



A new method for an economic assessment of heat and power plants using dimensionless numbers[☆]

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Abstract

A comparison of economic data for different technologies and fuels is difficult due to the number of parameters that can alter the profitability of heat and power production. In addition, the variation of currency exchange rates considerably reduces the possibility of comparing plants in different countries. In the present study, a new method based on dimensionless costs is proposed to overcome these difficulties. Dimensionless capital costs C (including maintenance) and dimensionless fuel costs F are introduced by dividing the costs by the price for heat or electricity. In a diagram of C versus F the economy of different technologies can be compared. The diagram is divided into a profitable and an unprofitable area. The orientation of the data from one specific plant shows immediately whether the plant can be operated economically or not. Furthermore it can be seen by which factor either the fuel costs have to be reduced, or the price for electricity or heat has to be increased, or the capital and maintenance costs have to be reduced to reach the profitable area. The dimensionless diagram is independent from currency exchange rates. To demonstrate the application of the method, data from an economic assessment study of power production plants from biomass using pyrolysis, gasification and combustion technologies are presented. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Economic assessment; Dimensionless costs; Combined heat and power production (CHP)

1. Introduction

The fuel costs as well as the achieved prices for

heat and power vary in a wide range, depending on the local geographic and economic boundary conditions. Therefore a direct comparison of the economic results of technologies for combined heat and power production (CHP) in different countries is difficult due to the varying fuel costs and energy prices and it is further complicated by the different currencies and their volatile exchange rates.

The economy of power and heat production

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from biomass is basically influenced by the fuel costs, the capital and maintenance costs, the conversion efficiency of fuel to power and heat and the prices for power and heat paid by the customer or the prices from competitive power and heat producers. If the plants are located in countries with different currencies, the exchange rate is an additional parameter. The choice of the plant technology strongly depends on the expected fuel costs. If the fuel costs are low, cheap plants with low efficiency are more profitable than efficient plants with high investment costs. If the fuel costs are high, a high efficiency is necessary and capital cost can be higher to get minimal total costs. The price of power and heat achieved on the market limits the maximum total costs for plant operation without a deficit. The closer the ratio between fuel costs and price is to one, the smaller the amount of money which can be used for capital and maintenance costs. Furthermore the lower the efficiency the smaller is the amount of money that can be used for capital and maintenance costs. Ratios between costs and prices are a characteristic feature for investment decisions. Therefore it is proposed to introduce dimensionless numbers for the costs. This procedure reduces the number of variables and solves the difficulty of comparing different currencies. The presented method allows a comparison of the production cost of heat, power, or combined heat and power from different fuels in different countries and with different currencies. It is shown that the dimensionless visualisation of economic data, which has been developed and introduced in detail by Nussbaumer et al. in 1997 [1] allows a fast and easy evaluation of a certain technology under different economic boundary conditions.

2. Dimensionless costs

The dimensionless fuel costs F are on the abscissa of the diagram, the dimensionless capital and maintenance costs C on the ordinate. F and C are defined as follows:

1. for heat production (with index f for fuel and

h for heat):

$$F = F_h = \frac{\text{Fuel Costs} \left[\frac{Rp}{\text{kWh}_f} \right]}{\text{Heat Price} \left[\frac{Rp}{\text{kWh}_h} \right]}$$

$$C = C_h$$

$$= \frac{(\text{Capital Costs} + \text{Maintenance Costs}) \left[\frac{Rp}{\text{kWh}_h} \right]}{\text{Heat Price} \left[\frac{Rp}{\text{kWh}_e} \right]}$$

2. for power production (with index e for electricity):

$$F = F_e = \frac{\text{Fuel Costs} \left[\frac{Rp}{\text{kWh}_f} \right]}{\text{Electricity Price} \left[\frac{Rp}{\text{kWh}_e} \right]}$$

$$C = C_e$$

$$= \frac{(\text{Capital Costs} + \text{Maintenance Costs}) \left[\frac{Rp}{\text{kWh}_e} \right]}{\text{Electricity Price} \left[\frac{Rp}{\text{kWh}_e} \right]}$$

Fuel cost, electricity price, heat price, capital costs and maintenance costs are given as specific data per kWh (kWh_f of fuel input, kWh_h of heat output and kWh_e of produced electricity).

