Environment, energy and housing:
A location model for sustainable community planning

Johan O. Lamm and Anders Görling, Chalmers University of Technology

1. SYNOPSIS

The relation between energy use, environmental questions and housing pattern is analysed by a welfare model. The main result is a distribution of dwellings.

2 ABSTRACT

There is a relation between emissions to the environment, the use of energy and the housing pattern. The relationship depends upon the fact that the use of energy needed to operate a dwelling is different at different locations. The emissions generated from energy use are therefore also different at different locations. The base for a healthy and ecological sustainable environment should therefore be a planning process in which energy use and emissions from energy use form part of the basis for the housing pattern. In this study such a process is described. The municipality under planning is divided into squares of land, each 500x500m. For each such square investigations are made: Local climate, potential energy supply systems and transportation systems. Using this information it is possible to calculate the energy use for the operation of a a potential dwelling in each square of land. We take into account energy for thermal comfort, for operation of household equipment and for transportation of persons to and from the dwelling. Knowing the relation between the emission volume and the energy conversion processes involved we calculate the emission volumes generated by location in each square. We introduce an environmental tax for each pollution type. We have also investigated the estate prices, the exploitation costs, the construction costs and the users' preferences for different locations. The users' preferences are expressed as the willingness to pay for a dwelling in each square of land. Matching the users' preferences against the costs for a dwelling in each square of land, each square will recieve a specific number of dwellings. The process is performed by computer. The result of the process is a distribution of dwellings/a housing pattern which has the property to be economic effective. The emissons of SO_x, NO_x and CO_2 and all relevant energy as well as economic aspects have been considered as location criteria. The model thus acts as a mean of reducing and controlling emissions to the environment emanating from energy use in housing and transportation. It can also be used as a part of the municipality energy plan as well as a tool for the physical master planning. The model is able to apply to any country and situation at the municipality level. The report on the model is BFR report D1:1992 (english) and can be obtained from Svensk Byggtjänst, S-171 88 Solna, Sweden.

3. INTRODUCTION AND BACKGROUND

There is a relation between emissions to the environment, the use of energy and the housing pattern. This relation exists due to the fact that energy needed to operate a dwelling is different at different locations.

The demand of energy for thermal comfort is dependent on the position of the dwelling in relation to the local climate. The possibilities to supply energy to a specific dwelling depends on the location of the potential energy supply: district heating systems, gas pipes, local sources, firewood, etc. The use of energy in transportation is related to the travel distances between home, work, service and recreation as well as the transportation systems available (1). The emissions of SO_x, NO_x and CO_2 emanating from the use of energy are therefore also indirectly dependent on the location of the dwellings.

By locating dwellings in different patterns one will affect the use of energy of different quantities and qualities (Owens 1986) and thus indirectly affect the emissions with regard to quantity and type. The base for a healthy and ecological sustainable community should therefore, from the point of view of pollution, be a planning process in which location of dwellings is performed considering emissions emanating from energy use.

In this paper a method is described for the location of dwellings. The location can be performed considering energy use and emissions from energy use. This includes energy use for thermal comfort, the operation of household equipment as well as energy use in transportation. The emissions taken into account are SO_x, NO_x and CO_2; however, in principle any emission could be considered. The method is demonstrated with the aid of a case performed at full scale. The municipality demonstration case is Kungsbacka in western Sweden.

4. PLANNING PROBLEM AND PLANNING SITUATION

The municipality is located at the shore of the ocean approximately 30 kilometres south of Gothenburgh, the second largest city in Sweden. By 1990 the municipality had approximately 20 000 dwellings. However, the nearness to Gothenburgh as well as the attractiveness of the area has caused a large demand for housing. The planning problem is to locate a sufficient number of new dwellings considering the criteria noted above.

The planning situation in which these new dwellings should be located has its legal frame in the new Housing and Planning Act that was passed by the Parliament in 1987 (PBL 1987). This law requires all Swedish municipalities to redesign their municipality master plan. In the second paragraph of the law, several criteria for the location of dwellings are noted. Most of these criteria are familiar to the urban and regional planner, however, there is one new criteria added:
"Buildings and other structures which for their operation demand energy supply shall be located in a position which is favourable with regard to energy supply and energy conservation".

