	small	5.0 MW	5.0 MW

Table 1 List of alternatives

2.3 Identification of criteria

The main objective for the planner is to cover the increase in energy demand in the area. Within this framework, the planner wants to assure a stable/reliable energy supply, with minimal costs for the consumers and minimal impact on the environment. Therefore, the objectives for this planning problem were organized as following:

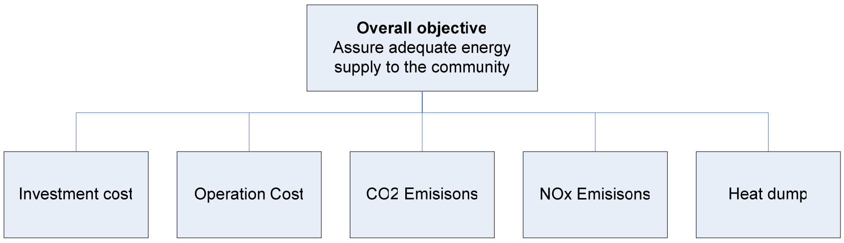

Figure 2 The hierarchy of objectives

In this hierarchy one can observe that four of the objectives are related to the system operation planning (operating cost, CO2 emissions, NOx emissions and heat dump from CHP plants to the environment) and one is related to strategic planning (investment cost). In order to deal with the multiple objectives, measurement scales had to be decided for each of these objectives (or criteria):

No.	*Objective*	*Unit*
1	Operating cost	[MNOK/year]
2	Investment cost	[MNOK/year]
3	CO_2 emissions	[tons/year]
4	NO_x emissions	[tons/year]
5	Heat dump	[MWh/year]

Table 2 Attributes considered in the case-study

(MNOK is million NOK)

3 MODELLING THE PROBLEM

3.1 Gathering data

The data used for this case study was extracted from a realistic case of an existing planning problem in Norway.

In order to simplify the analysis we only considered the operations of the system for one time stage (year) in the future. Hence, in this analysis we do not consider the long-term changes in demand, and the timing of investment decisions. Total investment costs were therefore converted to annualised costs and could therefore be compared to the operating costs. An interest rate of 7 % was used for investment costs.

Hourly data for electricity and heat demand were specified for 8 different days in the year. The load days represented four seasons and two days within the week (weekday and weekend day). A 122 bus network was used for the electricity grid, with hourly electricity load specified in 55 of them. DC load flow equations were used to calculate the load flow and corresponding losses in the impact model. Potential district heating networks were represented with either 14 or 16 heat demand points, all of them with hourly demand data for the 8 load days. Note that while the electricity load can only be met by electricity, any connected energy carrier can meet the heat load. In this case that is electricity or district heating.

3.2 Considering the uncertainty

The main uncertainty considered in the analysis is the price of electricity. The electricity price is very important for the total cost of meeting the load, since there can be substantial exchange of electricity from the area, both imports and exports. Three scenarios were used for hourly prices of electricity, as shown in Figure 3. For simplicity we used the same price data for all the 8 load days.

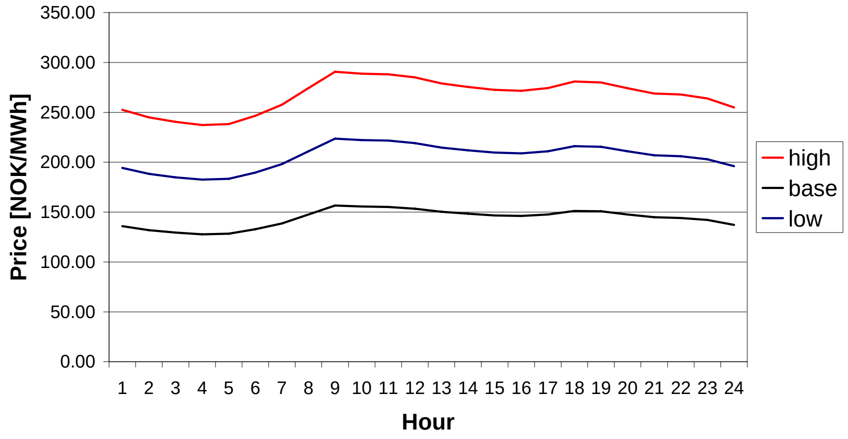

Figure 3 Price scenarios. Currency rate: € 1 ≈ NOK 8

In addition to the price uncertainty, it has also been assumed that the marginal change in global CO2 emissions from exchange of electricity was uncertain. This factor affected the total CO2 emissions from different investment alternatives.

