LIFE CYCLE ANALYSIS OF DISTRICT HEATING WITH BIOMASS

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ABSTRACT: In spite of more than 15 years of biomass district heating (BMDH) and more than 300 realised plants in Austria there are still some essential bottlenecks. By means of a life-cycle analysis the energy system **District Heating with Biomass** was described, evaluated and compared to other heating systems in order to specify bottlenecks and find out possible solutions. The results presented in this paper focus on the two main limiting factors for a future extension: the fuel supply and the economic situation.
The additional long-term potential of biomass for thermal utilisation in Austria is as high as the amount used at present. A future large-scale and professional biomass fuel supply will have to focus on mechanised forest wood chip production from first thinnigs.
The weak points culminate in the fact that high public investment grants are required to render such systems economically efficient and competitive on the market. Measures taken in order to lower costs and overcome this barrier are avoiding poor plant design and reducing investment costs (standardisation, serial manufacturing, learning effects). A gradual reduction of subsidies is essential in order to reach this aims.

1 IMPLEMENTATION OF BIOMASS DISTRICT HEATING IN NATIONAL ENERGY SYSTEMS

1.1 Renewable energy in Austria

A survey of the use of renewable energy in Austria is given in Table I. About 80% of the renewable energy consumption is covered by solid biomass, mainly wood which is used in private households.

Table I Austrian renewable energy balance, 1993 [1]

	Primary energy in PJ
Retail consumer	
firewood, forest wood chips	47.3
wood residues, sawmill side products	11.4
straw	0.8
Industry	
firewood, forest wood chips	2.5
reused wood, sawmill side products	18.5
black liquor	18.1
Biomass district heating plants	
forest wood chips	0.6
bark	1.0
sawmill side products	0.6
straw	0.1
Biogas, RME	1.9
Others (wind, solar heating, heat pumps....)	5.8
Renewable energy, in total (without waste and hydropower)	108.7
Total Austrian primary energy consumption	1,120.2

1.2 Biomass district heating in Austria

The first biomass district heating plants were built in the early 1980s. Until 1996 about 300 plants with an overall thermal capacity of 430 MW were put into operation. The plants are owned by agricultural cooperatives (58%), private enterprises (mainly sawmills – 30%), municipalities (10%), and by utilities (2%) [2]. In contrast to fossil-fired district heating systems for large cities, biomass district heating plants are mainly situated in rural areas, which is illustrated by the low average thermal output of 1.4 MW. The biomass fuel consumption in 1995 was 3 PJ [3].
One of the most important driving forces for the development are high public subsidies, i.e. direct subsidies or subsidised loans. Beside the intention to increase the use of renewable energy the subsidies are also designed to support agricultural infrastructures.

1.3 Biomass district heating in Denmark and Sweden

In **Denmark** about half of the country’s heat supply is based on district heating systems. In 1995 about 11 PJ, i.e. 10% of the total district heat, were produced by 140 biomass district heating plants burning straw, wood chips and pellets. The thermal capacity of Danish BMDH plants is 1 – 10 MW. Most of these plants replaced old oil- or coal-fired heating plants during the 1980s and 90s. This was in general the result of a vigorous energy policy with broad political support and the strong commitment of all actors concerned. Since 1976 four energy plans have been passed by parliament. The majority of measures focus on investment subsidies, energy and environment taxes.
Since all of the bigger cities in Denmark already operate a district heating system the further development of BMDH will concentrate on the erection of new plants in small communities with less than 300 houses. Furthermore, decentralised CHP plants - new ones or the conversion of existing heating plants - are of great interests. Thus the Danish parliament already ordered the utilities to replace 6% of the coal currently used by 1.4 million tonnes of straw and wood before the year 2000 [4, 5].
In **Sweden** there are about 100 district heating plants using biomass, in most cases combined with fossil fuels. The wood fuel used in these plants amounted to about 37 PJ in 1995.
The further Swedish development in this area will focus on the combined heat and power production either in existing district heating plants or in new CHP plants. This

is mainly caused by the intention to decrease electricity productionfrom nuclear power stations [4].

2 FUEL SUPPLY

2.1 Current use and potential

The fuel consumption of Austrian biomass district heating plants is primarily based on sawmill side products (bark, wood chips, saw dust) and, to a lower extent, on wood chips from forestry (see Table I). This fact is caused by the wide variety of biomass fuel prices in Austria and the necessity to keep district heat production costs low.