There is also an emphasis on the environmental side of the location problem.
As a basis for the practice of the law, The National Board of Housing, Building and Planning has published a book (Planverket 1987) with advices and recommendations about how the requirements of the law shall be considered. The major items to be considered are, according to the book, energy demand from variations in local climate, energy supply system and energy use in transportation. The location model introcuced in this essay, should be evaluated against this legal framework, the very basis of which is the conciousness about the ecological crisis syndrom of the world (Söderquist 1986).

5. CONDITIONS AND RESTRICTIONS

Our planning process starts whith a delimitation of the municipality. Kungsbacka has a size of 30 km from west to east and 32 km from north to south, see Figure 1. This means that the municipality can be delimited within a matrix of 30x32 km. (The illustration is a reduction of a map to the scale of 1:200 000)

It is now necessary to divide this matrix into smaller subareas. If we use a grid of 0,5 km we can divide the municipality into a matrix of 60x64=3840 squares of land, each 500x500 metres. However, several of these squares of land are outside the municipality border while others are covered by ocean and lakes. In some of these squares we have found that they are not available for housing because they are dominated by existing infrastructure such as motorways, railroads, major gas pipes or high voltage electricity lines. There are also several squares of land with existing buildings which are so dense so that they cannot recieve any more structures. The municipality authoroties also want to protect several areas from housing due to natural beauty, cultural interest, recreational purposes, agriculture, as well as forestry (2). If we take all these areas out of the analysis there remains only 1511 squares of land to which dwellings theoretically could be located, see Figure 2, squares of land marked: location possible. (In this model a test restriction is put upon emissions of CO_2. The restriction is = 0,25 SEK/kg CO_2 as recommended by the state. As a biomass from the point of view of CO_2-emissions emissions are calculated as zero, the result is a certain priority for the areas with this kind of fuel.)

We must now decide upon which number of new housing we want to investigate. In collaboration with the planning office of the municipality we decided to perform the process with 32 000 new dwellings. Any

