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Determination of an economic energy supply structure based on biomass using a mixed-integer linear optimization model

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Abstract

Biomass can be used for heat or power generation or for a combined heat and power generation in order to substitute fossil fuels. As a result of the low fossil fuel prices and the higher investment and operating costs of biomass-fired plants, the energy use of biomass has to be checked for every case in each application area. The preferred field of application is the rural area because of the reasonable relation between the potential of biomass and the transportation distances that have a great influence on the economic viability. The knowledge about the location of consumers as well as of the energy plants and the possible laying of a district heating pipe is important for the clarification of an optimal heat supply structure in an isolated area. A mixed-integer linear optimization model based on the dynamical evaluation of economic efficiency can help to find the most economical and ecological supply structure. The model has to be developed for three different types of operating companies. The influences of different parameters on the target function can be analyzed by defining scenarios and by running sensitivity analyses. The results show that the energy prices have the greatest influence on the economy. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Energy model; Mixed-interger linear optimization; Scenarios; Sensitivity analysis; Operating companies; Dynamical evaluation of economic efficiency; Yes–no variables

1. Introduction

Since most heating systems in the New Federal States of Germany, especially in Brandenburg, are out-dated (Viele veraltete Wärmeerzeuger in deutschen Heizungskellern, 1997), the municipalities have the historically unique opportunity of re-organizing the heating supply and improving the energy utilization (Ministerium für Wirtschaft, Mittelstand und Technologie des Landes Brandenburg, 1994). The amount of biomass and the rural structures of Brandenburg where biomass can primarily be used facilitates an integration of biomass into energy supply. More than 84% of the useful area in Brandenburg is cultivated by agriculture and forestry (Landes-

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umweltamt Brandenburg, 1994). The biomass potential of wood, energy plants (rotational fallow, long-term fallow), straw, grass and animal excrements that are available amounts to 30.2 and 46 PJ/a (Haschke et al., 1994). The biomass potential could cover ≈ 12–19% of the total energy consumption of Brandenburg households, which in 1994 amounted to 247.64 PJ (Landesamt für Datenverarbeitung und Statistik Brandenburg, 1996). Up to 5.6% of the CO_2-emissions could be reduced (Hartmann, 1994). However, the following questions have not yet been satisfactorily answered:

- If the economic potential of biomass sufficient?
- What kind of technology and service can stand the economic comparison,
- What kind of general political, economical and ecological conditions are required? And;
- Which influences on the supply structures are caused by the use of bionic fuels?

To answer these questions a computer-based method can be used as an instrument of decision-making.

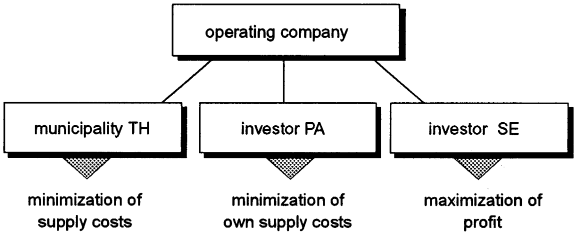

Fig. 1. Operating companies.

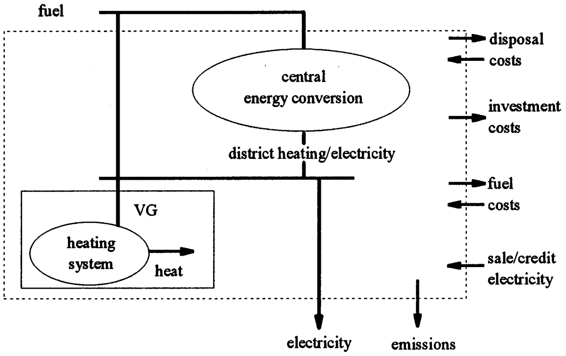

Fig. 2. Balance boundary for 'municipality TH'.

2. Description of the optimization model

The computer program is based on the mixed-integer linear optimization using the dynamical evaluation of economic efficiency. Because of the 1-0-condition of the mixed-integer linear formulation, it is possible to pinpoint the location and therefore to answer the question of whether to build or not to build a heating system, a heating plant, or a co-generation plant.

Different operating companies have to be taken into account for analyzing the energetic use of biomass in rural areas in competition with fossil fuels. In the rural area, three types of operating companies are typical (Fig. 1). First of all, the municipality can amalgamate to an operating company to provide itself with heat (and electricity) (municipality that uses its heat production for itself — municipality TH). Secondly, an investor, a farm for example, can produce biomass for energy generation to cover his or her own demands (investor PA). Additionally, he or she can sell surplus energy to surrounding consumers if it is economically viable. Finally, an investor, like a power supply company, can generate and sell energy with a profit motive (investor SE). The three types of operating companies have different aims for using the produced energy and therefore different ways of looking at the costs that arise.

Different balance boundaries have to be defined for these three operating companies before a mathematical transformation can be made. For the operating company 'municipality TH' the boundaries have to be drawn around the total supply area (Fig. 2). However, for the operating company 'investor PA' and 'investor SE', the boundaries have to be drawn just around their own area (Fig. 3).