The annuity, determined by the interest rate and the life time of the plant, as well as the annual operating hours are considered in the definition of the capital costs. The investment costs are defined as specific costs per kW. For a heat production plant, all investment costs are related to the heat which gives specific investment costs per kWh_h , while for electricity production, all investment costs are related to the generated electricity which gives a specific investment cost per kWh_e . For a CHP plant, the costs are partly counted for heat production and partly for power production as described below under paragraph (c). With this definitions, the capital costs

with CHF as currency (1 Rp = 0.01 CHF) are determined as follows:

1. for a heat production plant:

$C_{Cap, h}$ = Capital Costs

$$\left[\frac{Rp}{kWh_h} \right] = \frac{\text{Investment Costs} \left[\frac{CHF}{kWh_h} \right] \cdot \text{Annuity} \left[\frac{\%}{a} \right]}{\text{Annual operating hours} \left[\frac{h}{a} \right]}$$

2. for a power production plant:

$C_{Cap, e}$ = Capital Costs

$$\left[\frac{Rp}{kWh_e} \right] = \frac{\text{Investment Costs} \left[\frac{CHF}{kWh_e} \right] \cdot \text{Annuity} \left[\frac{\%}{a} \right]}{\text{Annual operating hours} \left[\frac{h}{a} \right]}$$

3. for a CHP plant, the costs for a heat production plant with the same heat output are calculated as heat production part, while the

difference in costs between a CHP plant and a heat production plant count for the electricity production.

The maintenance costs are also defined per kWh_e or h and can either be calculated from assumed data from staff and maintenance costs or be estimated as a certain percentage of the investment costs.

With a given efficiency a certain proportion of the income of the heat or electricity sold is used to pay the fuel. The capital and maintenance costs have to be paid from the remaining income. Lines of net profit equal to zero are plotted for different efficiencies in Fig. 1. For CHP plants a proportional distribution of fuel costs to heat and power is assumed in this figure. A CHP plant is often built instead of a plant for exclusive heat production. In this situation the overall efficiency is often reduced and the efficiency of a hypothetical plant for pure heat production can be used as a reference for the fuel cost distribution of the CHP. Fig. 2 shows the cost distribution for a CHP plant.

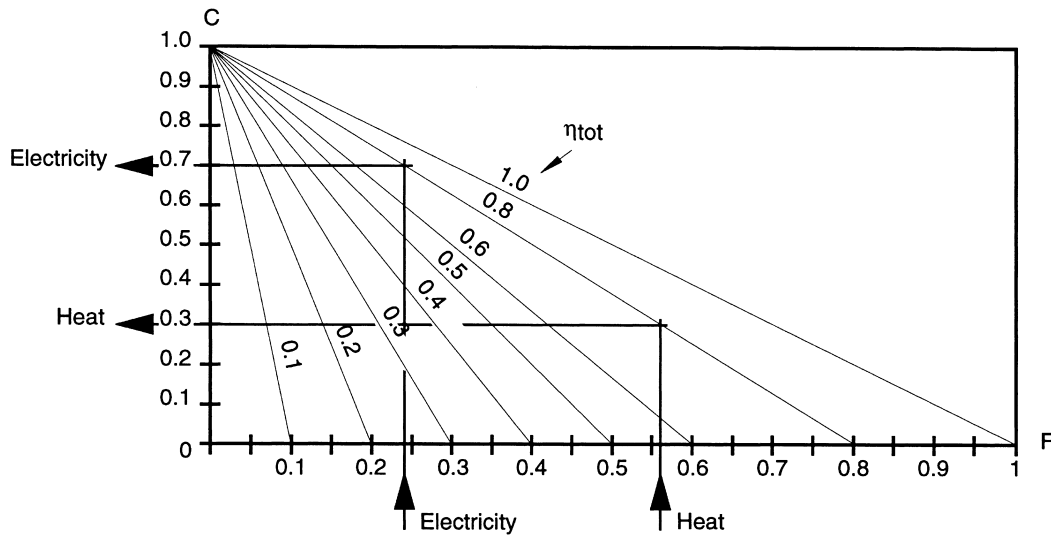


Fig. 1. Maximum capital and maintenance costs as a function of fuel costs and electric or heat price if the fuel costs are distributed proportionally to the heat and power output. The profitable area is below the relevant efficiency curve (efficiency based on Lower Heating Value, LHV). Example with results from diagram: Overall efficiency 80%. $F_e = 4.25 \text{ Rp/kWh}_e / 17.5 \text{ Rp/kWh}_e = 0.24$; $F_h = 4.25 \text{ Rp/kWh}_e / 7.5 \text{ Rp/kWh}_h = 0.57$. Permissible capital and maintenance costs of heat production 2.2 Rp/kWh_h. Permissible capital and maintenance costs of electrical production 12.2 Rp/kWh_e. (100 Rp = 1 CHF = 0.63 Euro = 0.67 USD, Feb 1998).