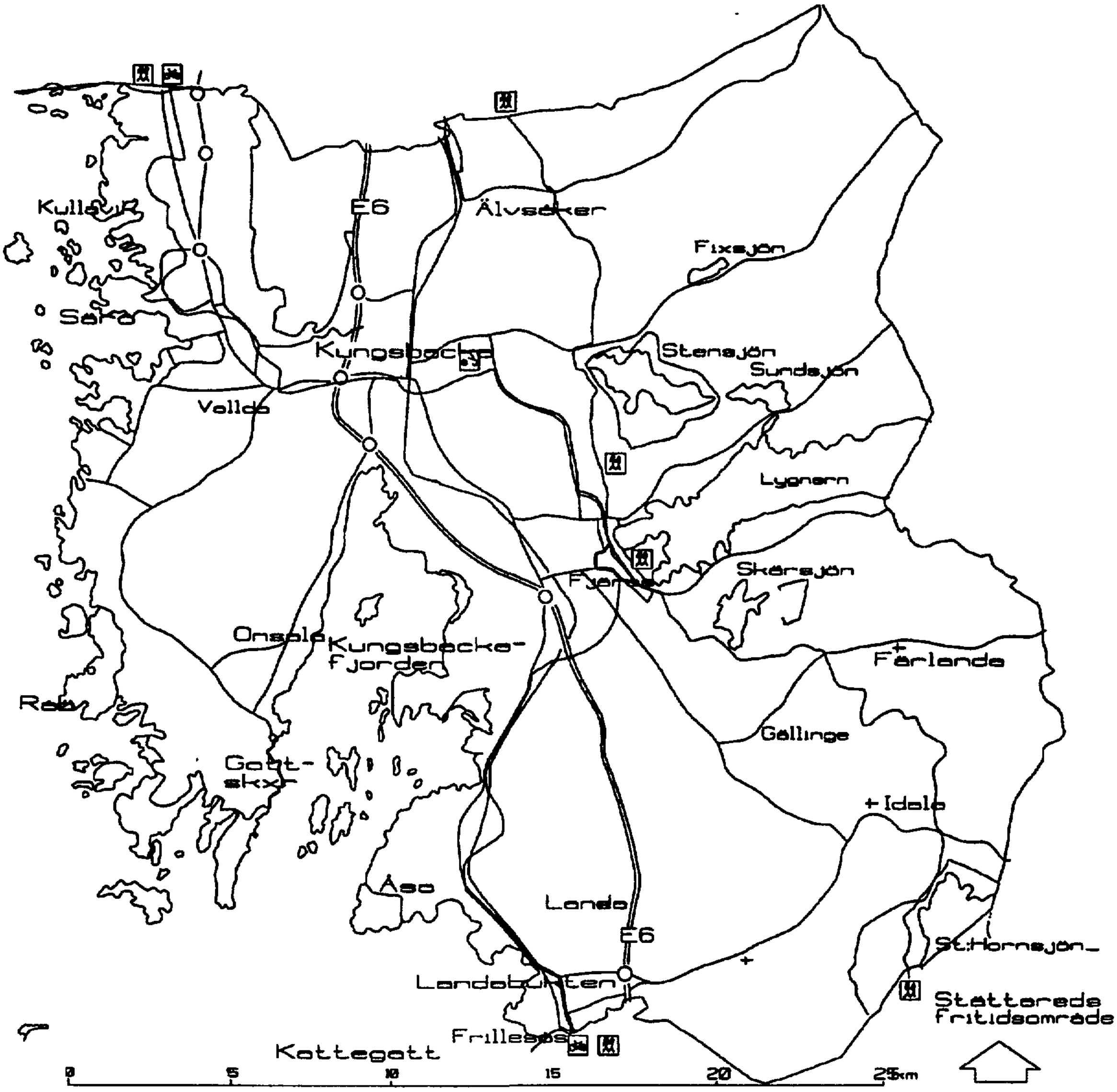


Figure 1. ***The municipality of Kungsbacka south of Gothenburgh on the Swedish west coast.***

number could be appropriate for our model test; however, this figure is supposed to be a long-time ultimate maximum for future development.

Another figure that is to be stated is the maximum of dwellings allowed in each square. Based upon studies of what is considered to be a future mixture of housing types, an average of 250 dwellings on 500x500 metres of land is decided a goal for the planning simulation.

6. ENERGY AND ENVIRONMENT

6.1 The energy demand

In order to calculate the energy demand for thermal comfort (heating and cooling), a climatic investigation is carried out (3). For the 1511 squares of land, five climatic elements are studied: solar input, average wind speed, cold air production, level over ocean and nearby large water storages. At this moment of the study we state a goal for future average energy use. Using a computer program developed for the purpose, it is possible to calculate the impact from these elements on the demand of energy for thermal comfort for a dwelling located at any of the squares included in the analysis. As a result we now have the demand for energy for thermal comfort in every square of land for a dwelling.

From estimations about the use of household equipment in the future, we state a figure for the electricity demand in the average dwelling. We use the same figure for dwellings in all squares of land.

According to Swedish law it is compulsary for every municipality to have a plan for how energy shall be supplied to the public (4). The energy supply plan must cover the whole municipality area. It is therefore possible to get information on how energy for thermal comfort is going to be supplied in each of the 1511 squares of land that we have in our analysis. In this case, one alternative for energy supply is the following. For some areas 100% electricity is suggested, for some 25% electricity and 75% natural gas. Large areas are suggested to be supplied by 25% electricity, 25% oil and 50% firewood.

With this information it is now possible to calculate the energy turnover (5) for an average dwelling located in any of the land squares included in the study. We put prices on the different kinds of energy, and thus we get the potential cost of energy for thermal comfort at any location.

Since we know which kind of emissions must come out from the diffent energy conversion processes proposed in each location, we can also calculate the potential emissions (6) emanating from the quantity and quality of energy used in the operation of a dwelling at any location: X kg SO_x, Y kg NO_x , Z kg CO_2, etc. According to Swedish law, a pollution tax is put upon each kind of pollution: 30 SEK/kg SO_x, 40 SEK/kg NO_x and 0,25 SEK /kg CO_2. If we use these figures, we can now calculate the environmental costs from emissions emanating from energy use for thermal comfort and operation of household equipment at any of the 1511 squares of land investigated.