The operating companies 'investor PA' and 'investor SE' can sell heat and electricity to other consumers. The question of whether an individual energy supply (heating systems) is more economical for other consumers is not relevant for them. The different balances cause different mathematical formulations.

Before the mathematical model can be built, the problem has to be abstracted and a model of the municipality has to be developed. In the mathe-

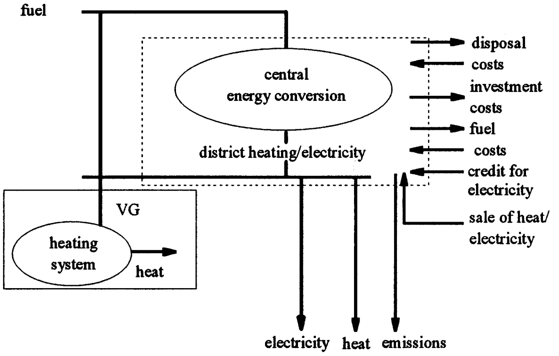

Fig. 3. Balance boundary for 'investor PA' and 'investor SE'.

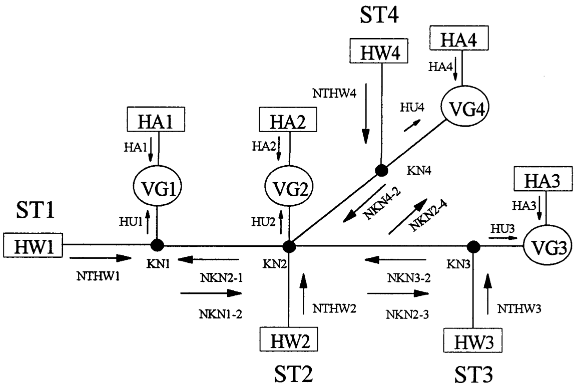

Fig. 4. Energy supply model.

matical formulation, the number of mixed-integer variables has to be limited to ensure the mathematical solubility. On the other hand, a precise solution can only be achieved if the costs for each technology in the supply area are exactly determined. In order to realize both solubility and precision, a special model is developed starting with the demand for heat of each inhabitant (consumer) in the municipality. Corresponding to the spatial structure, the supply area is divided into grid squares (groups of consumers, VG). At the same time these are locations for energy conversion plants. Based on this, heat supply can be reproduced by numerous variants of supply types using heating systems (HA) or heating/co-generation plants (HW) (Fig. 4). Different technologies are available for the components HW and HA. They can be operated with the corresponding fuels.

District heating systems start from four locations (ST1 to ST4) of heating plants (HW). At the junctions (KN), the district heating systems are split up into two streams, with one going to a group of consumers (HU) and one to the next junction (NKN). The complete heat supply of one grid square is described by the stream NKN. Within the distribution system the stream HU leads to each building. These systems are designed for the heat consumption of each single consumer and cause corresponding costs. Costs have to be calculated separately for each group of consumers, such as households, trade, farms or buildings such as multiple-unit dwellings. For simplification of the model, similar types of consumers for example households or restaurants within the grid square can be united if the demand for heat is the same. In this way the inspection of the total heat consumption of VG is transferred into a single inspection of each consumer. As a result, an exact calculation of the costs that are caused by the heat consumption is possible. The same conditions are valid for decentralized supply structure using heating systems. The costs must be calculated for each consumer as well.

In order to determine the costs of district heating systems, their length in the grid squares (VG) has to be registered. In view of the change of diameter of district heating systems proceeding with the reduction of heat consumption, an average diameter within each VG is used for calculations.

This energy supply model facilitates a spatial relation of consumers, energy conversion plants and distribution systems. In addition, the heat flow within the supply area can be shown as well.

For analyzing a concrete municipality, the extensive data base of the model is specified by information about the consumer, the size of the buildings determining their total energy consumption, the spatial location and the structure of the district heating system in the grid squares (Fig. 5). The formation of typical seasonal structures of daily demand is based on the total energy consumption of each group of consumer types. Over a day the energy consumption is divided into four time zones over a day (morning, day, evening, night). Using this structure of the daily energy consumption, the model is able to split the plants into base- and peak-load range plants and to determine the model for running the plants within the four time zones.

The technologies are described by their capacity, efficiency and costs (investment, fixed and variable costs). Considering the cost decrease with increasing capacity, data are given for the smallest and the largest plant that is available on the market. The costs within the bounds can be interpolated (Gernhardt, 1996). Fuels available for the model are biomass (wood, straw, biogas, rapeseed oil), hard and soft coal, as well as natural gas, propane gas and heating oil. Inside the model they are described by their thermal value and their prices/rates. Together with the data of the emissions of CO_2, NO_x, CO and SO_2 caused by the transformation, the fuel data are specified to the technologies. The optimal energy supply structure can be found by comparing the fossil and biogenic fuels and the transformation technologies, of which the data are given inside the model.