The marginal CO_2 factors for electricity exchange were set to 400, 500 and 600 g/kWh respectively, for the low, medium and high price scenarios, assuming that more efficient technologies are used in the low price scenario. As mentioned, we assumed that emissions were not accounted for in the market price.

Subjective probabilities were assigned to the scenarios, using 0.25 for the high and low scenarios and 0.5 for the medium price scenario.

Other prices, such as the price for gas supply to CHP plants and gas boilers, and the price paid for heating at the industrial site were assumed constant in the analysis.

3.3 Energy system modelling

Because large amounts of data have to be processed when analysing different alternatives, a mathematical optimization model of the energy system must be used.

In this case study, and in many other examples carried out under the SEDS project, the eTransport model has been used to represent the energy system. eTransport is a user-oriented flexible and easy-to-use tool to support decision making. Energy systems can be easily modelled within the tool, and a variety of analyses can be performed. Shortly, the use of eTransport can be described in the following steps:

First, the user must draw the system under consideration, by dragging-dropping system components from a library of available components (seen to the left in Figure 4).

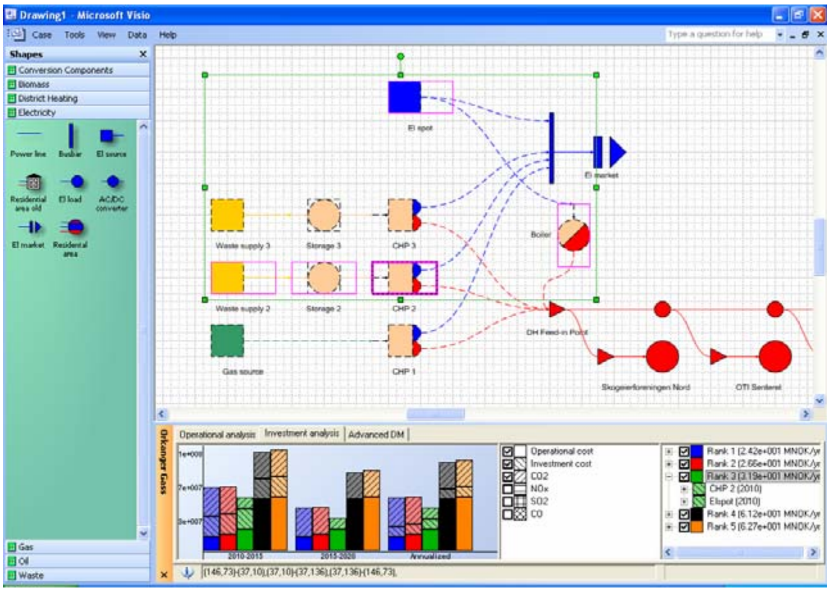

Figure 4 Representing the system with the eTRANSPORT model

Second, the model requires the user to provide specific data in order to define each system component. Edit windows such the ones shown in Figure 5 make this possible. Some component-specific default parameters are already available

The last step is to run the optimization by specifying the system components that should be included and the ones that are to be scrapped in each alternative during the time period set for analysis. Interest rates must also be specified to discount the future costs.