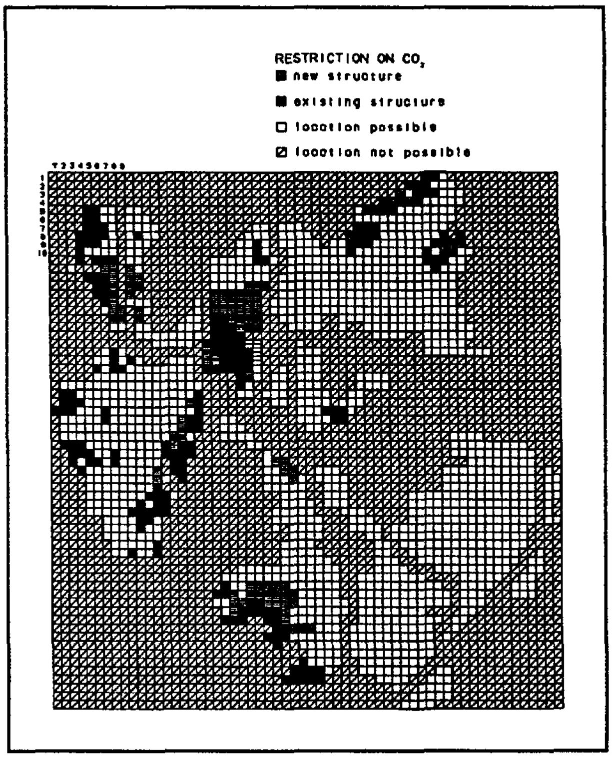
6.2 The transportation system

In a similar way the transportation systems are analysed. The potential transportation systems are briefly sketched: public transport by commuter train to Gothenburgh, bus feeder lines to the commuter train stops, and the major road system for car transportation. In areas which have a good public transportation system, a certain number of the future inhabitants are going to use these systems, depending on walking distance, travel standard of the system etc. The use of energy for personal transportation will therefore be different at different locations. We can now calculate the use of energy for personal transportation with a specific figure for a household located at any of the 1511 squares of land.

Since we know the fuels and the conversion processes of the different transportation systems we also can calculate the emissions from transportation with a specific value for each square of land. With a price on the different kinds of energy as well as an environmental tax as required by law, we will come out with a transportation cost for a household at any location possible for a dwelling.

7. THE MODEL AND RESULTS OF MODEL USE

The purpose of this study is to develop a model that locates dwellings over a municipal area subject to energy, environment and economy.



Eigure 2. ***In this model a test restriction is put on emissions of CO_2.***

Three main elements are distinguished in the analysis, the preferences and planning parameters of the municipal government, the preferences of the users and the cost structure. The characteristics of these elements are examined below.

We consider the use of the dwellings to be the main reason why we complete and locate dwellings at all. Thus in the model we regard the use of the dwellings to be the purpose of the location. At the first glance this must appear as a somewhat superflous statement, but below we will find out that it is most important statement. With this approach the task for the model is fairly clear:

Let the model find the pattern of location that maximizes the utility of housing. As discussed above we must also pay regard to the municipal government and the cost structure. The municipal government defines the planning parameters and the cost structure defines the economic requirements. Consequently, we let the model find the pattern of location that maximizes the welfare of housing for the users subject to all planning and economic requirements.

7.1 The welfare model

One way of handlling this is to hypothesize the existence of some social welfare function. This is supposed to be some sort of function that aggregates the individual utility functions generating some sort of social utility. We will refrain from making philosophical comments here and just postulate that some such function exists. We will suppose that we have a welfare function W, so that

$$W(U_1,U_2,...U_n)$$

gives the "social utility" resulting from any distribution

$$(U_1,U_2,....U_n)$$

of private utilities. We will assume that W is increasing in each of its arguments.

Now, according to the social welfare approach we should choose a pattern of location X^*, that maximizes the social welfare. Now we have:

$$\text{Max } W = W(U_1(X,Y),U_2(X,Y),...U_n(X,Y))$$

$$\text{s t } (1)\ S_{ij}\, X_{ij} = X^p$$

$$(2)\ X_{ij} \leq X^{**}$$

$$(3)\ X_{ij} \in X_D$$

$$(4)\ X_{ij} \in PA_k$$

$$(5.a)\ EV_l(EP) + EV_l(TF) \leq EV_l^{**}$$

$$(5.b)\ ENVCij = t^*Z_{ij}$$

$$(6)\ \mathbf{PX} + \mathbf{PY} = M$$

$$(7)\ C_{ij}(X_{ij}) = f_{ij}(P_h,P_{exp},P_{est},P_{tr},P_e,t)$$

Where X is a vector $(X_1,X_2,..,X_l,..,X_m)$ the index (l) refers to a specific preference area in the municipality. Y is a vector of all other goods.