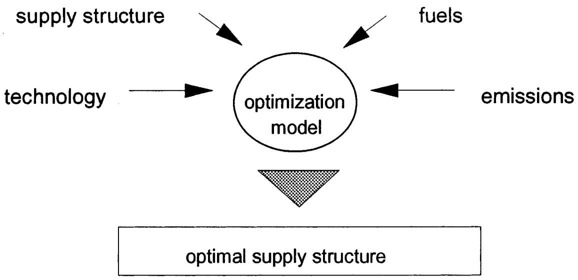

Fig. 5. Data base of the optimization model.

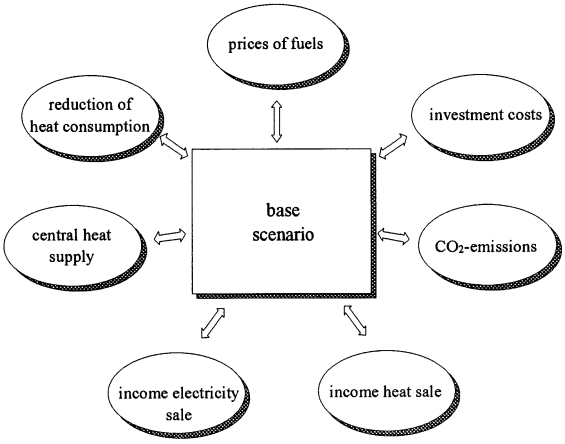

Fig. 7. Model of scenarios.

3. The decision model

The single components in a supply system have to be linked together to a decision model (Fig. 6). One part is the structure of the supply system with the data of the consumers, their annual heat consumption, as well as its seasonal distribution, which results in the thermal capacity and the spatial structure. These data have to be connected with the costs of energy conversion plants, which consist of the costs of centralized and individual conversion plants and, if it is necessary to build a district heating system, then the installation costs for the distribution system. Furthermore, the costs of the fuels that are transported from the system surroundings into the supply system for a certain price (this could also be an income, if waste is used) must be considered. Ash and other waste-products that are obtained at the conversion process have to be transported with costs to the system surroundings, if they cannot be used as fertilizers in farming. To complete the data of the structure and costs of fuels, the knowledge of the existing potential of fuels is important.

Furthermore, different future developments have an effect on the decision model that can be defined by scenarios in the mathematical optimization model. A scenario describes a certain situation with varied restrictions, and possibly includes basic conditions that could have an influence on the system. For example, one scenario could be that CO_2 taxes have to be taken into account within the system, or another, that only biomass can be used for combustion, or, that only central heat supply is allowed, or, that the prices for fossil fuels are higher than today. In this way, it is also possible to simulate political, economical and ecological circumstances or future aims. By fixing or changing different factors that act on the supply system, the scenarios shown in Fig. 7 as important for the problem being examined here can be defined.