Bark is the cheapest fuel due to low fuel quality (high water content, inhomogeneous particle size) but with limited supply. The price of bark is coupled to the price of heavy fuel oil and currently amounts to about 6 ECU/MWh (loco heating plant). On the other hand, forest wood chips are the most expensive biomass fuel. The production is based on labour-intensive motor-manual harvesting of trees from first thinnings, which causes high production costs of about 30 ECU/MWh. The cheaper wood chips production from felling residues (tops, branches) is not recommended in Austria due to nutrient depletion [3].

Therefore the fuel supply for additional BMDH plants has to face the following facts:

– the offer of cheap sawmill side products is decreasing and utilisation of sawmill side products does not create new jobs as efficiently as possible,
– wood chips from first thinnings do have a high potential, create new jobs very efficiently, but are too expensive for extensive use in biomass district heating plants.

A comparison of different possible biomass fuels and their respective supply chain (energy efficiency of fuel supply, CO_2 emissions caused by the fuel supply, job creation effects, production costs and long-term potential) is given in Table II and Figure 1. The results are described as follows [3].

– The supply chains of all biomass fuels investigated show lower values as regards energy input (motor fuels, electricity) and CO_2 emissions than for fuel oil.
– There is an additional long-term potential of bark of about 1,6 PJ p.a. caused by an increase in sawn-wood production until the year 2020.
– Forest wood chips have an additional annual potential of 44 PJ. 50% of this amount could be harvested with mechanised harvesting systems. Mechanisation will lower the job creation effects by 2/3 but will also lower the production costs to about 18 ECU/MWh.
– Presently, pellets are introduced into the Austrian fuel market. The utilisation in district heating plants will depend on the possibilities to reduce the investment costs for the heating plant (high quality fuel: low water content, high energy density) and the further development of the pellet price.
– Straw is an interesting fuel in the eastern part of Austria, but up to now hardly used. The relatively poor fuel properties of straw as compared to wood has to be considered as well. The higher contents of Cl, S, N and K result in higher investment and maintenance costs for the conversion plant.
– The comparison of energy crops on set-aside-land (short rotation forestry-SRF, cereals) shows clear advantages for SRF. Furthermore, the above-mentioned influence of fuel characteristics makes SRF more preferable.
– Comparing wood chips from conventional forestry to short rotation forestry the pros for conventional wood chips are the high existing fuel potential by thinnings of forest stands and the better job creation effects thus obtained.
– Up to now about 200 new jobs have been created by biomass fuel supply for BMDH plants. The use of biomass in the way shown in Figure 1 would create a total of about 8,000 new jobs.

2.2 Biomass fuel market

There is no professional market for biomass fuels in Austria. The reasons are poor co-operation between the fuel consumers (heating plants) respectively fuel suppliers (sawmills, farmers), mainly self-supporting owners of heating plants burning forest wood chips, poor marketing skills of farmers and the dominant role of the pulp and paper industry. So there are in many cases no long-term fuel delivering contracts and there is less possibility of just-in-time fuel delivery. On the contrary the stiff offer of sawmill side products and forest wood chips can cause fuel shortage during the heating period and forces the heating plant to store fuel. The additional storage costs are 1 - 10 ECU/MWh [3].

2.3 Comparison to Denmark and Sweden

The biomass fuel supply in **Sweden** is concentrated on sawmill side products (53%), forest wood chips (34%) and pellets (13%). The fuel price varies between 11 ECU/MWh for sawmill side products, 13 ECU/MWh for forest wood chips and 18 ECU/MWh for pellets [6]. Forest wood chips are mainly obtained from felling residues by means of highly mechanised production systems.

Big consumers purchase their wood fuel from wood fuel traders. In order to keep costs low the fuel stored at the plant just covers the fuel demand of some days.

Danish wood chips production is based on material from first thinnings harvested and chipped by means of highly mechanised equipment. The market price for fuel chips is 17 ECU/MWh. Straw as Hesston-bales is offered at a price of 15 ECU/MWh. The price for pellets for large scale consumers is 20 ECU/MWh.

The wood chips market in Denmark is dominated by two players. They organise the whole fuel supply from harvesting to delivering to the heating plant. Straw is in general supplied by farmers who may be organised into straw supplier associations. Long-term fuel delivering contracts and just-in-time fuel supply is usual [4, 5].