Four equations are derived from the following cost equation

$$\begin{aligned} &\eta_e \cdot Pr_e + \eta_h \cdot Pr_h \\ &= \frac{\eta_e + \eta_h}{\eta_{tot}} \cdot C_f + \eta_e \cdot C_{Cap,e} + \eta_h \cdot C_{Cap,h} \\ &+ \eta_e \cdot C_{M,e} + \eta_h \cdot C_{M,h} + \eta_e \cdot Profit_e \\ &+ \eta_h \cdot Profit_h \end{aligned}$$

where C_F =Fuel Costs [Rp/kWh_f]; C_{Cap} =Capital Costs [Rp/kWh_{e or h}]; C_M =Maintenance Costs [Rp/kWh_{e or h}]

An equation for the heat part, and equation for the electrical part:

$$\begin{aligned} \eta_e \cdot Pr_e &= \frac{\eta_e}{\eta_{tot}} \cdot C_f + \eta_e \cdot C_{Cap,e} + \eta_e \cdot C_{M,e} \\ &+ \eta_e \cdot Profit_e \end{aligned}$$

$$\begin{aligned} \eta_h \cdot Pr_h &= \frac{\eta_h}{\eta_{tot}} \cdot C_f + \eta_h \cdot C_{Cap,h} + \eta_h \cdot C_{M,h} \\ &+ \eta_h \cdot Profit_h \end{aligned}$$

where Pr =Price [Rp/kWh_{e or h}]; $Profit$ =Profit [Rp/kWh_{e or h}]; $\eta_{tot,0}$ =Efficiency for a hypothetical plant for heat production efficiencies are calculated on the basis of the Lower Heating Value (LHV) of the fuel.

And a special equation for CHP plants, if the fuel costs shall not be distributed proportionally to the heat and power production (Index zero for reference case):

$$\begin{aligned} Pr_{h,0} &= \frac{1}{\eta_{tot,0}} \cdot C_f + C_{Cap,h,0} + C_{M,h,0} \\ &+ Profit_{h,0} \end{aligned}$$

The cross points of the electricity related lines with the abscissa (Fig. 2) can be determined as follows:

