Comparison of Centralized and Decentralized Energy Supply Systems

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Communal energy programs are often embedded in a conception of a decentralized energy supply system where electricity is produced by a number of smaller power plants. For a comprehensive survey the question arises whether these decentralized systems are more advantageous than centralized systems with regard to the criterions energy consumption, safety of supply, environmental compatibility and economy. In the following, after a definition of the term "decentralized", the present structure of the energy supply system in the Federal Republic of Germany is examined under the point of view whether it is more centralized or more decentralized. Then, a detailed investigation into effects of a decentralized compared to a more centralized energy supply system is presented. Assuming two alternatives of supply, different energy generating plants are exemplary discussed. At last, problems concerning the organization of a decentralized energy supply system which are of special interest for local and regional energy strategies are considered.

1 The Term "Decentralized"

Decentralized energy supply actually means, that energy is produced and consumed at the same place. However, in public discussion, decentralized energy generating plants are understood as smaller plants in communal responsibility which are adapted to the local conditions [1]. These are for example installations of cogeneration and of waste heat recovery, plants for the energetic utilization of rotten, dump and sewage gas and of renewable energies (hydropower, solar radiation, wind energy and biomass). As to the field of production of electric power Grawe [2] suggests to classify plants with an electric power of less than 100 - 150 MW as "decentralized". The used fuel or the applied generating-technique do not facilitate a clear classification on their own.

From the political point of view the term "decentralization" is connected with the return to sovereignty over energy by the communities ("recommunalisation"). In this context, the transformation of a local energy supply company to an energy service corporation is often demanded.

In the following, decentralized energy supply means that the energy conversion takes place in small power plants close to the consumer with an electric power below the 100 MW-limit.

2 Objectives and Structure of the German Energy Supply System

In the following, the today's German energy supply system is examined under the question whether it has a more centralized or a more decentralized structure.

Because of the various demands of a complex industrial nation, the energy supply companies have to provide electric power and heat based on different levels of voltage and temperature, respectively. The supply of electric power and heat has to be carried out under economically justified conditions. Furthermore, the security of supply must be granted and the requirements of pollution control must be fulfilled. The development of energy demand is added as a further condition.

When explaining the structure of supply in the Federal Republic of Germany, the sectors of electricity and heat are considered by describing the situation in West Germany (former FRG) and East Germany (former GDR).

The generation and distribution of electricity in **West Germany** is divided into 3 groups: First, there are 8 nationwide interconnected distribution companies supplying large consumers. Second, about 40 regional companies take care of the regional supply of electric power. On the lowest supply level, about 900 local companies can be found. According to figure 1 [3] the distribution of electricity to the end consumers is regularly divided into these 3 groups whereas the interconnected distribution concerns contribute the biggest part concerning the generation of electricity. The electricity here is mainly generated in centralized big power stations. The composition of all public power stations can be seen in figure 2 [3]: 967 (87 % of all power stations) are under the suggested limit of 100 MW. They constitute 9 % of the total generation capacity. Whereas in the field of public supply of electricity nearly 90 000 MW are installed, the total installed capacity amounts to about 104 000 MW (including industry and railway).

After the unification of the two German states there are one interconnected distribution company and 15 regional companies for the generation and distribution of electricity in **East Germany**. The majority of each of the companies is owned by 9 West German energy supply companies. The formation of local companies is still in the beginning.

The installed capacity in the former GDR amounted to 24 094 MW in 1989, 19 043 MW belonging to the public supply of electricity.