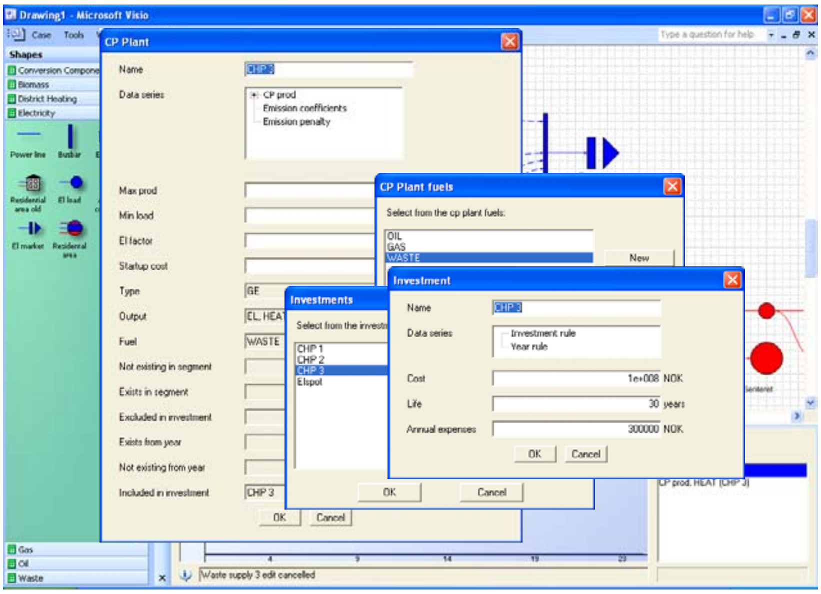

Figure 5 Data input into the eTRANSPORT model

3.4 Preference modelling

Preference modelling is necessary when decision-makers have difficulties in making a clear decision and choosing the alternative (solution) that would solve their planning problem. In particular, preference modelling is necessary when multiple criteria have to be considered and when not all of these criteria can be converted into costs (profits, net present values or other economic criteria).

The goal with preference modelling is to extract decision-maker's way of thinking - an indispensable ingredient in decision making. Among the multitude of theoretical methods designed for preference modelling (and belonging to the MCDA discipline), MAUT (Multi-attribute utility theory) has been chosen for this case study.

MAUT can offer support to decision-making under uncertainty, as it is the case presented in this case study. The method, its application and the use of its insights have already been described in Appendix A2.

From a practical point of view, the application of MAUT must be done in three steps. The first step is to identify decision-makers risk attitude with respect to each of the criteria considered (see Figure 7 in appendix A2). This can be done through a series of lottery questions (see Figure 8 in Appendix2)

The second step is to find out decision-maker's preferences regarding the criteria considered: ask the decision-maker which is the most or the least preferred one, and how much (see Figure 9 in Appendix 2)

The third step in a MAUT application is to combine the preference indicators obtained during the first two steps into a total utility function (preference function) and to order alternatives based on their total utilities. These results must then be presented to the decision-maker involved together with a final recommendation on which alternative to choose –see Figure 10 in Appendix 2.

4 USE THE MODELS TO INFORM THE DECISION MAKER

The main tools used for decision support in this case study where an energy system model (eTRANSPORT) and a preference model (based on MAUT). The complexity of analysis was increased by the fact that both economic criteria and criteria describing the environmental impacts (non-monetized) have been considered in the analysis.

The use of the two models brought invaluable insight into the problem.

First of all the decision-maker gained more knowledge about the problem and the alternatives analysed. For example, when running the eTRANSPORT model, the decision-maker had the opportunity to simulate how the system can be operated in one system configuration (system alternative) during different time-periods and under various price or load scenarios.

Figures 6 and 7 show how the optimization results with this model can be presented to the decision-makers. For example the model shows the optimal daily operation of each system component or of the system as a whole (Figure 6).

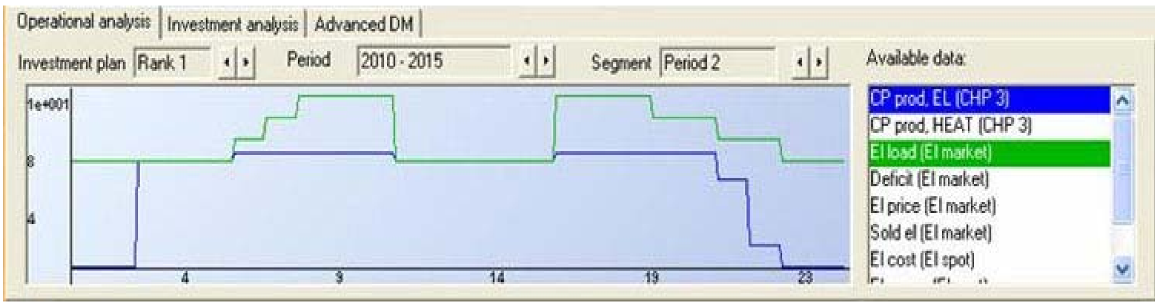

Figure 6 The operational analysis-mode

Moreover, the decision-maker can see how investment alternatives are ordered based on their total costs during the period of analysis.