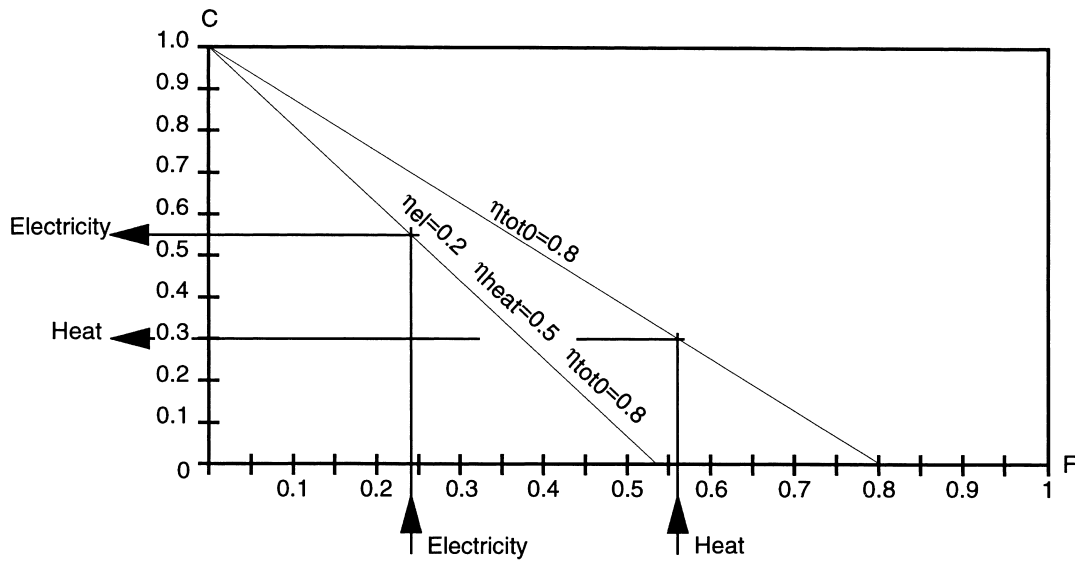


Fig. 2. Maximum capital and maintenance costs as a function of fuel costs and electric or heat price. The fuel costs are distributed with reference to the efficiency (based on LHV) of a plant with pure heat production. The profitable area is below the relevant efficiency curve. Example with results from diagram: Efficiency of pure heat production 80%. Overall efficiency CHP 70%. Efficiency of electrical conversion 20%. Efficiency of heat conversion 50%. $F_e = 4.25 \text{ Rp/kWh}_f / 17.5 \text{ Rp/kWh}_e = 0.24$; $F_h = 4.25 \text{ Rp/kWh}_f / 7.5 \text{ Rp/kWh}_h = 0.57$. Permissible capital and maintenance costs of heat production 2.2 Rp/kWh_h. Permissible capital and maintenance costs of electrical production 9.5 Rp/kWh_e.

$$F_e = \frac{\eta_e}{1 - \frac{\eta_h}{\eta_{tot.0}}} \quad (C = 0)$$

3. Impact of changes of costs and prices

For a technology which is not profitable at actual conditions, a graphical analysis of the sensitivity shows immediately, which change in one of the economic parameters is necessary to achieve economic operation of the plant: Either an increase in efficiency by a certain factor, a decrease in fuel costs or an increase in heat and electricity price is needed to reach the economic area in the diagram (Fig. 3). Since the diagram distinguishes between investment and operational costs, it can also quickly be evaluated if a non-economic process becomes economic with a certain subsidy of the investment costs or if it remains non-economic even with a 100% subsidy. In a similar way, limits to become unprofitable can be investigated, if a plant works with profit.

4. Comparison of plants and technologies

For the heat and power generation and combined heat and power production (CHP) by biomass the following processes for CHP and power plants are relevant:

- Combustion in furnaces combined with steam cycles, organic Rankine cycles (ORC), Stirling engines or hot gas turbines.
- Fixed bed gasification with internal combustion engines.
- Fluidised bed gasification with gas turbines or combined cycles.
- Production of liquid fuels through pyrolysis or synthesis from producer gas.

The mentioned technologies cover a wide range from of a few kW_e to more than 100 MW_e. The electrical efficiency varies from 10% for small steam plants to 45% for large combined cycle plants. In [1] costs and performance data from recent publications has been collected and actualized with own data. The data covers heat plants from 3 to 24 MW_h, CHP plants from 0.04 kW_e to 30 MW_e and power plants from 24 to 107

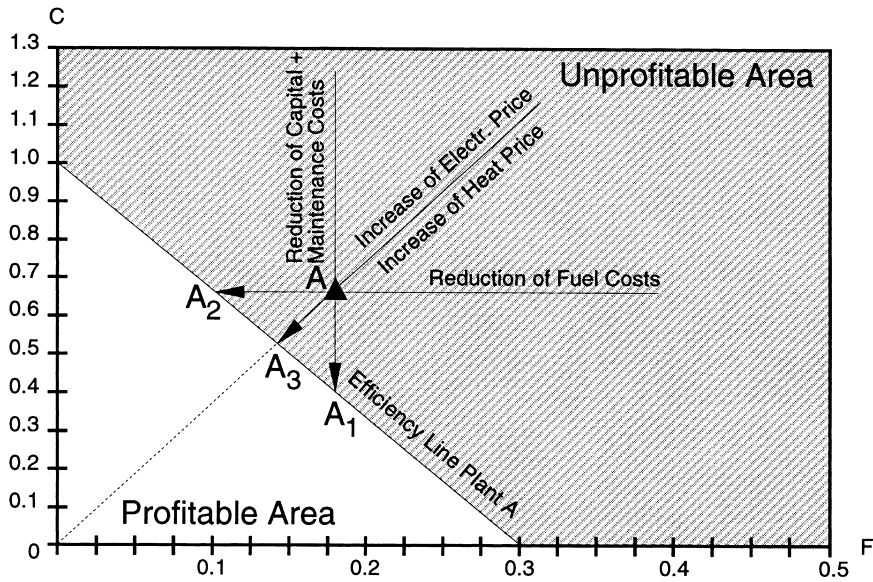


Fig. 3. Necessary increase of price or decrease of costs to reach the border of profitability. For the plant A the capital and maintenance costs have to decrease by 39% (Point A1) or the fuel costs have to be reduced by 43% (Point A2) or the heat or power prices have to be increased by 26% (Point A3).

