District heating and passive houses – Interfering strategies towards sustainable energy systems

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Abstract

Today, 'district heating systems' (DHS) in many cases are the most energy efficient option to provide space heating in densely populated urban areas. Such grid based systems involve heavy investments though, which in the form of 'sunk costs' create a 'technological lock-in situation', often accompanied by 'institutional lock-in'. After the decision for such an infrastructure is taken, these path dependencies usually rule out the application of decentralised efficiency strategies (such as investments in state-of-the-art insulation of houses) for many decades. In the long run, this can lead to non-optimal energy systems.

This raises two questions: a) whether and how the negative long-term effects of lock-in on efficiency can be reduced and b) on what basis optimal decisions on energy systems (in the long run) can be taken.

Scenarios about the path dependencies and the long term developments in energy systems (e.g. improved supply options and shifts in demand) are prerequisite for decisions on the most sustainable energy options. Ideally, such scenarios also show ways to reduce the prohibitive effects of DHS on future efficiency strategies in the planning phase. Technical factors like increasing efficiency standards are important for an adequate dimensioning of the generation and grid capacity. But even more important are institutional trajectories. As this paper exemplifies, specific tariff structures translate the technological path dependencies into economical incentive structures. They often prevent individuals to invest in efficiency improvements such as passive house standards or solar water heating. Since such tariff structures are often subject to public decision making processes, knowledge of such effects is crucial for opinion makers which seek to promote sustainable energy systems.

As a case study, the decision making process about the heat supply for 'Vauban District' in Freiburg, Germany is described and analysed. Indications are derived, what kind of alternative policy making process could have resulted in an outcome, that the actors were actually aiming for: the most efficient energy system available.

Introduction

In densely populated areas, modern 'district heating systems' – i.e. the central provision of heat ideally from efficient co-generation plants – are superior to most stand alone options in terms of energy efficiency and overall environmental impact (Ericson S.-O. and Anheden M. 2002). With decreasing energy demand of buildings due to improved insulation and 'passive house' design, the load density of urban areas is becoming critically low for such systems to be economically feasible.

One technical solution to that problem is to 'branch out' of the heat market into other sectors, such as cooling (Poredos A. 2000, Kitanovski A. et al. 2000). As long as there is sufficient demand, e.g. to substitute inefficient use of electricity for cooling, this is a promising approach, even in a long term perspective. Important is the feature of such infra-

Table 1. Cost components for a typical household (flat of 100 m^2 in a 5-family house).

1) share of building costs for DH system ('Baukostenzuschuss')	900 Euro/ 100 m²
2) costs for connecting the house to the grid	5 000 Euro / house
3) price of heat capacity (yearly)	40 Euro / kW
4) handling fee (yearly)	180 Euro / connection
5) price for heat consumption	22 Euro / MWh

Table 2. Resulting annual costs for the typical household (depending on level of consumption).

..in a house meeting the legal requirements (yearly consumption of 80 kWh/m²)	**637 Euro / a => 0,08 Euro / kWh**
..in a house with better design & insulation (yearly consumption of 45 kWh/m²)	**509 Euro / a => 0,11 Euro / kWh**
..in a house with passive house standard (yearly consumption of 16 kWh/m²)	**411 Euro / a => 0,26 Euro / kWh**

structures to provide opportunities for future shifts in generation technologies and improved efficiency. Another operational strategy to increase the economic performance of a DHS can be to store the heat produced in cogeneration in order to maximise the marketable output of (CHP-) electricity (Rolfsman B. 2004a, Rolfsman B. 2004b).

In some countries like Sweden, policy makers and the public are so much opposed to electric heat applications, that district heating is considered even for smaller and remote areas (see Dahm J. 2001).

But further improvements in the energy efficiency of buildings will cause a decrease in heat loads of many residential areas decrease to such low levels, that the distribution grid with its unavoidable losses is endangered to loose out against the de-centralised generation of heat (and cooling) - in terms of efficiency and environmental impact. The economic performance of district heating networks meanwhile depends highly on the connection of possibly all potential consumers within the grid area.

This situation frequently leads to frictions, since not all future customers of DHS are very happy about an obligation to connect their buildings to such a grid – especially if they have to bear relatively high costs. The future users of passive houses for example, with their low levels of consumption, often feel not well served by such infrastructures[1].

