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MICRO COGENERATION: TOWARDS A DECENTRALIZED AND SUSTAINABLE GERMAN ENERGY SYSTEM?[1]

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Abstract

Micro cogeneration – the simultaneous production of heat and power in an individual building based on small energy conversion units such as Stirling and reciprocating engines or fuel cells – is expected to increase energy efficiency on the level of household energy supply. A large-scale introduction of micro CHP may radically change the electricity system and turn consumers into power producers. At the same time, micro CHP could, if supported by favorable economic and policy conditions, represent a considerable market segment, promoting downstream innovations such as "virtual power plants", altered consumer awareness or new household energy management systems. This potential has to be evaluated with respect to its sustainability in both economic and ecological terms.

In the paper, we present selected results of a case study of an interdisciplinary research team (Pehnt et al., 2006). The case study considers the status quo and potential of micro cogeneration in Germany. The diverse consequences of a broader introduction of micro CHP for the energy market, the customers, the environment and the economy require an interdisciplinary investigation into the real benefits and barriers of micro CHP. We use various methods, including a life cycle assessment of ecological impacts, a model of its economic performance, and an institutional economics analysis of actors involved in (potentially) implementing micro cogeneration on a larger scale. In the public perception, high expectations are associated with the introduction of technologies such as fuel cells, while other – more developed – CHP options, such as Stirling and reciprocating engines, are hardly known yet. Correspondingly, perceptions and expectations on the level of government, industry, and science will impact on the level of policy support and incentives granted to micro cogeneration. The paper will discuss the status quo and perspectives behind this observation.

1 Introduction

During the last few years, the German energy market has witnessed the slow but steady emergence of a novelty in energy service delivery: With the liberalization of the electricity market in Germany, a handful of technology firms and energy service companies started to focus their business in the area of small and very small cogeneration units, that are installed in apartment buildings, very small heating networks, hotels and other commercial applications. These very small cogeneration units are often referred to as micro Combined Heat and Power (CHP) or cogeneration plants. They simultaneously generate heat and electricity in units smaller than 15 kW_{el}, allowing for a higher energy efficiency than separate generation.

The potential contribution of micro cogeneration in the energy system depends on the framework conditions for micro cogeneration and on the costs, availability, barriers and incentives of competing

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technologies for heat supply, such as boilers, solar collectors or heat pumps. In Germany, only about 60 MW of micro cogeneration capacity has been installed so far, generating about 240 GWh electricity annually. This is a very small share of overall electricity generation (about 0.04%) and, though sales volumes have been increasing in the last decade, micro cogeneration is still a niche market and far away from a broad market introduction. Even optimistic scenarios of a future "sustainable energy system" estimate the potential to amount to some 3 GW or 3% of electricity demand in the year 2050 only (Pehnt et al., 2006). This is substantially more than has been installed today, but it would not represent a technological revolution.

The environmental performance of micro cogeneration depends on the competing options for heat and electricity supply and the time perspective. Pehnt et al. (2006) show that in most cases micro CHP has a similar performance as larger CHP such as district heat, being environmentally favorable compared to heat supply with natural gas fired boilers and electricity supply with the generation mix in 2010 in Germany. However, other options for heat supply, such as solar collectors, may be economically and environmentally promising alternatives, depending on the specific circumstances. In the long-term, micro cogeneration plants might be fuelled with hydrogen from renewable resources. The environmental performance of different micro cogeneration technologies in relation to these competing options is subject to further ongoing research.

In this paper we aim at assessing the market chances of micro CHP in Germany in the short- and mid-term. For this purpose, we assess the economic feasibility of promising micro cogeneration technologies under present market conditions and analyze the interests, attitudes and strategies of important actors for the diffusion of micro cogeneration. We focus our analysis on Germany as one of the potentially most interesting markets. The paper does not compare micro CHP to other options to enhance energy conversation, such as energy efficiency measures at the buildings, the use of renewable energies such as solar collectors or biomass boilers.