Restriction (1) says that the number of the located dwellings must equal the planned number X^p. Restriction (2) says that the number of dwellings located to square of land (i,j) must not exceed a fixed number X^{**}.

Further more (3) defines which squares of land that are included in the analysis. X_d is the definition set defined by the municipal government. Restriction (4) divides the municipality into preference areas, where PA_k is a preference area. The restrictions 5.a and 5.b defines the environmental regulations. Only one of them can be used. 5.a defines an environmental restriction. 5.b introduces a predetermined environmental tax. Restriction 6 is an income identity. The last restriction 7 describes the cost function in a square of land (i,j). The terms within the bracket are the prices for the house, the exploitation, the estate, the energy and the transportation. t is the environmental tax.

Now we are especially interested in the optimal location of dwellings in the preference areas. The first order condition for welfare maximization is:

$$P_k = MC_k$$

Dwellings should be located to preference area (k) in such an extent that the price equals the marginal cost. This is a most familiar allocation rule in social welfare theory. Together with the restrictions above it gives a location of dwellings over the preference areas.

This condition is examined below. Actually the marginal cost condition is all we need from the maximization of the welfare model. We do not need the marginal condition for the users. They are supposted to use only one single dwelling. There is no marginal adjustment between the various preference areas giving a marginal adjustment between all types of dwellings.
Actually we now have a model that locates dwellings over the municipal area giving maximum social welfare subject to planning and economic restrictions.

What can be achieved by such a model? Well, it certainly gives a pattern of location that fulfils all the restrictions. That can be verified. It also reacts on changes in the parametars eg changes in the energy prices. That can also be verified. But what can the model offer, what can be produced? Well what we have in reality is a model with an intention to satisfy the needs of the users. It searches for the pattern of location that maximizes the aggregated utility of housing. Thus the solution performed by the model gives the highest possible welfare of housing subject to all planning and economic restrictions. There may be other patterns that fulfils the restrictions but they will give a lower welfare of housing. So if we use the above mentioned rules and fulfil all restrictions the model gives a very detailed pattern of location that maximizes the welfare of housing.

The three main elements in the model are treated as follows. In the first category we gather all planning parameters of the local government. These may be: the number of dwellings to be located, the density of the dwellings, areas that mustn't be used, the restrictions for the emissions of pollution, the energy supply system etc.

In the model the user's preferences for a specific location is a main ingredient. We therefore define preference areas, where an average user is assumed to be indifferent between the different squares of land. The preferences areas are seperated by different willingness to pay and we use a traditional linear demand function. The parameters in the demand function are estimated from data for purchase of house-properties.

In the cost structure we gather all relevant costs for building and using a dwelling. The costs are: construction costs, development costs (for roads, sewerage and water, investigation fees), energy costs (for thermal comfort, operation of household equipment), costs for personal tranportation and the estate price. As a special unit we use an environmental charge to handle environmental policies.

In optimum the model gives a distribution pattern of the dwellings where the welfare of housing is as big as possible, subject to the abovementioned conditions.

As mentioned above the model is capabel in handling environmental and energy questions. The environmental questions is handled by an environmental charge. The squares of land that generate large volumes of pollutants receive high environmental costs. Hence, there is a tendency for the model to disregard these elements. On the other hand, the squares of land that generate low volumes are favoured by the model and there is a tendency in the model to locate dwellings to them. A model result is shown in fig. 2. The pollution type is CO2 and the environmental charge is 0,25 SEK/KG CO_2. In the main report tests are illustrated on other pollutants.

The model is developed to handle questions of energy sypply systems and energy prices. A change in the energy supply system impacts the cost structure and hence a tendency to a change in the location pattern. Further more, different energy prices can be used. Here we investigate how sensible the cost structure is to such a change and the impact on the location.

7.2 Identification of the squares of land and equilibrium of the model.

In this part we develop the connection between the economic condition of the squares of land, the equilibrium of the model and the pattern of location.

As mentioned above the optimal criteria for welfare maximum is where the marginal cost equals the price of the dwellings. The parameters of the cost structure are described above and several of them are dependent of the location of the squares of land.