The case study – Freiburg in Germany

While planning a new district for 5 000 people in Freiburg (Germany) in 1995, town planners and politicians decided to provide heat by a district heating network. The buyers of premises were obliged to connect to the newly installed DHS. This was to be run by the local utilities, which were at the time still owned by the municipality.

At the same time, for ecological reasons, all developers were forced to build highly energy efficient buildings. In all bilateral contracts about the municipality selling land to developers, the developers had to assure, that the buildings they would erect will consume less than 65 kWh/m² a year. This had to be proven by data and calculations meeting the so called "Freiburg Standard", a methodology producing higher consumption rates than the methodology used for proving the standards along national law. At the time, according to national legislation (Wärmeschutzverordnung from 1995) the maximum for new buildings set a maximum of 90 kWh/m².a. The City of Freiburg thus forced the builders to reduce the consumption for another third. But yet, at Vauban district, many builders were even more ambitious and planned to reach the level of passive houses (< 15 kWh/m².a). These houses consume so little energy though, that the connection to a DHS becomes unattractive, especially if the heat tariff comprises a high percentage of fixed costs.

The general tariffs of the DHS in Freiburg comprise a diversity of cost components.

Due to the high share of fixed costs, the (specific) costs for one kWh of heat differ significantly depending on the level of consumption.

Specifically for dwellers of passive houses, the specific price of heat is unattractive – heating with electricity or even with bottled butane gas could be cheaper.

The tariff structure thus does not provide incentives for investments in good insulation or additional solar thermal collectors – nor for the saving of energy.

Very recent comparative calculations (January 2005) on the supply options of three newly planned passive houses in the area have shown again, that the three ecologically sophisticated supply options for passive houses in this area (DHS, Micro-CHP running on gas and efficient gas heaters) differ slightly in their economic and ecological performance. It is difficult to clearly nominate a winner, since many parameters of a life cycle analysis remain uncertain, such as the

1. See for example http://www.passivhaus-vauban.de/blockheizkraftwerk.html (in German)

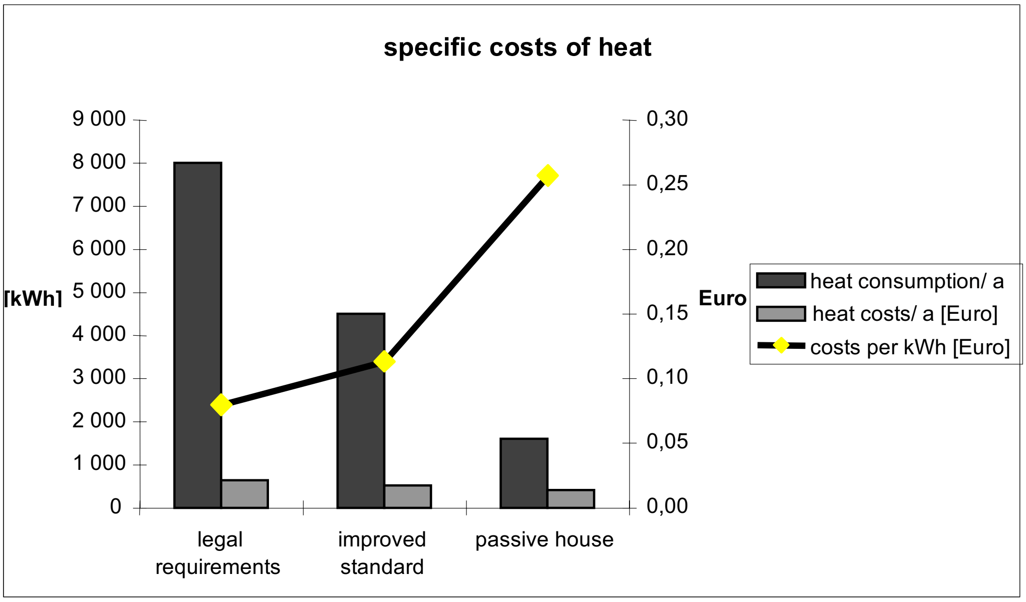

Figure 1. *Specific costs of heat at different standards of consumption, Spaeth 2004.*

development of prices for gas and electricity. Furthermore, it is difficult to determine the option with the least emissions, because data on the real everyday performance of the DHS are difficult to obtain (fuel consumption, hours of operation, partial loads, output in electricity etc.). Rough calculations have shown however, that a micro-CHP-unit will after all produce slightly fewer emissions. Concerning the economic performance, the given heat tariff and usual estimations on future gas prices clearly indicate overall advantage for a micro-CHP-unit.