The paper is organized as follows. We start with an overview on micro cogeneration technologies, including reciprocating engines, Stirling engines and fuel cells, and describe their current state of development. We examine their economic feasibility in a number of typical applications in Germany from an operator's and a societal perspective. On this basis, we explore the actual dynamics of micro cogeneration diffusion in Germany. We analyze the interests, attitudes and strategies of actors concerned with implementing micro cogeneration, such as network operators, appliance industry, gas and electricity suppliers, etc. We explore the impacts of their (diverging) interests and strategies and mirror them with the economic potential and institutional setting for micro cogeneration with respect to competition, grid access and transaction costs. We conclude with assessing barriers for and possible measures to facilitate the diffusion of micro cogeneration in Germany.

2 Micro cogeneration technologies

Micro cogeneration technologies convert chemical energy in fuels or solar radiation into electricity and heat. A number of different conversion technologies have been developed or are under development: Reciprocating engines, Stirling engines, fuel cells, gas turbines, steam engines, and thermo photovoltaic devices; others are still in their very early stages of research and development (Pehnt et al., 2006). Our focus is on the first three technologies.

Reciprocating engines in micro cogeneration applications are typically spark ignition combustion engines. They operate with little excess , causing relatively high NO_X emissions. NO_X emissions can be reduced by installing three-way catalysts or operating the engine in lean mode. Electric energy efficiency depends strongly on the system size and usually does not exceed 26%. Thermal efficiency depends on the type of heat generation. Fuel cells are expected to reach about 80%, reciprocating engines with a condenser for latent heat in the flue gas may reach thermal efficiencies well above 90%. Reciprocating engines are commercially available and produced in large numbers. In Germany, mainly modules of about 5 kW_{el} are being produced. Smaller units for single-family house applications are under development.

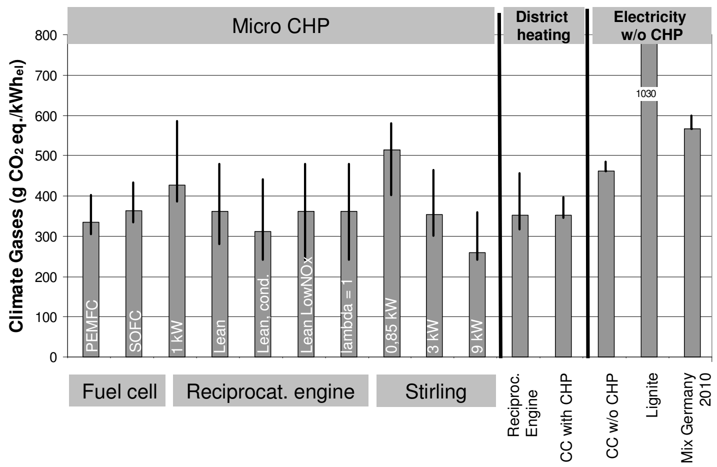
In *Stirling engines,* the heat is generated in an external combustion chamber. This offers a high flexibility to use different fuel types, including bio-fuels or solar radiation. Small Stirling engines for single-family houses are designed for low capital costs and thus achieve electrical efficiencies of only about 10 to 12%. For larger plants, electric efficiencies >24% are envisaged. Stirling engines are in between the pilot and demonstration phase and marketing. First commercial products are on the verge of series production. A number of companies have developed or are developing Stirling engines of about 1 kW_{el} for single-family houses, as this size appears particularly promising for the replacement of boilers in single-family houses. In addition, larger systems are being developed or tested.

In *fuel cells*, the chemical energy of the fuel is converted into electrical energy without combustion, but with an electrolyte which separates hydrogen and oxygen. Fuel cell micro cogeneration units are either based on polymer electrolyte fuel cells (PEFC, also Proton Exchange Membrane Fuel Cell PEMFC) using a thin membrane as an electrolyte and operating at about 80 °C, or solid oxide fuel cells (SOFC) which are high-temperature fuel cells working at 800 °C. Some recent efforts include the development of high-temperature molten carbonate fuel cells for this low power segment. Typically, natural gas is used for fuel cells and converted in a reforming reaction into hydrogen. Micro cogeneration fuel cells are expected to reach electrical efficiencies in the order of 28 to 33%, in the long-term possibly up to 36%. So far it is unclear whether fuel cell systems can achieve the same thermal efficiencies as promised by other micro cogeneration technologies. This is due to the fact that the heat can not be extracted at well defined points in the system, but rather at many dispersed heat sources, leading to higher efforts required for insulation and heat exchange. Despite of considerable research efforts, fuel cells are not yet commercially available.