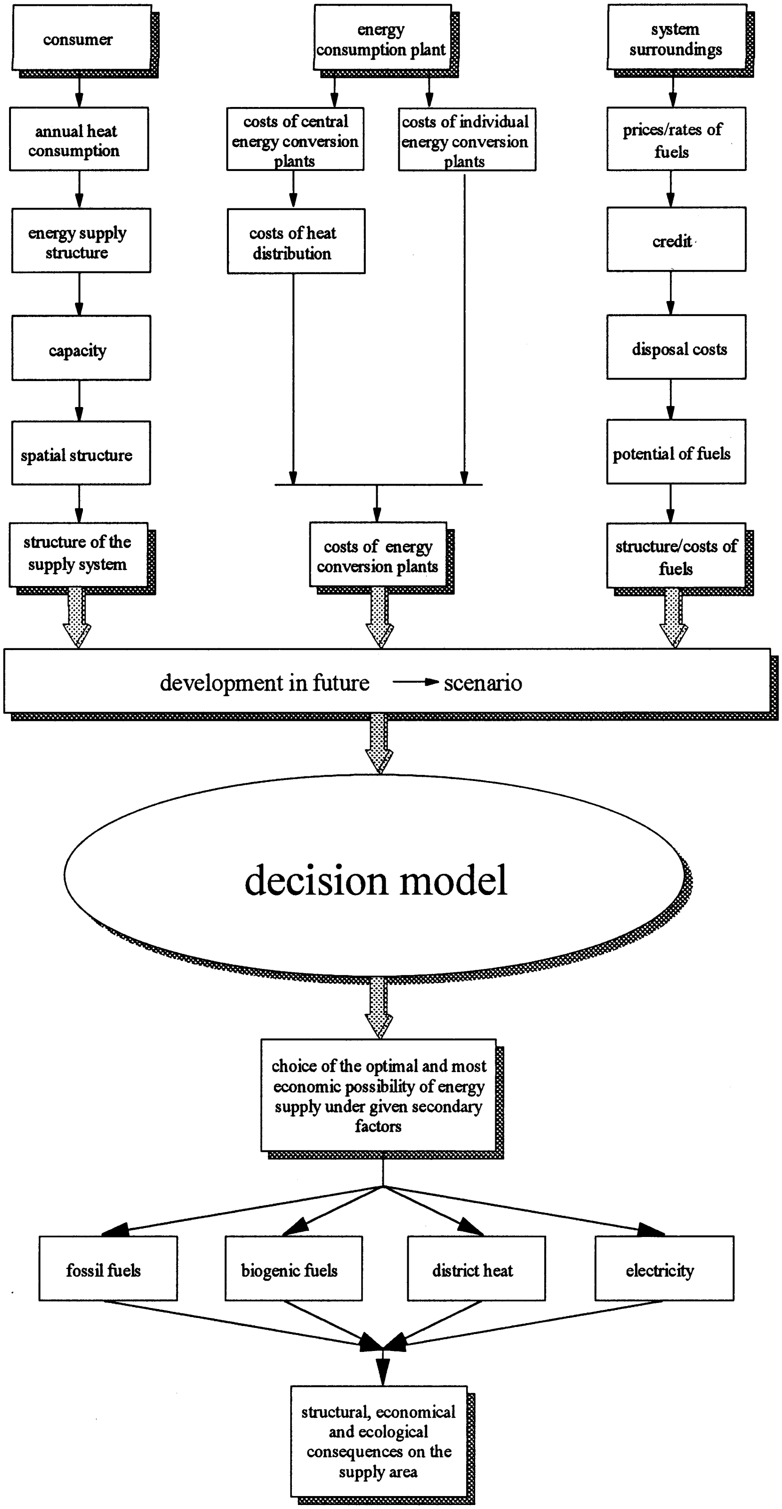

Fig. 6. Structure of the decision model.

Starting from a 'base scenario' that is based on the original prices, a scenario 'prices of fuels' can be defined. Here, measures like CO_2 taxes, energy taxes, subsidies for biogenic fuels, or other such examples take effect. For example, within the scenario 'investment costs', aid programs or investment-costs-reduction-mechanism caused by the increase of plant construction exist. A requirement of CO_2 reduction by the state is given within the scenario 'CO_2 emissions'. On the one hand, income can be made by selling heat. Within the scenario 'income heat sale' the amount of income is given as a starting point from the program user in order to analyze influences of different factors on the system. On the other hand, electricity can be sold, which produces an income as well. This can be taken into consideration within the scenario 'income electricity sale'. Of special interest is the refunding of biogenic produced electricity, which can be increased by political measures. An energy supply based on central energy conversion plants can be another requirement, and can be defined within the scenario 'central heat supply'. Within the scenario 'reduction of heat consumption', possible consequences on the supply structure caused by the reduction of the existing heat supply can be examined. This scenario uses a reduction rate of heat consumption that is less than today's levels as a starting point.

By checking which means changing one or more parameters within the system, such as fossil fuel prices, the effects on the target function as well as on the supply system and therefore the conditions for an economic use of biogenic fuels can be examined.

The economic supply structure is chosen by linking all components and defining secondary factors. Structural, economical and ecological effects on the total system are shown as well. Economical, ecological, political and structural conditions for the economic use of biomass can be given through defined scenarios.

4. The mathematical optimization formulation

It is important for the mathematical optimization formulation that the correct variable is used to describe the technologies. Within heat supply this is the heat capacity $\dot{Q}$. Additionally, it is important to define a yes–no variable (1-0-condition). The target function is the most important part of the mathematical formulation. Within the target function the components that derive from the problem and the variables are linked to solve the problem and the condition of minimization or maximization of the target parameter is given.

The construction or the mathematical model is explained by the example of the operating company 'municipality TH'. Considering only heat supply, the target function for this operating company must include the following costs:

- investment costs for:
    - central and individual energy conversion plants (*IHW*, *IHA*),
    - fuel tank (*THW*, *THA*),
    - district heating system (*NI*),
    - individual heat exchange systems (*IHU*),
- fixed costs for the energy conversion plants and the individual heat exchange systems (*LHW*, *LHA*, *LHU*),
- variable costs for the energy conversion plants (*AHW*, *AHA*),
- fuel costs (*BHW*, *BHA*),
- disposal costs for waste-products of the conversion process (*AEK*),
- costs for external district heat (*FKW*).

In order to consider different temporal amounts of income and costs, the dynamical evaluation of economic efficiency is used. If there is an income in the system, the annuity of the capital value has to be used in place of the annuity of the cash value. The annuity method describes an average capital or cash value referred in 1 year (Winje and Witt, 1991). Within this method the capital cash value is multiplied with the reciprocal of the cash value factor, which is called annuity factor *R*. If there are always the same amounts of income and costs in the time periods, the annuity of the capital value:

$$An(C) = E - A - I_0 \cdot q^t \cdot \frac{q-1}{q^t-1} = C \cdot R \qquad (1)$$

or the annuity of the cash value:

$$An(B) = A + I_0 \cdot q^t \cdot \frac{q-1}{q^t-1} = B \cdot R \qquad (2)$$

can be used. An average yearly expenditure in $[DM/a]$ results from these statements.