The politics involved

In Freiburg, from the very beginning, there was a strong alliance in favour of the district heating option. The utilities, – wanting to expand their grid and revenues, – were supported by the mayor, who at the time was heading the board of directors of the municipal utilities and who's natural interest was to extend its profits. Many members of the city council joined forces though in the intention to create a "model district" and a show case of best practice for efficient use of renewable energy in a DHS. The decision to build up a district heating system finally has been taken by the city council mainly because of the perceived ecological advantages and green image of this option (to meet the claim of building a "model district"). It has not been widely discussed on the basis of rationale comparison with other options though.

Once the decision had been taken, it had been fortified in the further planning of the district. Such an effect has often been observed and was described for DHS in detail first by (Summerton 1992). In the case of Freiburg, slots suitable for passive houses, for example, had been reduced by the south/north orientation of most building plots. An alternative layout allowing for more buildings to face south was dismissed during the selection process, arguing that there will be a DHS anyway.

The obligation to connect all houses to the grid – as well as the tariff structure discouraging investment in energy savings – was however challenged by ecologically aware builders. They put forward their protested against what the perceived to be unfair and unjustified financial burdens on the shoulders of those households, who invest in performance insulation to members of the city council and the administration ad even went public. Their claim to be released off the obligatory connection threatened to impair the economical performance of the district heating system though. The utilities (in coalition with the municipal administration) were therefore strictly opposed to such ambitions. The system operator (owned by the municipal utilities) argued, that this tariff structure truly represented the cost structure (building plus capital costs versus operational costs)[2]. After several discussions, the city council decided to retain the tariff structure, while the duty to connect to the grid was repealed for houses, which comply to three criteria:

1. Provision of proof for a heat demand of less than 15 kWh/m^2.a in detailed documentation
2. Installing of an additional solar thermal plant
3. Adherence to a ban on electric heating.

Thus, to meet the criteria in order to be released off the grid, several expenditures (arguably on ecological improvements) had to be settled: In solar thermal capacity (a certain number of square metres), the procedure to prove the passive house standard was quite costly, and the option of electric heating (probably the one with the lowest investment costs, since it requires no heat pipes) was ruled out.

2. This might even be the case. It nevertheless does not indicate, that the tariffs should be modelled according to this relation. The same utilities at the same time charged tariffs for drinking water that were based by 100% on consumption - without any fix costs. This tariff consequently produced high incentives to save water.

The outcome

But although (theoretically) all users of highly efficient buildings now had an option to avoid the cost structure of the grid, only a few builders opted for stand alone systems. Although some builders groups proved the viability of installing e.g. a micro CHP[3], only very few of over 100 housing units reaching about a passive house standard opted for stand alone systems. A reason might be found in social factors: The builders in the area were mostly families or groups of people, non-professionals, seeking comfort and showing a high reluctance to becoming an energy entrepreneur. They preferred the all-in-one deal offered by the utilities over running own infrastructure on their premises (which would involve risk and hassle), although this deal is very expensive in the long run.

Even without the obligation to connect, the infrastructural and institutional path dependencies crucially limited the competitiveness of stand alone systems. Additionally, the utilities used several 'soft' measures to further reduce economic potentials for such stand alone systems: For example, they have abandoned the possibility to share 'independently produced' heat among neighbouring houses.

Since most houses were thus connected to the grid, the tariff structure impaired the number of housing units built according to passive house standards and the number of additional solar thermal systems. Furthermore, due to the tariff structure, there are very little incentives to save energy by respective behaviour.

Many more efficiency measures could have been realised in co-existence with the grid infrastructure – being both technically and economically viable. The city council, which had (at least theoretically) the power to dictate tariff structures and connection rules, could therewith have supported the realisation of these potentials – if the political will to accept the economic risks, e.g. of a reduced dimensioning of the DHS and heat generating plant, would have been established.

What had happened? The concept of 'technological' and 'institutional lock-in'

As a first step, we need to understand, what economic effects and political dynamics impede the coexistence of a DHS with unconnected (more efficient) alternatives. The concept of technological 'lock-in' explains, how such grid based systems with their heavy investments ('sunk costs') and effects like 'scale economies' and 'network economies' finally achieve increasing returns - stabilising its dominant position (Foxon 2002). Adding on this, 'institutional lock-in' constraints human behaviour by laws, contracts (here: tariffs), rules and codes of behaviour related to such socio-technical systems. This phenomenon can be observed not only in the sector of heat provision but also with regard to other grid based infrastructures such as water provision and electricity generation.