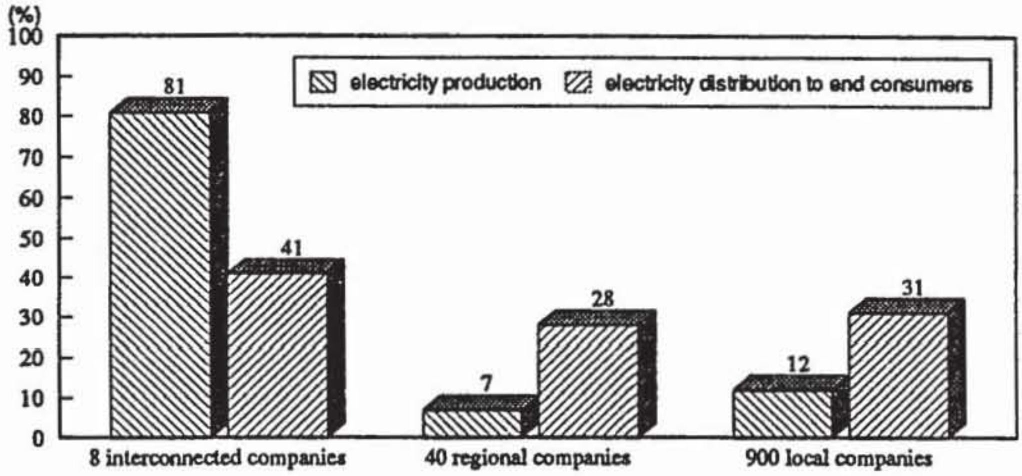


Fig. 1: Production and distribution of electricity in West Germany [3]

Before the unification of West and East Germany they belonged to different European interconnected networks. Therefore there was no electricity network between West and East Germany. At present it is being reconstructed.

The explanation of the **thermal sector** reduces to the district heat, which can be coupled out of heating stations and combined heating and power stations (CHP). These are often suggested as decentralized.

In **West Germany** about 140 district heat supply companies could be found in 1989 which operated 506 networks on the whole [4]. The heat was produced in 163 combined heating and power stations and 404 heating stations. The total installed gross heat capacity amounted to 39 801 MW in 1989. It was provided by 52 % of heating and power stations and by 46 % of heating stations, while 2 % originated from the utilization of waste heat. The number of all additional operating block-type thermal power stations (BTP) was 886 in 1988 with a total electric power of 386 MW [5]. All cogeneration plants together (CHP and BTP) had a total electric power of 16 515 MW. They contributed with 11,4 % to the total generation of electricity in 1987 [6].

In **East Germany** there are 143 district heat networks, 108 heating stations and 36 heating and power stations at present. The installed gross heat capacity is 15 813 MW, divided into 53 % of plants using the cogeneration principle and into 36 % of heating stations. The heating power stations provided an electric power of 1440 MW [7]. The district heat in the GDR was the only alternative to the individual coal-heating system over decades and played therefore an important role. The domestic lignite was preferred to other sources of energy, that could not be imported because of the lack of foreign exchange.