For the said operating company, regarding only heat supply the annuity of the cash value has to be used with the condition of minimization of the target parameter because there is no income inside the system. The target function with the individual costs can be written as following:

$$\begin{aligned} Min \overset{!}{=} Z = {} & IHW + LHW + AHW + BHW \\ & + THW + IHA + LHA + AHA \\ & + BHA + THA + NI + IHU + LHU \\ & + AEK + FWK \end{aligned} \qquad (3)$$

If the combined heat and power are additionally included, the costs of the co-generation plant (KWK-plant) (*IKWK*, *BKWK*) have to be taken into consideration in the target function as well the sale of electricity (*ELS*) or heat (*EFW*). A credit (*EG*) is defined if electricity is produced and used by the producers. The target function is based on the annuity of the capital value because of this income within the system. To keep to the condition of minimization, Eq. (1) is multiplied with minus one. The target function can be written as following:

$$\begin{aligned} Min \overset{!}{=} Z = {} & IHW + LHW + AHW + BHW \\ & + THW + IHA + LHA + AHA + BHA \\ & + THA + NI + IHU + LHU + AEK + FWK \\ & + IKWK + BKWK - ELS - EG - EFW \end{aligned} \qquad (4)$$

The costs are calculated by the specific costs that are given in dependency of the capacity or the work. The costs are calculated separately for the central and individual plants. Furthermore, a separation into either fossil- or biomass-fired plants is done, so that different technology-specific cost factors for defining a scenario as well as a sensitivity analysis can be varied.

The mathematical model has three dimensions, which means that most of the variables depend on the three components (index): technology; location and time. Within the mathematical equations the technical, ecological and economical parameters and variables are assigned to these three components. The components are united in groups, that can again be divided. Making up a sum from these components means that the values of variables and parameters of the individual components in a group are added up.

Therefore, the target function consists of costs depending on the capacity or the work. Mathematically, the target function can be written as following:

$$\begin{aligned} \mathrm{Min} \overset{!}{=} Z = {} & R \cdot \sum_{HW} \sum_{ST} k1_{HW} \cdot \dot{Q}_{HW,ST} \\ & + \sum_{HW} \sum_{ST} k2_{HW} \cdot \dot{Q}_{HW,ST} \\ & + \sum_{HW} \sum_{ST} \sum_{T} k3_{HW} \cdot Q_{HW,ST,T} + \ldots \end{aligned} \qquad (5)$$

$k1$ to $k3$ are parameters of the specific costs that are given in dependency of the work or the capacity. Whether the parameters have constant values or are interpolated, they must be calculated out of different values. The capacity $\dot{Q}$ as well as the work Q are positive variables that have to be ascertained by the program, where secondary factors are necessary. For the operating company 'municipality TH' the following secondary factors are valid:

- balance for each location of energy conversion plants,
- balance for each distribution node,
- balance for each group of consumer types,
- limitation of capacity,
- linkage of thermal work and capacity,
- linkage of thermal and electrical capacity,
- calculation of electrical work,
- combination of the groups of consumer types within a grid square to supply units,
- condition for supplying each consumer type either centrally or individually and
- guarantee of secure supply.

Corresponding to Fig. 4 an equation for each energy conversion plant is formulated, where the sum of work of each energy conversion plant at each location (ST) and at each time sequence T has to be equal to the work taken away from the pipes at each time sequence T.

$$\sum_{HW} Q_{HW,ST,T} - \sum_{NTHW} Q_{NTHW,T} = 0 \qquad (6)$$

This equation has to be set up at each location (ST). The balance causes the demand for heat to be covered at each time sequence (T).

Also, for each distribution node, the heat coming from the pipes going to the individual heat exchange systems (HU) has to be sufficient at each time sequence:

$$\sum_{HU}\sum_{VG} Q_{HU,VG,T}\cdot AZ_{VG} - \sum_{NKN+0-ab} Q_{NKN+0-ab,T}\cdot NV + \sum_{NKN+1-ab} Q_{NKN+1-ab,T}\cdot NV + \sum_{NTHW-ab} (Q_{NTHW-ab,T}\cdot NV) = 0 \quad (7)$$

The positive variable $Q_{NKN+0\text{-}ab,T}$ represents the work of the pipe leading away from node (0). $Q_{NKN+1\text{-}ab,T}$ is the work of the following node (1) leading to the node (0). $Q_{NTHW\text{-}ab,T}$ describes the work of a HW at a location leading away to the node (0). $Q_{HU,VG,T}$ is the positive variable of the individual heat exchange systems. Because these plants are required by each consumer within each group of consumer types VG, this variable is multiplied with the number of consumer within each group (AZ_{VG}). Furthermore, the loss of heat of the pipes has to be taken into account by the factor NV.