3 Environmental performance of micro cogeneration

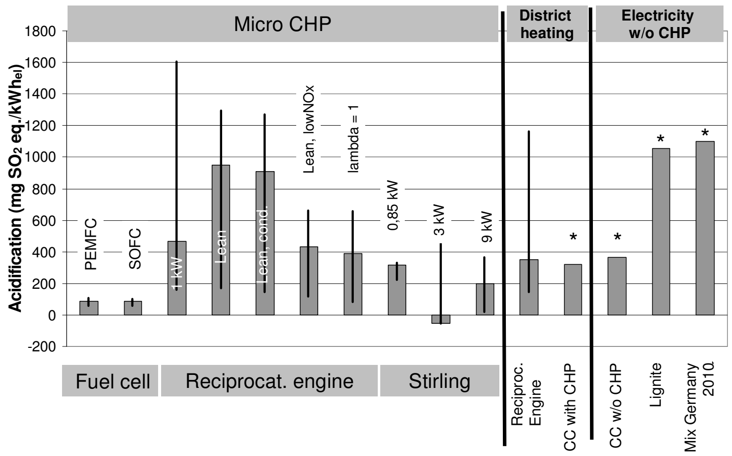
Results of the environmental Life Cycle Assessment at a technology level (Figures 1 and 2) show that micro CHP systems are superior, so far as the reduction of GHG emissions is concerned, not only to average electricity supply mixes, but also to efficient and state-of-the art separate production of electricity in power plants and heat in condensing boilers (η = 0.97). This, despite strong dependence on the electrical and thermal efficiency of micro CHP technologies and the "reference systems" to which the micro CHP system is compared. That means that at an electrical capacity up to 500,000 times smaller than that of large gas combined-cycle power plants, lower GHG emission levels can be achieved, assuming that state of the art gas condensing boilers are substituted. Even larger reduction effects could be achieved if heating systems based on more carbon-intensive fuels, such as diesel oil, were displaced.

Figure 1: Life cycle GHG emissions of micro CHP technologies compared to large CHP and conventional electricity production in the year 2010



Source: Pehnt and Fischer (2006). Functional Unit: 1 kWh electricity at low voltage level. CHP co-product heat is considered by applying a heat credit ("avoided burden"), assuming that a gas condensing boiler is substituted. District CHP with small reciprocating engine (50 kWel) and large gas combined cycle plant. The error bars represent the bandwidth of achievable efficiencies/emission factors depending on the specific application and technical system and on the data uncertainty range.

Figure 2: Life cycle acidifying emissions (NO_x, SO_2, NH_3) of micro CHP technologies compared to large CHP and conventional electricity production in the year 2010



Source: Pehnt and Fischer (2006). For explanations see Figure 1.

The GHG advantages of micro CHP plants are comparable to district heating with CHP. When, due to unfavorable heat integration, the systems only achieve the lower end of assumed total efficiency, however, they come rather close to central production in modern combined cycle plants without CHP.

The performance of micro CHP technologies with respect to climate and resource protection depends mainly on the total conversion efficiency that can be achieved. Under the assumption that gas-condensing boilers are the competing heat-supply technology, all technologies (fuel cells, reciprocating and Stirling engines) are within a very narrow range, with the exception of the Stirling engine with lower electrical and total efficiency. The high electrical efficiency of the large Stirling engine leads to the lowest GHG emissions, while fuel cells reach almost the same GHG emission level when they achieve a total conversion efficiency of 90 %. For reciprocating engines, the values for methane emissions due to unburned natural gas vary considerably. Therefore, the error bar for this technology is larger. Further research is needed in this area.