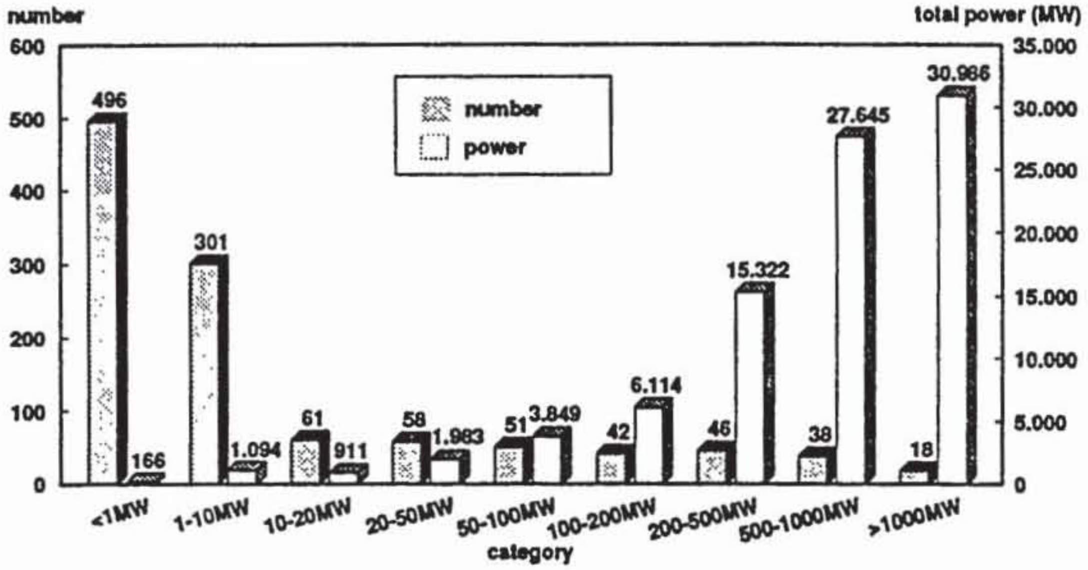


Fig. 2: composition of all public power stations in West Germany [3]

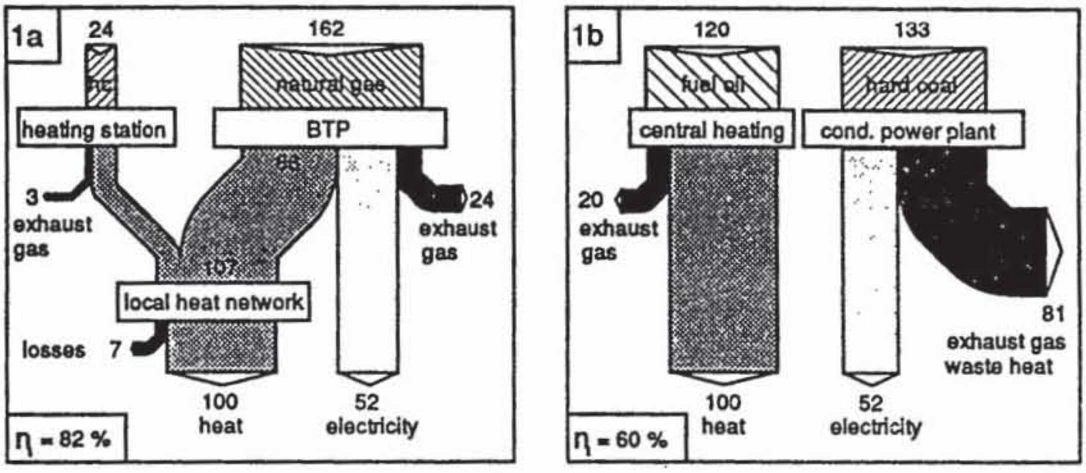
Analyzing the actual generation and distribution of electricity and heat it can be realized that the German energy supply system shows a complex structure where decentralized power stations already are integrated. How far a decentralized structure can guarantee an optimal energy supply is examined next.

3 Consequences of Increasing Decentralization

The consequences of increasing decentralization will be examined in the following with regard to the criterions energy consumption, safety of supply, environmental compatibility and economy. There, the question is reduced to the treatment of different degrees of decentralization for the case of fossil fired power stations.

Consequences for the Energy Consumption

For the analysis a comparison of combined and separated generation of electricity and heat will be undertaken for different demands. The high efficiency of the transformation of energy by decentralized heat and power production will be discussed using the example of cogeneration power plants. In order to make clear the advantages and disadvantages of the analyzed generating plants, two different alternatives of supply will be defined. The covering of the heat demand of 100 energy units is the basis for all cases compared.