A balance around each group of consumer types can show that the work of the individual heating systems and the individual heat exchange systems covers the requirements of the consumers $RVA_{VG,T}$. To calculate the work of HA of each consumer the positive variable $Q_{HA,VG,T}$ is multiplied with the number of consumers AZ_{VG}. In addition, the heat loss of the HU has to be considered by the factor VHU. If there is a possibility of an external district heat connection, this also goes into the equation.

$$RVA_{VG,T} - \sum_{HU} Q_{HU,VG,T}\cdot AZ_{VG}\cdot VHU - \sum_{HA} Q_{HA,VG,T}\cdot AZ_{VG} = 0 \quad (8)$$

Caused by the secondary factors:

$$\dot{Q}_{HW,ST} \geq N1_{HW,ST}\cdot LL_{HW,ST} \quad (9)$$

$$\dot{Q}_{HW,ST} \leq N1_{HW,ST}\cdot LU_{HW,ST} \quad (10)$$

for central heating plants and KWK-plants at each location the possible variable $\dot{Q}_{HW,ST}$ is bounded within the upper and lower bounds of capacity ($LL_{HW,ST}$, $LU_{HW,ST}$). The product with the binary yes-no variable $N1_{HW,ST}$ indicates the building or not-building of a technology. For individual heating systems, pipe and individual heat exchange systems, the same secondary factors have to be made with the corresponding binary yes-no variables $N2_{HU,VG}$, $N3_{HA,VG}$ and $N4_{NT}$.

To connect the work of the energy conversion plants within the balances with the capacity of the energy conversion plants within the target function the work and the capacity have to be linked:

$$\frac{Q_{HW,ST,T}}{ZAB_T}\cdot VSF \leq \dot{Q}_{HW,ST}\cdot VF_{HW} \quad (11)$$

In this way, it is determined that the produced work of each HW at each location and at each time sequence ($Q_{HW,ST,T}$) divided by the hours of the time sequences ZAB_T has to be, at best, as high as the capacity $\dot{Q}$ multiplied by the availability VF_{HW}, which gives the real reachable permanence of operating, considering the prevailing technical and operational conditions (VDWE e.V., 1981). To ensure the secure supply, a 25% higher capacity is required by the factor VSF. On the one hand, it is taken into account that the real heat peak could be higher than the predicted mean. On the other hand, a general safety factor is included that for dimensioning technical equipment and plants usually has a value of approx. 10% to 15%. This secondary factor also has to be made for heating systems, pipes and individual heat exchange systems by changing the indexes.

If co-generation plants also exist within the system, electricity produced is linked to the heat production. The linkage of the heat and power work is carried out by the electricity code number reference SIG_{KWK} that is assigned to each energy conversion plant.

$$SaE_{KWKF,ST,T} = Ea_{KWKF,ST,T}\cdot SIG_{KWKF} \quad (12)$$

Additionally, the electrical (P) and the thermal ($\dot{Q}$) capacity have to be linked by the electricity code number reference:

$$P_{KWK,ST,T} = \dot{Q}_{KWK,ST,T} \cdot SIG_{KWK} \qquad (13)$$

It has to be ensured that all consumers within a grid square VG are supplied either centrally or individually. This is attained by equating the yes-no variables $N2_{HU,'VG'}$ and $N3_{HA,'VG'}$, which are summed up over the corresponding technologies and each examined consumer group 'VG', with the product of the number of groups of consumer types (AZV_{VG}) and the binary variables ($B1$, $B2$). These binary variables have to be defined for each grid square, for example with ongoing numbers.

$$\sum_{HU}\sum_{'VG'} N2_{HU,'VG'} = AZV_{VG} \cdot B1$$

$$\sum_{HA}\sum_{'VG'} N3_{HA,'VG'} = AZV_{VG} \cdot B2 \qquad (14)$$

Moreover, the sum of the binary variables $B1$ and $B2$ must have the value one for each grid square:

$$B1 + B2 = 1 \qquad (15)$$

To ensure that the demand for heat of each group of consumer types is covered by only one technology:

$$\sum_{HU} N2_{HU,VG} + \sum_{HA} N3_{HA,VG} = 1 \qquad (16)$$

the sum of the binary variables of HU and HA has to have the value of one.

By defining further inequations in the form of secondary factors different conditions for the supply and therefore for the result can be made. For example, it could be required that a CO_2 emission boundary be raised or a certain potential of biomass to be used.

Because heat supply in rural areas is of priority interest it is only important to ensure the energy supply if serious problems occur such as a long-term breakdown of an energy conversion plant. Otherwise anticipated that repairs are made at appropriate times. For special consumer groups, for whom the energy supply has to be ensured, as, for example, hospitals, it is anticipated that power as well as heat supply is maintained by an emergency power unit. In the field of planning the use of energy conversion plants, where mainly the power supply is analyzed, the question of ensuring the secure supply is very important, because in producing industries power failures can cause restrictions of production and therefore financial losses. In rural areas there is normally no need to ensure the energy supply by special plants. But there are still possibilities within the model to require at least two central energy conversion plants at each location 'ST' by defining secondary factors

$$\sum_{HW} N1_{HW,'ST'} \geq 2 \qquad (17)$$

so that one plant is mainly used to ensure the secure supply.

The transformation of the mathematical model into a computer-based process (analytical process model) makes it possible to use the mixed-integer linear optimization formulation and therefore the determination of conditions for the economic use of biomass in energy supply.