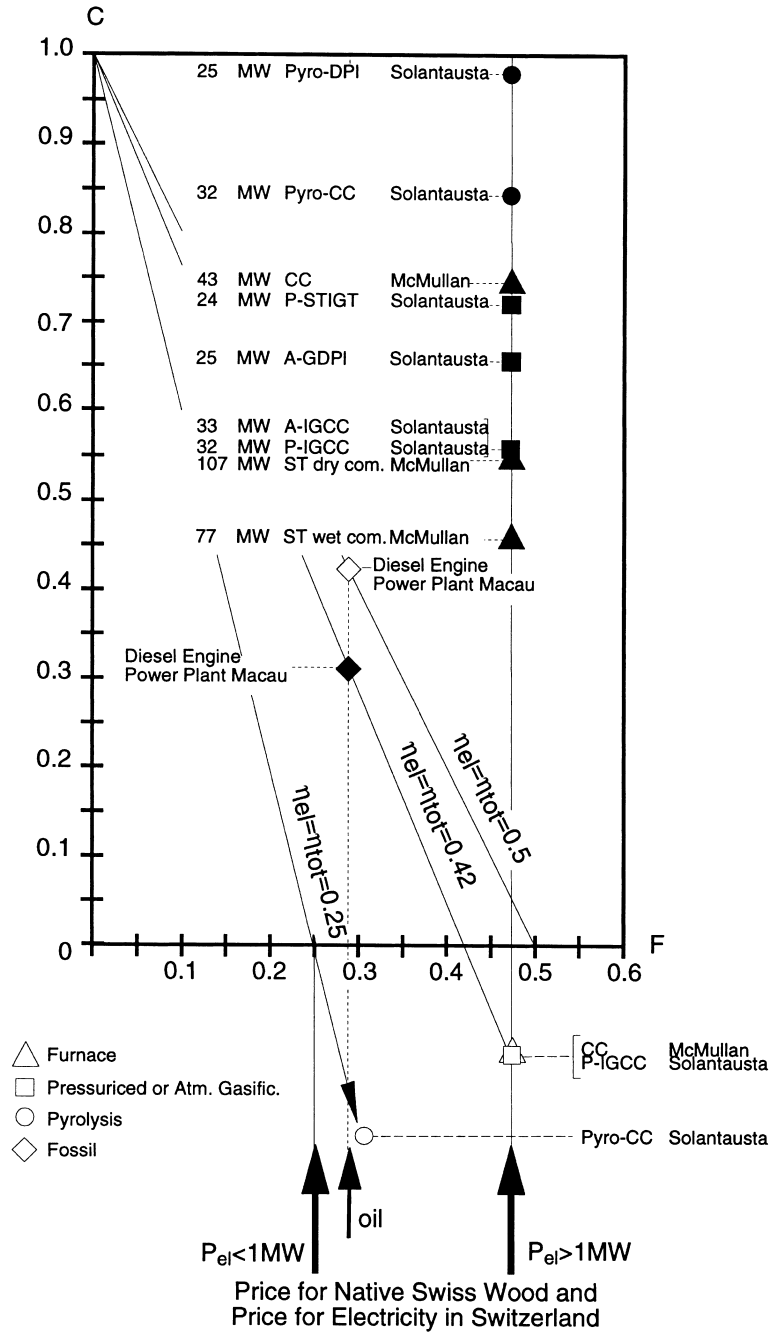


Fig. 4. Comparison of technologies for power plants. White symbols mark the maximum possible capital and maintenance costs for profitable operation if the fuel costs and the electricity price are given. Black symbols mark the effective capital and maintenance cost. Efficiencies are based on LHV. Data from Nussbaumer et al. [1], Solantausta et al. [3] and McMullan et al. [4].