2.4 Results

In case of further extension of biomass utilisation in Austria the development and implementation of mechanised harvesting systems for first thinnings is necessary. Also the co-operation between suppliers respectively consumers in order to lower prices by building up a professional market and fuel logistic system is required.

Table II Parameters for the fuel supply of Austrian biomass district heating plants

Notes: all values related to the energy content of the fuel (NCV); *energy input*: direct use of energy (motor fuel, electricity, incl. up- and downstream efficiency) for the fuel supply chain (crop cultivation, fertiliser production, harvesting, upgrading, transport); *CO_2 emissions*: caused by the use of fossil fuels for the fuel supply chain; mm ... motor-manual, me ... mechanised; [3]

fuel	energy input %	CO_2 emissions kg/MWh	working time min/MWh
bark	2	5	9
wood chips (sawmill)	2	5	12
sawdust	2	4	11
straw	6	10	17
forest wood chips (mm)	5	13	88
forest wood chips (me)	5	8	11
short rotation forestry	7	8	7
grain (whole crops)	10	17	19
fuel oil	14	35	

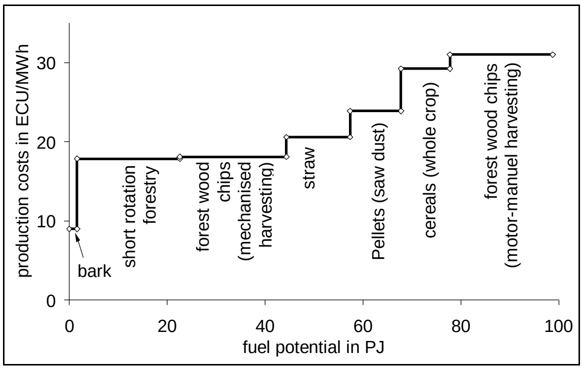

Figure 1 Biomass fuel potential vs. production costs

Notes: production costs for fertiliser, cultivation, harvesting, upgrading, transport, storing; *fuel potential:* maximum long-term additional fuel potential; [3]

3 HEATING PLANT AND NETWORK OF PIPES

Austrian biomass district heating plants have a nominal thermal capacity of 0.1 to 10 MW. State-of-the-art combustion technologies are underfeed stokers and moving grate furnaces. Several plants are equipped with flue gas condensation units.

The preferred material for the tubes of the network of pipes is steel. Usually the client is connected to the network of pipes by a heat exchanger.

Biomass combustion technologies have been developed since the eighties and can now be described as advanced with as yet untapped potentials for optimisation in the areas of emissions (NO_x, dust), process control, corrosion and fouling problems. Moreover, potentials for heat recovery and reduction of electricity costs should be better utilised.

The total emissions of different heating systems are shown in Table III. Compared to chunk-wood central heating the use of biomass in district heating systems reduces CO and C_xH_y emissions. Central heating with fuel oil brings about essentially more CO_2 emissions, more SO_2 and C_xH_y emissions, but less emissions of CO, dust and NO_x. To abolish this competitive disadvantage and to maximise ecological digestibility further improvements of the biomass combustion technology in regard to dust, NO_x and CO emissions are required.

Furthermore, major weak points result from poor plant design caused by

- inaccurate inquiry of the consumer heat demand,
- too optimistic assumptions concerning heat sale,
- wrong design of the biomass boiler capacity (no sharing in base load biomass boiler and peak load oil boiler, no consideration of simultaneity factor of the heat demand)
- and overdimensioning of the network of pipes.

The effects of these mistakes are low rates of plant utilisation, low overall energy efficiency and high investment- and operating costs.

A good indicator for the quality of the plant design are the full-load operation hours of the biomass boiler. Due to overdimensioning the average full-load operation hours amounts to about 1,600 hours p.a.. This is quite a low value compared to better designed Danish and Swedish BMDH plants with 4,000 full load operation hours [4].