5. Results and discussion

The optimization model (analytical process model) was used on the operating company 'municipality TH' in a typical rural municipality of Brandenburg with 660 inhabitants and with the structure of a linear village. Under the given conditions, consumers in this municipality with a demand for heat higher than 100 kW and a high total heat consumption can be economically supplied with a biomass-fired, automatically loaded solid-fired boiler (H_FABio) (Fig. 8). The supply component amounts to $\approx 22\%$ of the total capacity. Other consumers are supplied by an oil-fired boiler (H_OLGO).

A sensitivity analysis of the fossil (pF) and biogenic fuel (pBio) prices shows that the variable Z, representing the annuity of cash value, increases or decreases according to the variation of fuel costs (Fig. 9). A change of the supply structure is linked to this. The gradient of this curve has a steeper course, principally because mainly fossil-fired heating systems have been used.

The change of the structure of energy supply becomes visible through the change of used biomass potential. The use in decentralized heating systems increases with decreasing prices for

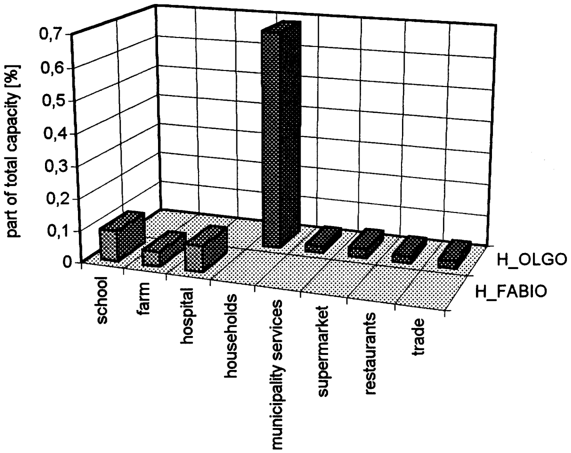

Fig. 8. Supply structure of a rural municipality.

biomass. Correspondingly, biomass is no longer used with decreasing prices for fossil fuels (Fig. 10).

The CO_2 emissions could decrease up to 25% by the increasing use of biomass (Fig. 11).

Biomass can be fired in a heating plant with a capacity of 2.4 MW if a district heating system already exists and the prices for biomass are reduced by 30% or the price for fossil fuels increases by 15%.

If heat and electricity are produced in co-generation plants, profits can be made by selling the electricity to power supply companies and a credit can be given for the non-use of electricty from the power supply system. This is possible for a farm that uses the produced electricity itself and receives credit for this. A total energy supply based on biomass can be achieved if the prices for biomass are decreased to 10% of today's biomass prices. A wood-fired heating plant (2.2 MW) and a rapeseed oil-fired district heating power station (144 kW) are suggested. The thermal load shared between the heating plant (HW_UBio) and the district heating power station (BHKW) is illustrated in Fig. 12 for the different time sequences (summer morning SM; summer day ST; summer evening SA; summer night SN, and also for winter and transitional period).

Fig. 13 shows the power consumption of a farm (VG5) that is not supplied completely by the fired district heating power station. This is caused by the optimization of profits and expenses that is reached at that point.

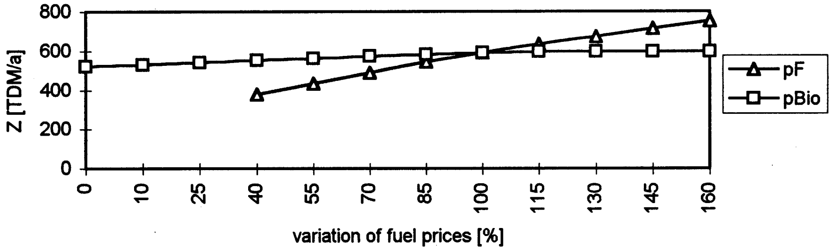

Fig. 9. Value of the variable Z by variation of the fuel prices.

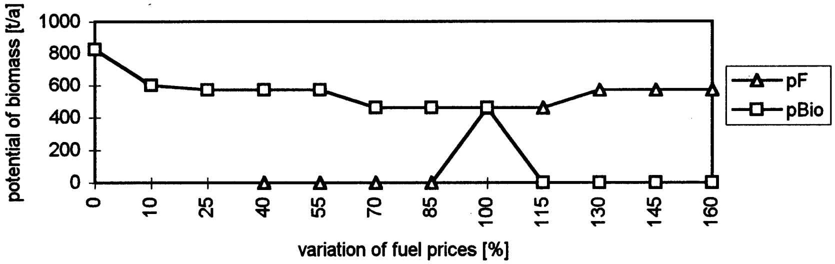

Fig. 10. Potential of biomass by variation of the fuel prices.