What makes the case of 'passive houses' (PH) particularly delicate is the fact, that they not only reduce energy consumption to such low levels, that the heat demand, required for the economic feasibility of a DHS (compared to stand alone options), is geographically spread ever more widely. By doing so, they also increase the necessity to connect really all potential private and industrial consumers within the area to the DHS.

In Freiburg, as in many German cities, this was reflected in a municipal legislation of the type "Kommunale Satzung". It is binding for all citizens, requiring them to connect their buildings to DHS where applicable, and to pay the mentioned cost components. The municipality has licensed its own utility to run the DHS in certain areas as local monopoly on floor heating. The revenues earned in this monopoly have thus to be regulated. Since the utilities were owned by the municipality (and any profits could hence be used to compensate losses in other municipal businesses - such as public transport), there was a wide acceptance of asking relatively high prices from the consumers of the DHS. The cost structure and the actual prices had been laid down in the municipal law a few years before, when the alternative heat options and the building standards had been completely different. The municipal actors were still reluctant to adjust this legislation, since they feared a never ending debate, once the "eternal" status of the DHS-regulation had been questioned.

As with a transmission belt, the trajectories of the technical infrastructure thus are translated by institutions such as the tariff structure and connection rules into effective and enduring incentive structures.

This process of translation of course reflects the given power relations. In the case of Freiburg, effective was not the principle power of the city council to vote for the most effective system and to design an appropriate tariff structure. This power was rather constrained as was the capability of the city council members to anticipate the effects of their decisions. The technically given opportunities of co-existence (of grid and high performance stand alone systems) were not realised because of the institutional path dependencies such as the emerging interests to secure grid performance and profitability. As in many cases and sectors, a grid based infrastructure therewith restricted the potential of efficiency strategies in the grid area. The path dependencies (comprising technical artefacts and related institutional aspects such as tariff structures and rules) thus got in the way of reaching the original goal to create the most eco-efficient energy supply system.

Precautionary measures to alleviate the drawback of infrastructural lock in and local monopolies

District heating systems, very much like other grid based infrastructures, are a challenge to regulate. Market, managerial and governmental imperfections are compromising on its environmental and economical efficiency (see Agrell and Bogetoft 2005). The importance of such regulation is often underestimated, maybe because of the relatively small size

3. For a detailed documentation on such a passive house with a stand alone system (micro-CHP), see http://www.vauban.de/projekte/wa/

of such systems, limited to the local scale. The actors responsible for this regulation – members of the city council, often lack the capacities to come up to their responsibilities. It seemed that these actors had furthermore difficulties to mobilise adequate support.

In order to come to the most efficient and sustainable energy systems, decision makers need to balance the performance criteria of the currently available options (often pointing to DHS) and the long term implications (the tendency of grid infrastructures to 'freeze' the level of efficiency and to support high levels of demand).

The negative tendencies in the long-term are of course not completely determined. They arguably can be influenced by the technical and institutional design of the DHS. Ways need to be explored by which the prohibitive nature of DHS with regard to efficiency improvements can be tackled.

If at all possible, a co-existence of grid based and stand alone efficiency strategies can only be achieved with integrated and long term strategies. For example, the transportation and generation capacity could be dimensioned lower to accommodate for future improvements in heat consumption.

Regarding district heating systems in general, the case study indicates, that in the future, such systems might be economically viable only in very limited areas, where a high density of the population is concentrated around centres of high additional demand for heat and/or cooling (e.g. shopping centres etc.).

In the case of Freiburg, exhaustingly tapping the potential for energy efficient building would have required a special tariff (with a reduced share of fixed costs) to accommodated also the low level consumers – either at the costs of the other consumers in the network or on the costs of the overall profitability of the system. Only by this compromise, the whole system could have been optimised in terms of environmental impact (all households get connected to the most efficient grid plus incentives to reduce levels of consumption are given).