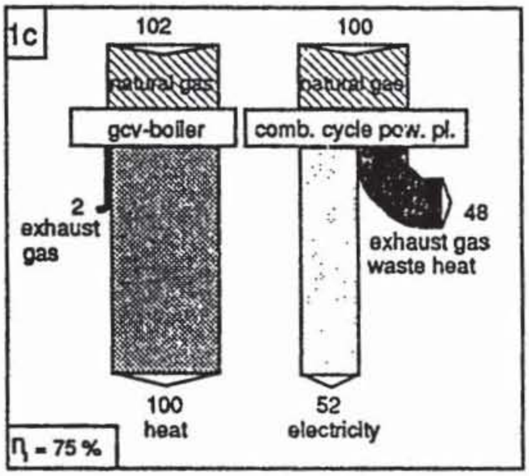


Fig. 3: Energy flow diagramm, cases 1a - 1c

For the first alternative of supply a electricity demand of 52 energy units is assumed. Here, heat and electricity are produced by a BTP (total efficiency η_{tot} = 85 %, electric efficiency η_{el} = 32 %, gas-fired) combined with a heating station for the thermal peak-load power (η_{tot} = 87 %, hard coal-fired, covering 20 % of the annual heat demand), *case 1a*. This is compared to a separated heat generation in central heating systems of households (η_{tot} = 83 %, fuel oil-fired) together with an electricity generation in a condensing power plant (η_{el} = 39 %, hard coal-fired), *case 1b*. In addition, a possible future power plant situation is considered, *case 1c*, where the heat is generated by a gross calorific value (gcv-)boiler (η_{tot} = 98 %, gas fired, central heating system of households) and the electricity is produced by a combined cycle power plant (η_{el} = 52 %, gas fired), see figure 3. Because of the heat-network in 1a, heat-losses of 7 % (5 % distribution losses and 2 % losses in the buildings) have to be considered. From figure 3 yields a total efficiency of 82 % in the case 1a, of 60 % in the case 1b and of 75 % in the case 1c.

The other alternative of supply consists of a different electricity demand which is about 2.5-times higher than in the first case. Here, (*case 2a*) a BTP, a heating station and a power station, each with the same data as above, are compared to (*case 2b*) a combined heating and power station (η_{tot} = 62 %, η_{el} = 37 %, hard-coal fired) and a heating station (same data as in 1a). Again, a possible future power plant situation is considered, cases 2c and 2d. In *case 2c* there are a BTP (η_{tot} = 82 %, η_{el} = 42 %, gas-fired), a combined cycle power plant (like 1c) and a heating station (like 1a). This is compared (*case 2d*) to a combined cycle heating and power plant (η_{tot} = 85 %, η_{el} = 45 %, gas-fired), a heating station and a combined cycle power plant (like 2c). The heat losses are 5 % (2a, 2c: local heat network) and 10 % (2b, 2d, district heat network), while the losses in the buildings are the same in every case and therefore not relevant in this comparison. Figure 4 shows the 4 different cases. Similar total efficiencies result for the cases 2a and 2b (59 % and 61 %) and for the cases 2c and 2d (73 % and 75 %).

Summarizing the two alternatives of supply with regard to the energy consumption, advantages can be found for the BTP in the first case. These advantages reduce in the possible future situation, case 1c. Concerning the second alternative of supply, there are no preferences at all for one of the systems. The cases 1c, 2c and 2d show that using natural gas only, the efficiency of the systems increases. This means, that the efficiency of the discussed systems depends not only on the degree of centralization, but also on the used fuel.

The efficiency of 85 % or 82 % of the BTP is valid only, if the heat and electricity demand arise during a year regularly. The more irregular the load course of the electricity demand is compared to the heat demand, the lower the efficiency becomes. This leads to advantages for the centralized systems. Therefore, instead of assuming fixed values for the electricity and heat demand, a complete examination should compromise the variation of the demand over time, e. g. over a whole year.

Consequences for the Security of Supply

The discussion concerning the security of supply concentrates on the judgement of the used fuels. In BTPs mostly natural gas and fuel oil are burnt. If the BTP-technology would be expanded, a higher contribution of imported liquid and gaseous sources of energy would lead to an increasing use of these sources. This would prevent a broad-