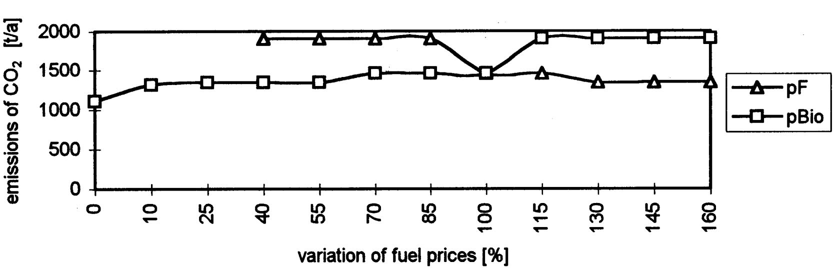

Fig. 11. CO_2-emissions by variation of the fuel prices.

Different factors can improve the economic viability of biomass. In this connection, especially fuel prices/rates of fossil (pF) and biogenic (pBio) fuels, electricity sales of biogenic produced electricity (EINB), and the investment costs for biomass-fired heating plants (IBHW) as well as co-generation plants (IBKWK) have to be named. The value of the target function reacts with different sensitivities on these parameters (Fig. 14). The digit 1 standing in brackets within the legend symbolizes the operating company ‘municipality TH’ with an individual heat supply. The same is valid for digit 2, with the difference of central heat supply. Digit 3 symbolizes the operating company ‘municipality TH’ with central heat and power supply. Digit 4 stands for the ‘investor PA’ with central heat and power supply. Only those values are shown that result in a supply based on biomass by surpassing or subsiding under 100% of today’s levels. The figure shows that subsiding biogenic fuel prices as well as the investment costs of heating plants and co-generation plants result in a reduction of the target parameter *Z*. *Z* is also reduced by increasing the electricity sale based on biomass. For all operating companies the increase of fossil fuel prices results in an increase of *Z*. Negative values of *Z* can only be reached for the operating company ‘investor PA’ (besides the cost-free purchase of KWK-plants for the operating company ‘municipality TH’, Fig. 14). In this connection a profit can be made by selling electricity and heat. The variation of fuel prices leads to a change of *Z* sooner than the variation of other parameters. Therefore, fossil fuels are substituted earlier by biomass. Moreover, the course of the graph of the biogenic fuel prices has the steepest gradient. Altogether it can be shown that energy prices especially for biomass have the highest influence on the economic viability.

The given results show that a supply based on biomass is possible. Using biomass in individual plants is already economic for some consumers without changing the origin prices. With a central supply, the fossil and biogenic fuel prices have the greatest influence on the economics of energy supply based on biomass for the operating companies ‘municipality TH’ and ‘investor PA’. An attempt should be made to reduce the biogenic fuel prices, because this would result in lower total consumption costs in compared to an increase of fossil fuels.

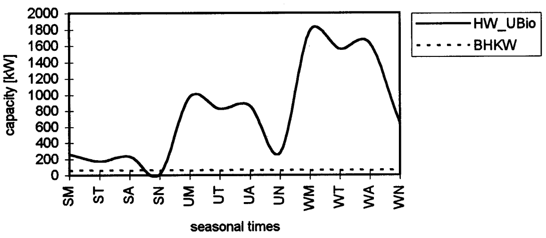

Fig. 12. Thermal energy structure of a heating plant (HW_UBio) and a district heating power station (BHKW).

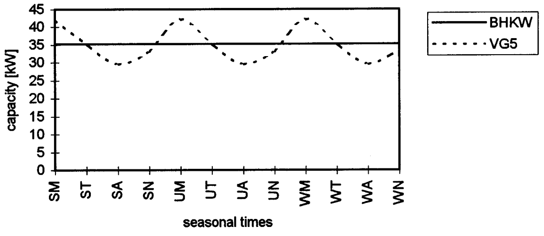

Fig. 13. Power structure of a district heating station and a farming industry (VG5).

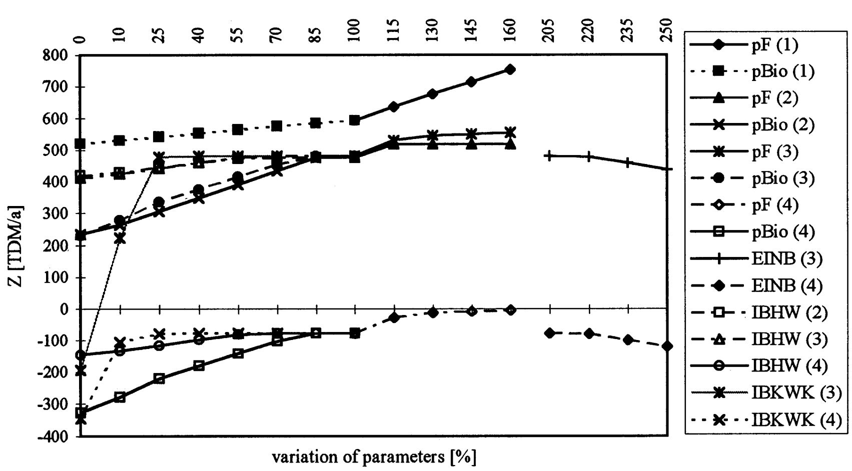

Fig. 14. Value of *Z* by variation of different parameters for the operating companies 'municipality TH' and 'investor PA'.

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