Table III Emissions caused by heat production from biomass district plants compared to central heating with oil or chunk wood

Notes: *) useful energy; [1]

parameter (kg/TJ*)	biomass district heat	chunk wood central heat	fuel oil central heat
CO_2 (net)	5,000	4,000	115,000
SO_2	20 – 80	30	110
NO_x	180 – 380	190	170
C_xH_y	5 – 13	70	70
CO	130 – 2,100	5,000	100
dust	40 – 420	70	10

4 ECONOMIC ANALYSIS

The statement of costs for the heat delivered to the clients of an Austrian BMDH plant with average characteristic values is shown in Table IV - column *actual*. Due to high investment costs and poor plant utilisation rates heat production costs are dominated by high capital costs (annual depreciation and interests), and production costs are much higher than the price for district heat. Therefore an average Austrian BMDP needs subsidies for economic operation.

4.1 Plant utilisation rate

The effects of overdimensioning of the plant described in Table IV are shown by low peak load, low heat recovery in the flue gas condensation unit and low full load operating hours. Therefore the heat production costs are high and amount to 170% of the actual district heat price.

The prerequisites for economic plant operation without subsidies are described in Table IV - column *optimised*. Decreasing the production costs to the level of the district heat price requires more than doubling the sales of heat. Under these circumstances the full load operating hours of the biomass boilers would double as well.

Table IV Production costs for district heat for an average Austrian biomass district heating plant

Notes: Cost calculation based on VDI 2067; rate of interests 5% p.a.; optimised values consider an extension of the network of pipes of 20%

parameter	unit	actual values	optimised values
nominal thermal capacity			
- biomass boiler	kW	5,000	5,000
- flue gas condensation	kW	1,000	1,000
- oil boiler (peak load)	kW	5,000	5,000
length network of pipes	m	7,500	9,000
investment costs (total)	1.000 ECU	5,700	6,600
- only heating plant	1.000 ECU	3,400	3,400
heat production (p.a.):			
- biomass boilers	MWh	9,400	16,000
- flue gas condensation	MWh	900	3,200
- oil boiler	MWh	-	600
full load hours	MWh	1,600	3,200
peak load heating plant	kW	3,500	6,500
heat sold	MWh	8,000	18,400
statement of costs (p.a.):			
- capital costs	ECU/MWh	44.6	22.0
- maintenance costs	ECU/MWh	9.1	4.4
- fuel costs	ECU/MWh	10.8	10.8
- electricity costs	ECU/MWh	3.0	3.0
- personnel costs	ECU/MWh	5.4	2.4
- other costs	ECU/MWh	2.3	1.0
heat production costs	ECU/MWh	75.2	43.5
district heat price	ECU/MWh	43.5	43.5

4.2 Investment costs

The total investment costs for Austrian biomass district heating plants are about 800 ECU/kW(th) (standard deviation 400 ECU/kW) [4]. About 50% of the investment costs are caused by the network of pipes. In spite of the fact, that over 300 plants have been built in the last 15 years, the investment costs show no decrease during this period [7]. Apart from the price increase caused by the improvement of the technology there must be a potential for cost savings due to the standardisation of technological components (respectively the whole heating plant), serial manufacturing and learning curve effects. The reason why this cost reduction has not been achieved in Austria is mainly due to the national subsidising policy, which allows generous plant design and does not reduce costs.

A comparison of the investment costs for the heating plant at a European level reveals a remarkable difference. The investment costs for Danish and Swedish BMDH plants fired with wood chips are about 300 ECU/kW (costs for building, boiler and flue gas condensation unit). This is - beside optimised plant design - the main reason for the economic operation of biomass district heating systems in these countries under the side constrains of higher fuel prices and similar district heat prices [4, 5].

4.3 Investment subsidies

In **Austria** subsidies for BMDH plants are granted in the range from 30 – 50% of the investment costs. Especially agricultural cooperatives usually obtain a 50% investment support and supported loans. The percentage of subsidising was kept stable during the years.

Danish BMDH plants are subsidised with 5 to 35% of the investment costs. The percentage is based on the amount of money needed to keep consumers' heating costs at roughly the same level as prior to the implementation of the plant.

In **Sweden** the investment costs for BMDH plants were subsidised during the 1980s with a steady falling percentage. As a result of simultaneously falling investment costs and the implementation of energy and environment taxes at the beginning of the 1990s, Swedish BMDH plants are nowadays economic and do not require subsidies.

4.4 Results

For a future economically competitive extension of BMDH the subsidies have to be lowered gradually. Furthermore projects should have to meet strict technical and economic requirements regarding plant design in order to be eligible for subsidies.

The introduction of specific and detailed guidelines for the correct design of BMDH plants seems to be inevitable.

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