The welfare model approach implies a cost minimization behaviour and in our case this means that we order the squares of land with respect to the cost parameters. Thus, we order them from the least to the highest cost. The squares of land are supposed to be small enough to justify constant unit costs within each square of land. Hence, the marginal cost for the whole preference area is a positive stepwise linear function.

Lets take a look at Figure 3 which shows the connection between the squares of land and the marginal cost. When the costs in each square of land are defined the marginal cost for the whole preference area can be derived. Square of land (3.5) has the lowest cost in preference area 1 and it is ordered first in the cost function. Second comes square of land (1.7) etc. In preference area 2 square of land (3.12) is ranked first, next in turn is (2.10) etc.

Now the marginal costs for all preference areas are derived and every square of land is connected with a certain step in the marginal cost curve.

Lets turn to the question of equilibrium of the model. Lets look at Figure 4. The optimal criteria for the model, the marginal cost is equal to the price of the dwelling, occurs where the demand function intersects with the marginal cost curve. The volume of dwellings in each preference area is adjusted to this level.

For a fixed number of dwellings to locate the model adjusts the demand in each area untill this state is reached.

Now to the question of location. The welfare model approach implies a cost minimization behaviour. Hence, the dwellings should be located to those squares of land where the cost is equal to or lower than the equilibrium price. In the figure this connection is obvious. All cost units i.e. squares of land to the left of the intersection will have a location of dwellings. For example units A and B in preference area 1 corresponds to squares of land (4.2) and (1.5). Units E and F in preference area 2 corresponds to squares of land (3.11) and (4.12). Units C and G and corresponding squares of land will not recieve location, the costs are to high.

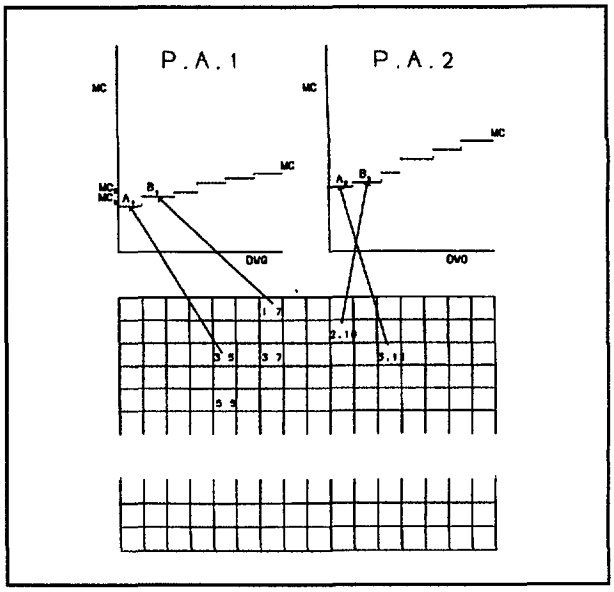


Figure 3 ***The connection between squares of land and steps in the cost function***

8. DISCUSSION

As noted before, the model is based on several parameters. The question arises what will happen to the result maps if one or several of these parameter values changes? Such changes may happen to any part of the cost structure (environmental, energy, construction, development or land costs) or to the users' preferences. The basis for these changes may be outside or inside the municipality. The generating force behind such changes could be the integration to EG, international agreements on the environment, a new price crisis on energy a.s.f. All such scenarios can be studied in the model.

We will describe the scenario and its effect(s) on the parameter value(s) which goes into the model. When the location model is then applied (7), it is necessary to perform one simulation for each possible value on every parameter - a sensivity analysis. The results are several maps, one for each parameter value that one wants to investigate. On these maps over the municipality every square of land has, or has not, recieved a location of dwellings. Some of the maps will, however, have dwellings in the same squares in all iterations. If we choose to locate dwellings to these squares, we can say that dwellings located in such an urban pattern will be resistant to changes in those parameters investigated, such as different energy prices, technical systems, environmental restrictions, etc. When the model is used in this manner the results will be robust against such scenario changes as discussed above.