It is important to note that not only electrical efficiency determines the environmental performance, but also total efficiency (including the thermal output of the system). However, the more complex thermal management and the more diffused heat sources inside the fuel cell system make it more difficult to harvest the heat co-produced in the system than, for instance, in a Stirling or reciprocating engine (Krewitt et al., 2004).

The emission-reduction and resource-protection potential of micro CHP could partially be offset by a "rebound effect". This means that energy savings achieved by a more efficient technology are at least partly compensated, and sometimes overcompensated, by an increase in energy demand. One potential rebound effect may result from the German Energy Savings Decree (Energieeinsparverordnung, EnEV). The decree sets a maximum level for the overall energy demand in new buildings. Building owners who install a micro CHP plant are permitted to apply less stringent heat insulation measures. However, a poorer insulation of buildings has very long-term implications on energy demand, while a micro CHP plant, that has achieved its technical lifetime, may be replaced by a conventional boiler, increasing the energy demand of the building.

A second potential rebound effect could result from behavioral change. A direct analysis of such behavioral change has not yet been carried out for micro CHP. However, from the analysis of energy efficiency and renewable energy technologies it can be gathered that a rebound effect may occur, which potentially foils energy savings through micro CHP. This depends, among other things, on the relevance of ecological norms to the user, on behavioral consciousness, on the degree to which micro CHP possession is perceived as ecologically relevant, and on knowledge of its effects. In the initial market introduction phase, micro CHP is targeted at homeowners, who, in Germany, form a relatively wealthy section of the population. It is safe to assume that the comfort levels of their dwellings are already high. Research on the rebound effect suggests that in such cases a significant increase in energy consumption is improbable (Genennig and Hoffmann, 1996; Haas et al., 1999; Henderson et al., 2003). On the contrary, a positive effect of feedback and increased involvement with energy topics is possible, both with respect to total consumption and adaptation of time-related consumption patterns, which opens up interesting possibilities for load management. This effect depends greatly on the specific form, timing and detail of feedback, and on the presence of other incentives, such as price incentives, importance of independence and ecological motives. It seems advisable to provide information both on electricity production and consumption patterns in the individual dwelling to allow users to compare and match them.

Environmental impacts other than those related to climate and resource protection relate more specifically to technology. Whereas for fuel cells and Stirling engines (as long as these use innovative flameless burner technologies) emissions of air pollutants are extremely low, reciprocating engines emit more significant amounts of NO_x, CO and hydrocarbons. Furthermore, the emission factors of reciprocating engines depend heavily on operation characteristics (lean operation or $\lambda=1$; partial load or full load, etc.) and on the maintenance of the systems (catalyst exchange, engine characteristics, etc.). Thus, larger bandwidths characterize this system (Pehnt et al., 2006).

As a consequence, acidifying emissions of small reciprocating engines (considering the heat co-product) are somewhat higher than those of centralized gas power plants, due to more efficient emission control in large power plants. The significance of pollutant emission reductions not only depends on the absolute environmental impact of the pollutants, but also on the specific contribution to total European emissions, including from other sectors. For instance, only 19 % of European NO_x emissions stem from the "energy industry" sector while the dominant part is emitted by the transport sector. Generally, differences in acidification or eutrophication of electricity generation systems are therefore considered to be of lower overall significance than GHG emission reduction.

4 Economic feasibility of micro cogeneration

The potential for the diffusion of innovative micro cogeneration technologies depends significantly on their economic performance. We therefore assess the economic viability of micro cogeneration plants from an operator's and a societal perspective. The operator's perspectives should demonstrate in which cases micro cogeneration plants could become an economically attractive alternative to other heat generation in a boiler and electricity supply from the grid. Operator's of micro CHP plants may include the building owners, energy service companies or energy utilities. With the societal perspective we want to find out whether and in which cases micro cogeneration is an economically and environmentally beneficial innovation for the society. In the societal perspective, we exclude all subsidies, taxes and levies. We do not include external environmental costs in the calculation of supply costs but calculate greenhouse gas abatement costs to assess environmental benefits for the society. We compare heat and electricity supply costs in three different scenarios:

- In a *reference scenario*, all electricity is purchased from a utility and heat is generated with a condensing boiler.
- In the *micro cogeneration scenario*, the buildings are supplied with heat and electricity with representative micro cogeneration technologies. Where necessary, an additional boiler covers the peak demand of heat. Additional electricity is purchased from a utility and, as electricity generation is at times larger than electricity demand, a portion of the electricity generated by the micro cogeneration plant is fed into the grid.
- In an additional scenario, several buildings are jointly supplied with heat and electricity by *local heat and electricity networks with CHP*. In this case, a CHP plant (with an electric capacity of about 10 to 50 kilowatt) and an additional boiler supply heat to a small district heating network and serve electricity consumers through an own small electricity grid. As consumers may choose electricity suppliers deliberately in liberalized markets, it is assumed that only 80 per cent of the consumers within the supplied area prefer to purchase electricity by the operator of the micro cogeneration plant. In addition, we assume for electricity consumers a discount rate of 5 per cent compared to the market price. Such discounts have been applied by energy service companies in Germany and proved to be a sufficient incentives for most consumers to be supplied by the operator of the micro cogeneration plant.

4.1 Reference technologies

In the following, we select representative technologies and buildings for micro cogeneration application in Germany, describe economic parameters and assumptions, and finally compare supply costs of the different options. We select five reference micro cogeneration technologies that are either already available in the market or that are at an advanced development stage and expected to be brought onto the market soon (Table 1). Due to the high capital costs of fuel cells and high uncertainty with respect to the achievable target cost (Krewitt et al. 2004), we do not include fuel cells in the comparison of economic performance.

Table 1: Economic parameters of selected micro cogeneration technologies

		Reciprocating engines		Stirling engines		
Capacity						
Electric	kW_{el}	1.0	5.0	0.8	3.0	9.5
Thermal	kW	3.3	12.6	8.0	15.0	26.0
Efficiency (seasonal)						
Electric	-	20%	25%	10%	15%	24%
Thermal	-	65%	63%	75%	75%	72%
Investment costs						
Module	EUR	5,700	14,400	4,300	13,300	25,900
Installation	EUR	1,000	3,700	1,200	3,400	5,300
Operation and maintenance costs	$Cent/kWh_{el}$	5.0	2.6	2.0	1.5	1.0
Economic Lifetime	hours	20,000	80,000	80,000	80,000	80,000

The small reciprocating engine of 1 kW corresponds to an engine marketed by a Japanese gas company since 2003 (Honda Ecowill/Osaka gas). The engine is sold together with a boiler and a heat storage tank as a package for about € 5,500 in Japan, but not yet in Europe. The 5 kW reciprocating engine has been sold many times in Germany (Dachs, by Senertec). Various companies are developing Stirling engines of about 1 kW for single-family houses (ASUE 2004). A plant that is expected to be brought onto the market by 2005 has been used as reference technology (WhisperGen, by Whispertech and EA Technology). After completion of field tests in the UK, the British E.ON company Powergen ordered 80,000 engines that should be sold for about £ 3,000 in the UK. This price is used as a reference for the investment costs. The Stirling engine of 3 kW corresponds to an engine developed in Germany by Meyer & Cie. Investment costs are referenced with EUR 13.000 for 2004 (ASUE 2004). The large Stirling engine of 9.5 kW (by Solo) has been sold so about 30 far. Purchase costs are referenced with EUR 24.900 for 2003 (ASUE 2003). Note that some cost estimates are still rather uncertain, in particular the operation and maintenance costs of the Stirling engines.

4.2 Reference buildings

Micro cogeneration technologies can be installed in different residential or commercial properties. The economic performance of the plants does not only depend on investment, operation and fuel costs, but also significantly on the heat and electricity demand characteristics of the buildings. To reflect differences in heat and electricity demand, the economic performance of the reference technologies is assessed in five different existing buildings, representing typical applications in Germany. We consider two single-family houses, two apartment buildings and a hotel. The heat demand characteristics of the buildings are taken from a CHP simulation tool (ZSW 2000). The electricity demand is based on a representative survey of households in Germany (FHG-ISI et al. 2004). Key parameters of the five buildings are illustrated in Table 2 below.