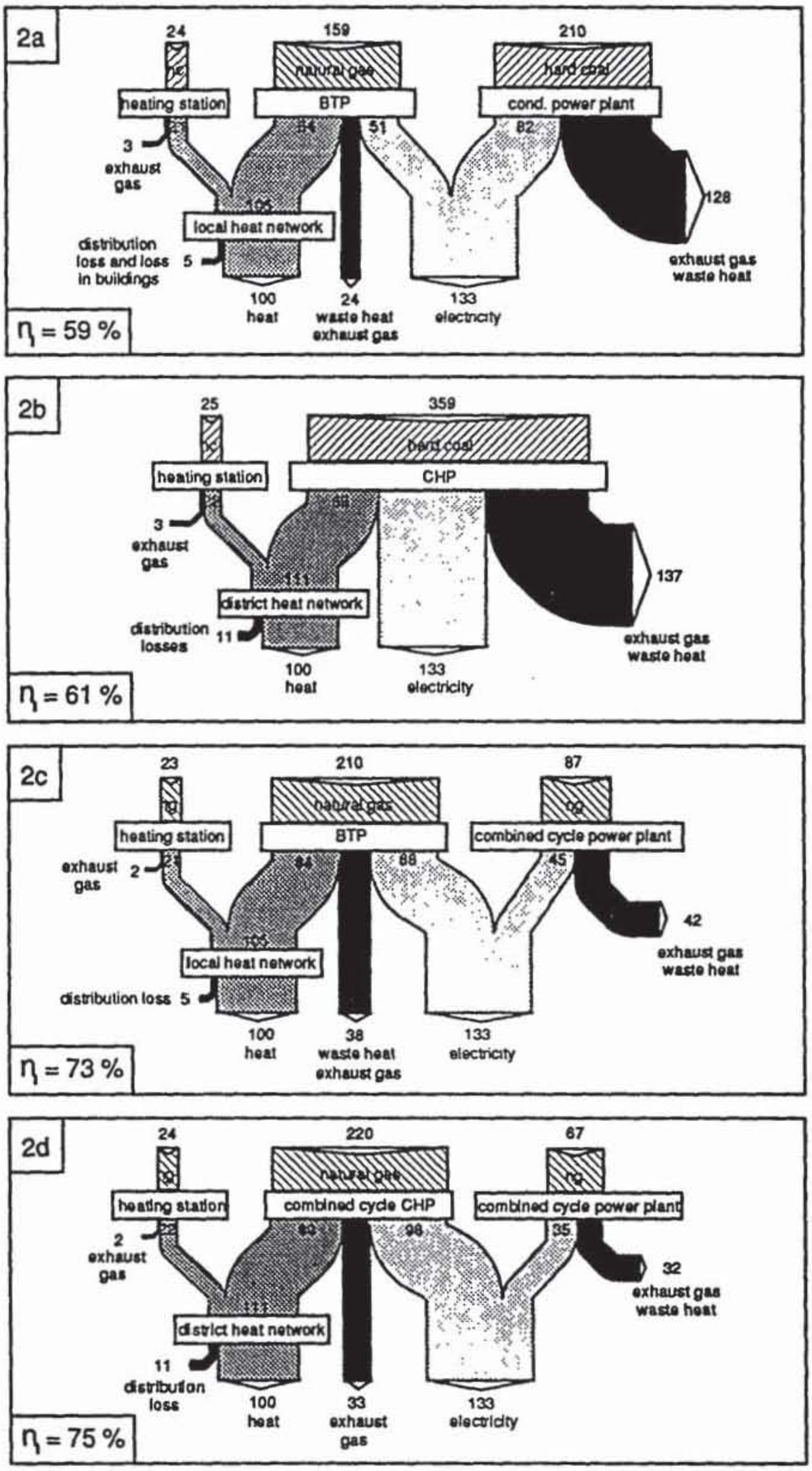


Fig. 4: Energy flow diagram, cases 2a - 2d

ening of the energy basis, the quarrying of the rare natural gas and petroleum resources would be accelerated and coal would be driven out as domestic source of energy. In the future, this could lead to a reduction of the security of supply. Using biogas, sewage and dump gas as fuel, this problem would not occur.

Consequences for the Environmental Compatibility

Today's technical developments allow that for all analyzed energy generating plants the legally required measures for emission reduction for the conventional air pollutants (SO_2, NO_x, CO, C_nH_m) can be carried out. In many cases the emission standards are fallen below. But as a rule, it is more difficult to carry this out for a large number of smaller plants than for a small number of big plants, especially if new air pollutants have to be considered.