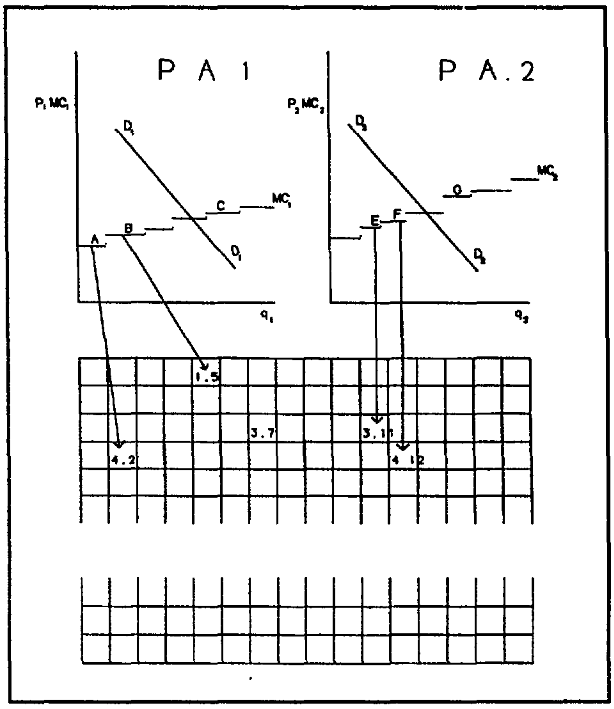


Figure 4. ***The connection between the state of equilibrium and the pattern of location***

9. FUTURE USE OF THE MODEL

The final report on this research project is published it in English as report BDF D1:1992, ISBN 91-540-5405-2, in the series published by BFR, The Swedish Council for Building Research. The study has been financed by The Swedish Council for Building Research (BFR) and The National Energy Administration (STEV). Future work on the model aims to make a version for use on PC. The model is at present operational on the research level as a tool for the planning of environment(8), energy(9) and housing. Present reseach is directed towards the intergration of the model with models for optimization of enery supply systems (MARKAL) and models for transportation simulation (NPK).

ENDNOTES

1. For an analysis of the theory behind these statements see Lamms (1990) dissertation.

2. This information expresses thus the preferences of the municipality's citiziens as formulated by the executive board of the local government. In the the model these preferences act as conditions.

3. There are several methods for performing such investigations. The method applied here is the one published by Holmer and Linderstad (1985). The investigation was carried out by G. Loman, Ph. D. Thus, the impact of local climate is considered in detail for each square of land investigated.

4. The Law is The Law on Municipality Energy Planning (Lag om kommunal energiplanering). According to the ministers application of the law, it has to cover the whole municipality area.

5. The energy turnover is defined as the energy supplied into the system minus the energy stored within the system over a year. The system line is the municipalitys' border. However, also indirect use of energy is included.

6. The specific values for the pollutions emanating from different kinds of energy and processes of conversion were partly calculated by the Lund Institute of Technology, Department of Energy Economics and Planning, and partly by the National Environment Protection Board.

7. As noted previously the new law requires the municipalities to develop new master plans. The task of preparing this plan was, in the case of Kungsbacka, performed by the local planning office in collaboration with a planning consultant. We had the opportunity to collect data for our model test from this porcess. However, the master plan for the municipality was developed while our model was still under test runs in the computer. We have thus had realistic statistics for model development and for tests, but the result maps were available only after the planning process was completed.

8. The model can handle a restricion on the environment in two ways. One can introduce an environmental tax. Then the model will calculate the sum of all emissions. The other way is to introduce a quantitative restriction on each type of emission. In this case the model will calculate the respondent environmental tax.

9. During the computer process the model calculates the quantities and types of energy for each specified subarea as well as for the municipality. This output can be used as a basis for the energy supply plan respondent to the new structure as well as for production-oriented energy planning.

REFERENCES

Holmer, Björn and Linderstad, Hans *Energiindex* Stockholm BFR-rapport 115:1985

Lag om Kommunal Energiplanering SFS 1977:439

Lamm, Johan *Fysisk planering med hänsyn till energi* diss. Lund 1990

Owens, Susan *Energy, Planning and Urban Form*, Pion Ltd., London 1986

PBL *Plan- och Bygglagen*, SFS 1987:246

Planverket *Boken om Översiktsplan* Statens Planverks Publikationer, Stockholm 1987

Söderquist, Thomas *The Ecologists. From Merry Naturalists to Saviours of the Nation*, diss., Stockholm 1986