The contribution of each cost element (the operating cost, the investment cost or different emission costs) to the total costs figure is also clearly showed (Figure 1).

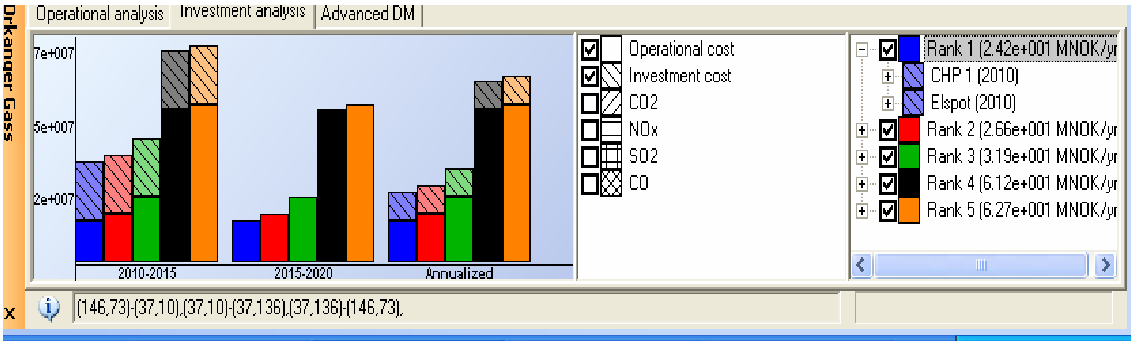

Figure 7 The investment analysis mode

eTRANSPORT can be easily set to simulate if/how the ranking of alternatives changes when some of the relevant input data are modified: costs, prices, demands profiles, or the restrictions set on emissions (quantities / taxes). These simulations contribute significantly to the understanding of correlations and synergies between the many issues that matter in planning decisions.

Second, by applying MAUT (as described in Appendix A2) valuable insight has been obtained about the way decision-maker's think when faced with such problems. The application of this method implies a more in depth thinking about the impacts alternatives might have on the economy or the environment.

Several decision makers have been involved in the case-study. The answers of decision makers to all types of MAUTpreference elicitation questions contributed to the construction of utility functions. In this example *expected utilities* have been calculated, because several expected electricity price scenarios (with the afferent probabilities) have been considered. The three possible different scenarios in electricity price lead to three possible impact values in all five criteria considered – see figure 3.

The exercise has shown that different decision-makers have different risk attitudes and preferences regarding the different criteria, and that these differences may lead to different decisions. Figure 8 shows the results of preference modelling for two decision makers according to expected utility assigned to the alternatives considered. For each decision maker, the four alternatives have been ranked according to the total expected utility.