If grid based infrastructure is preferred to decentralised options because of ecological and efficiency reasons (and there are still many reasons to do that), precautions should to be taken to limit the negative effects of lock-in, especially compromising efficiency measures. Besides the institutional provision for a coexistence of highly efficient stand alone units within the grid area, high attention needs to be put on reaching a maximum of adaptability in the technical artefacts (dimensioning, modular structures etc.).

Given the heat demand per square metre will further decrease in he future, and that DHS-infrastructure is still ecologically favourable (no local emissions, option for CHP running on local renewable sources etc...) such investments can probably no longer be fully paid by the consumers. Such investments would than have to be at least partly be financed by the public, charging consumers only for running costs and a share of the capital costs.

How to decide upon the optimal energy system in the long run?

The decision making process in Freiburg was not reflecting long term effects and thus led to an inconsistent and controversial policy.

The problem to balance short term benefits (here: profits for utilities and a most efficient system at the moment) versus long term requirements (here: the most efficient and adaptive system accommodating for decreasing levels of consumption) is a rather ubiquitous problem in policy making, especially when sustainability goals are at stake and the future developments yield much uncertainty (see e.g. Späth et al. 2005, Bardouille and Koubsky 2000).

Political processes are furthermore characterised by distributed steering capacities, shared among many stakeholders. Real world policy making will therefore never resemble text-book methodologies.

But still, several conclusions can be drawn from the example (and should be addressed to actors involved in such decisions):

The impact of infrastructure systems need to be assessed on a life-long basis, including the aspects of technological and institutional lock-in. This reflects the scientific debate on the co-evolutionary development of socio-technical systems (Ashley R. et al. 2002). In order to promote the most efficient and sustainable energy systems, decision makers need to anticipate possible path dependencies. Only on that basis, ways can be explored e.g. to reduce the prohibitive effects of DHS on efficiency strategies.

For example, the interacting strategies on the supply-side and on the demand-side of the heat supply system and the cross market interactions, e.g. between heat and electricity applications (de Almeida et al. 2004, Grohnheit P.E. and Gram Mortensen B.O. 2003) are a matter of point here. The case study clearly indicates a need for more integrated decision making processes in district planning, involving a long-term perspective and consideration of interfering effects of several infrastructural, planning and policy decisions. This might involve the articulation and negotiation of goals on a 'higher level' as compared to the traditional policy fields such as 'energy', 'transport' or 'housing'. The overarching 'sustainability goals', which in some cities are set up to guideline the development of the whole city or certain districts, could fulfil this function, if selected carefully and accepted widely.

Only ambitious policy processes, successfully integrating the interwoven policy issues (such as the density of the district and its effects for several supply systems such as water, transport, etc.) can produce the desired outcome. And even they can easily fail, if assumptions turn out to be wrong, or if priorities of the constituency change over time.

The old approach of integrated resource planning (IRP) – hastily dismissed from energy economics after the liberalisation of markets - might be a rich source of inspiration in this regard (D'Sa 2005).

The approach of 'transition management', developed to enable governments and other actors to influence such long-term changes in socio-technical systems (hence introducing a 'new mode of governance'), can presumably contribute to the improvement of decision making processes (Kemp 1994).

As the case study has shown, special attention should be paid to tariff structures and connection rules (the transmission belt between infrastructural and institutional closure). Since such tariff structures are often subject to public decision making processes, political control of these issues is of high importance and knowledge of such effects is crucial for opinion makers which seek to promote sustainable energy systems.

Scenarios about the path dependencies and the long term developments in energy systems (e.g. improved supply options and shifts in demand) are prerequisite for sound decisions on the most sustainable energy options. Ideally, such scenarios also show ways to reduce the prohibitive effects of DHS on future efficiency strategies in the planning phase. Technical factors like increasing efficiency standards are important for an adequate dimensioning of the generation and grid capacity. But even more important are institutional trajectories. Municipalities governing DHS as local monopolies should be supported with the planning and decision making by a supporting agency, for example by documenting many municipalities' experiences. This could become a sub-task of the national regulator e.g. on gas, of the national energy agency or any other suitable association.

The ecological impact of DHS and the many decades, for which they determine the levels of ecological performance, would justify a lot more research – on the dynamics of these monopolies, on possible improvements and how these could be implemented - than is currently carried out.

Glossary

CHP	combined heat and power (co-)generation
DHS	district heating system
DSM	demand-side management
IRP	integrated resource planning
kWh	1000 Watt . hours
PH	passive house (standard)
ST	solar thermal

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