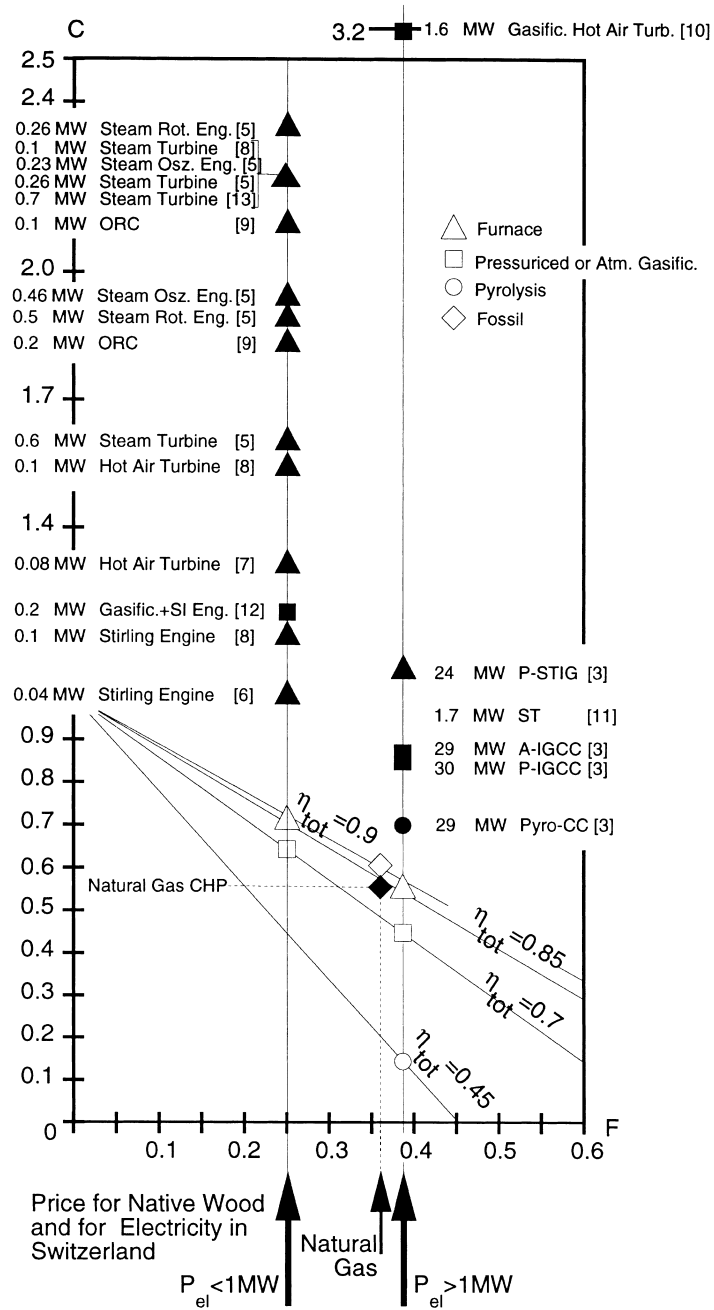


Fig. 5. Comparison of technologies for CHP plants. White symbols mark the maximum possible capital and maintenance costs for profitable operation if the fuel costs and the electricity price are given Black symbols mark the effective capital and maintenance cost. Efficiencies are based on LHV. Data from Nussbaumer et al. [1], Solantausta et al. [3], Biollaz et al. [5], Carlsen et al. [6], Holzer and Harasek [7], Podesser et al. [8], Renz [9], Schaller [10], Seeger [11], Sharan et al. [12], and Baumgartner and Finger [13].

MW_e. Data on combustion and fixed bed gasification are based on experiences from realized CHP plants in Switzerland and on data from literature, which is given in detail in [1] and [2]. Data for large scale power production units with gasification or pyrolysis is mainly based on an assessment of Solantausta et al. in 1996 [3]. In Figs. 4 and 5 the data is presented graphically for typical fuel costs, heat and electricity prices in Switzerland. The figures show the importance of high efficiency for energy conversion in Switzerland due to the high costs for wood fuel.

5. Conclusions

The new method with diagrams of dimensionless costs allows a fast and easy assessment of a certain technology under different economic boundary conditions and it can be used for a comparison of the production cost of heat, power, or combined heat and power from different fuels in different countries and with different currencies.

The difficulties with different currencies are solved with this method. Challenges concerning currency remain only if the fuel is bought with another currency than the electricity or heat is sold. Nevertheless different costs of labour and ground have to be considered in studies which cover different regions. However, these problems are not basically related to currency, they can also occur in one single country.

The method is proposed to be used for future assessment studies of heat and power production systems based on biomass and other fuels.

Acknowledgements

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