In the following, the CO_2 emission of the discussed power stations and their fuels will be treated, as this problem becomes more important in the public interest regarding the eventual increase in the global temperature on earth as a consequence of the rise in CO_2 in the atmosphere (greenhouse-effect).

Calculating the CO_2 emissions of the different situations, the emission factors for CO_2 of the used fuels were multiplied by the units of fuel. The ratio of the emission factors of hard coal to fuel oil to natural gas was chosen 100 : 78 : 59 [8]. The results of the cases discussed show figure 5.

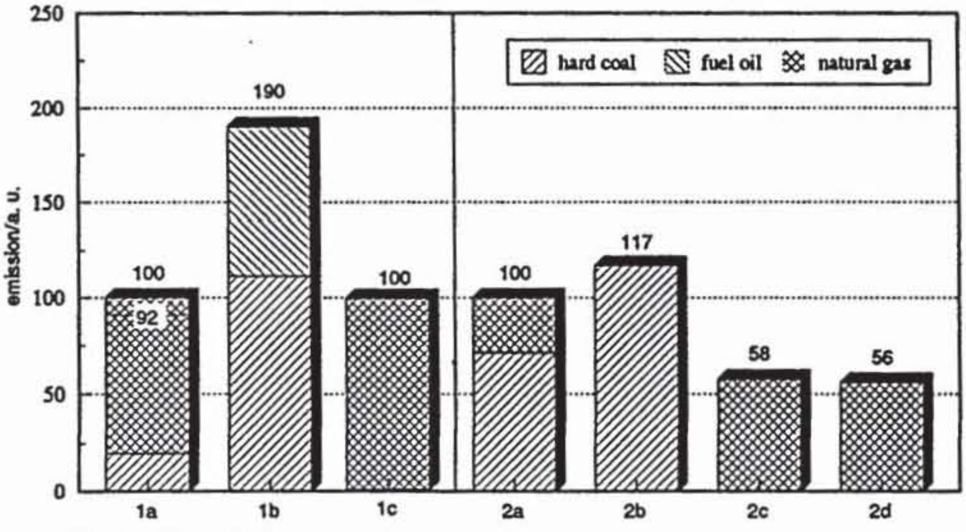


Fig. 5: CO_2 emission

According to figure 5, the CO_2 emission is reduced for all gas fired plants. This leads to advantages for the decentralized systems 1a and 2a. The doted line in the bar explaining case 1a shows the emission using natural gas instead of hard coal for the heat production. The emissions for the cases 2c and 2d are nearly the same because of the similar total efficiency and because of using natural gas only. Summarizing this comparison it follows that the CO_2 emission depends mainly on the used fuel and not on the degree of decentralization.

Consequences for the Economy

The statements about the economy of the analyzed power plants depend highly on the development of the prices of the different fuels and of the electricity. Nevertheless, an estimate was carried out for the total annual costs of each of the power station combinations under price assumptions of the Enquete Commission [8] (regarding different prices of domestic and imported hard coal) and with a real discount rate of 4 % p.a. Here, real prices in terms of 1987 were taken and the begin of operation of the plant is assumed to be in 2000. The contribution of the components of the generating systems and of the heat networks to the total costs are explained, too. The results for cases 1 and cases 2 show figure 6.

From the comparison it follows that the subsidized domestic hard coal has an influence on the total costs of the systems, which can not be ignored. The biggest contribution to the costs is determined by the heat production. Regarding case 1, where the demand situation is optimal for the BTP, the decentralized generating system has economic advantages. In the case of a higher electricity demand and of the application of cogeneration principle on all generating systems (case 2), the centralized system lead to lower costs. For the possible future systems, the advantages of centralization reduce.