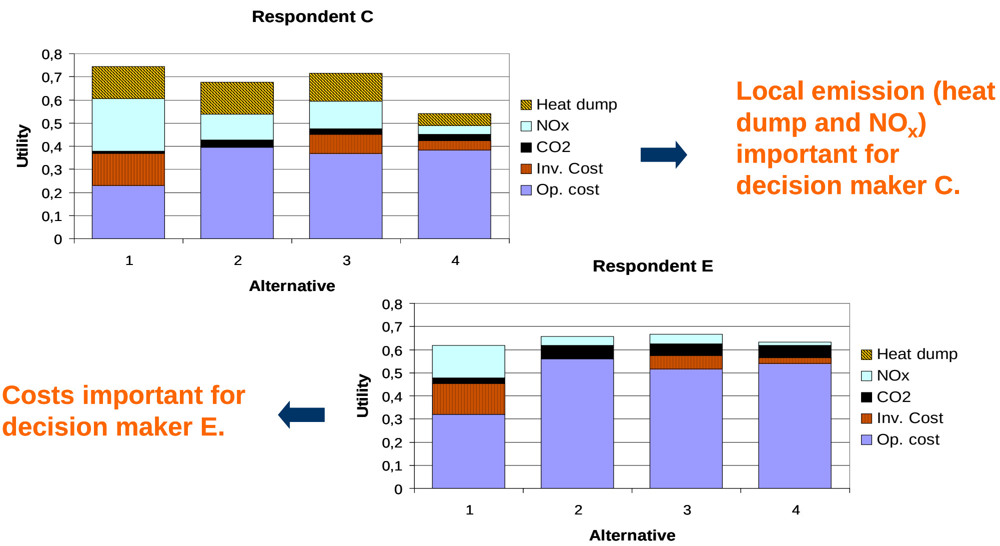

Figure 8 Synthesis of preference modelling

The illustration clearly shows which attributes (criteria) that are considered to be important for a decision maker and why a certain alternative is given a high rank. Note that a high utility value (large "bar") means that this alternative is preferred (given a high value) by the decision maker.

A possible approach to improve the interpretation of results form a MAUT analysis is the Equivalent Attribute Technique (EAT) as proposed in [2]. The EAT principle is straightforward. Assume for example that there are two alternatives (*a* and *b*) that have different performances in a number of criteria, one of which is cost. An expected total utility has been determined for each alternative, and E(U(a)) > E(U(b)), thus *a* is preferred to *b*. For the decision maker this recommendation might not be complete. He/she would probably like to know, for example, how much the cost of the least preferred alternative (*b*) must be reduced (ΔRed) so that *b* will reach the same expected utility as *a*, provided that all other attributes are held at a fix level. ΔRed will be in this case the equivalent cost difference between the two alternatives. Another possibility is to calculate how much the cost of the best alternative *a* would have to increase (ΔInc) so that its total expected utility will decrease to the value corresponding to alternative *b*.

Figure 9 illustrates this principle for one of the decision makers (DM A) in the example above. For this decision maker, the alternative that gives him the highest utility is alternative 3 ($U_{A,\ alt3}$=0,679) while alternative 1 gives him the lowest utility ($U_{A,\ alt1}$=0,631). A simplified EAT linear model is used further to determine the equivalent cost reduction (ΔRed_{A1}) that would make the two alternatives equal from the total utility point of view.

The figure below shows that the cost for alternative 1 must be reduced from 21,2 MNOK/yr to 20,0 MNOK/yr for this alternative to be assigned the same utility as the original preferred alternative (alternative 3).

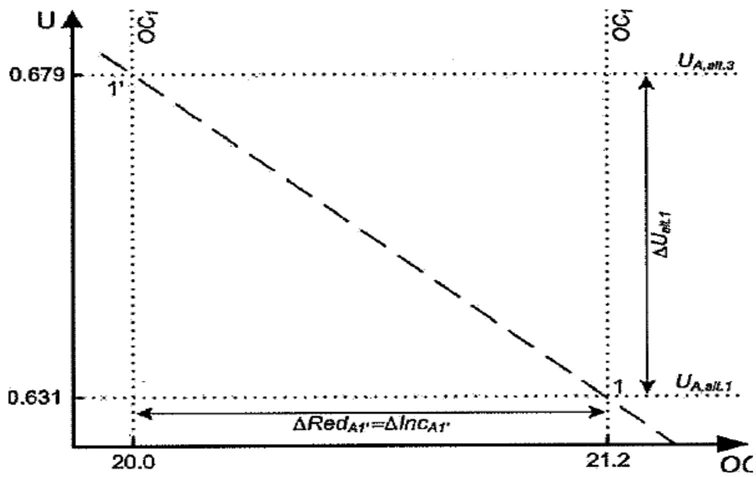

Figure 9 Expected total utility for DM A as a function of alternative's 1 OC
(assuming that all other attributes are held constant)

The main reason for using EAT is to be able to offer decision makers a better interpretation of MAUT results by making a distinction among alternatives with similar utility values. In cases where there are large utility differences, the choice between the alternatives will be clear and consequently there is no particular need to use EAT.

Planning is not a trivial task, and without using a multi-criteria method to structure and encourage this type of thinking, the final decision would probably not have been complete.

5 REFERENCES

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