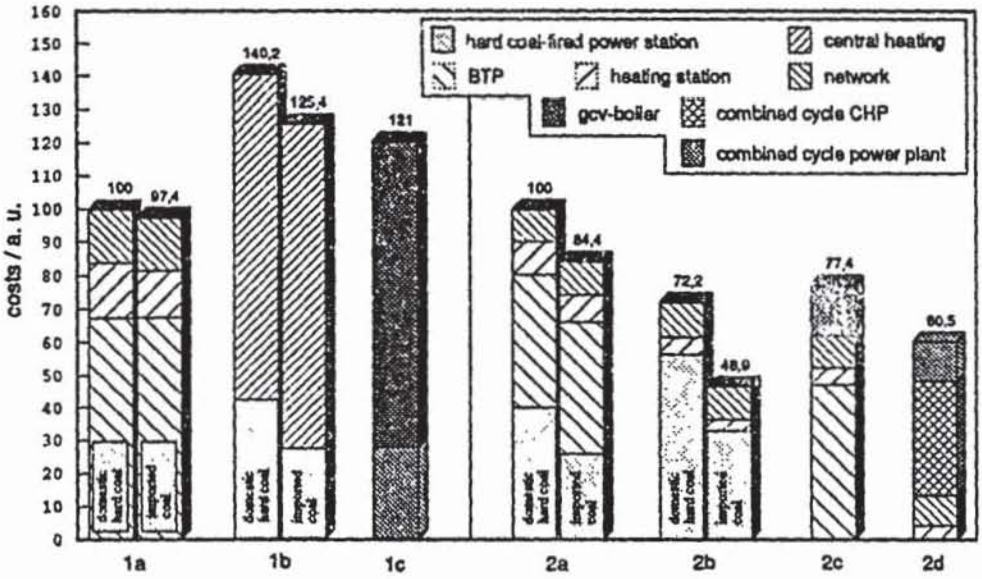


Fig. 6: Annual total costs

However, the comparison has no general validity. In general, the advantages of smaller plants lie in their shorter time taken for construction and in the possibility to build them close to centers of consumption. In the case of towns and communities with high densities of heat demand, smaller plants can be operated economically as well, if they use the cogeneration for a combined generation of electric power and heat. As a rule, these plants were designed for the heat demand, while the additional needed electricity has to be obtained from the interconnecting network. For big industrial companies and for the district heat supply of towns with 30 000 to 50 000 inhabitants, coalfired combined heating and power stations with a power from 20 to 30 MW are supposed to be economic. Single gasfired BTPs covering the heat demand of large buildings or building complexes can be considered as economic, if the heat demand arises over time regularly. The ratio of generated electric to thermal power can be varied according to the used technique for a CHP or a BTP in a wide area. Thus, the number of possible applications increases [9]. In general, an economic operation can be only found out if the concerning energy demand is examined in detail. General economic advantages or disadvantages for centralized or decentralized plants can not be found.

4 Communal Energy Strategies

The economy of decentralized energy generating plants depends mainly on their optimal design for each situation of energy demand. For plants using the principle of cogeneration the advantages by saving primary energy can be more significant than those by the degression of costs in the case of centralized power stations. In order to find out, whether it is possible to use decentralized plants, a special energy analysis for a town or a region should be drawn up. Concerning the environmental compatibility of decentralized stations, the immissions as well as the emissions have to be taken into account. Furthermore, the demand of electricity and heat, the organization-structure of the network energy supply, the potential for an energetic use of waste and renewable energies as well as the heat insulation of the buildings have to be examined.

The use of district heat from a combined heating and power station or from waste heat of an industrial company as well as the determining of priority regions for town gas and district heat could be recommended as a result of such analysis. If a district heat network is not worthwhile today, as a first step single areas could be supplied with BTPs. Furthermore, energy supply companies should put the main emphasis of their work on the total optimization of the supply of energy regarding the supply and saving of energy. This comprises an equal judgement of the rational use of energy and the expansion of the energy supply.

5 Conclusion

From the comparison in chapter 3 follows that, depending on the energy demand, there are advantages for both the decentralized and the centralized system. An individual analysis of each situation is necessary. Therefore, towns and communities which want to use the advantages of both should carry out a detailed strategy in their supply areas.

Besides the energy generating plants discussed there are other energy systems which can be considered under the question of the optimal degree of centralization like e. g. heat pumps and power stations using nuclear energy or renewable energies. These should be included in a complete investigation.

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