Table 2. Characteristics of representative buildings for micro cogeneration application

		Single-family houses		Apartment houses		Hotel
Heat demand		Low	Average	Low	Average	
Heating surface	m²	131	112	457	913	1,263
Maximum heat load	kW	7	11	23	67	75
Annual heat demand	MWh/a	9	16	29	109	84
Annual hot water demand	MWh/a	2	3	12	19	38
Annual electricity demand	MWh/a	4	3	13	27	49

4.3 Economic parameters

Costs of the different supply options are calculated in 2005 prices, without VAT. Inflation is assumed with 2% per year. Levelized supply costs are calculated for a time horizon of 10 years, from 2005 to 2014. If the technical lifetime of components (boiler, district heat grids) is larger than 10 years, a salvage value is taken into account, which is based on linear depreciation over the technical life time. The nominal rate of return for capital is 8% in calculations from an operator's perspective and 5% in calculations from a societal perspective. Future prices and costs for electricity and natural gas are estimated in own scenarios (Table 3).

Table 3. Average nominal prices and costs for electricity (low voltage) and natural gas

	2005	2010	2015	2020
Electricity consumer prices				
(incl. electricity tax and levies)				
Households (3 MWh/a)	17.2	18.2	19.8	21.8
Commercial users (70 MWh/a)	12.9	13.4	14.5	15.9
Feed-in (CHP bonus until 2014)	8.7	9.2	4.9	5,6
Electricity supply costs				
(w/o taxes and levies)				
Households (3 MWh/a)	11.8	12.5	14.1	15.8
Commercial users (70 MWh/a)	10.1	10.8	12.1	13.7
Natural gas consumer prices				
(incl. gas tax and concession levy)				
Consumers with 50 MWh/a	3.7	4.1	4.6	5.1
Consumers with 300 MWh/a	3.4	3.7	4.1	4.6
Consumers with 1,200 MWh/a	3.2	3.6	4.0	4.4
Natural gas supply costs				
(w/o gas tax and concession levy)				
Consumers with 50 MWh/a	2.9	3.3	3.7	4.3
Consumers with 300 MWh/a	2.5	2.9	3.3	3.8
Consumers with 1,200 MWh/a	2.5	2.8	3.2	3.6

Without VAT and electricity and natural gas tax. - *Source*: Own scenario based on European Commission 2003b; European Commission 2003a; European Commission; Schlesinger et al. 2000; KrziKalla, Schrader 2002; Deutscher Bundestag 2002.

The operation of micro cogeneration plants is promoted by legislation in Germany. The most important effects are

- the exemption from the electricity tax for power plants with an electric capacity below 2 MW,
- the exemption from the natural gas tax for CHP plants with an average energy efficiency above 70%, and
- the payment of an bonus of 5,11 Cent per kilowatt hour for electricity fed into the grid from small CHP plants that are commissioned before 2006.

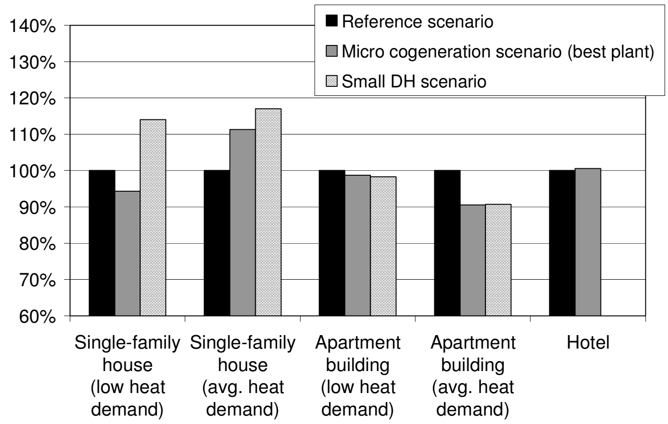
This legislation and other levies are considered in the perspective from an independent operator. In the societal perspective, the economic performance is assessed without consideration of natural gas and electricity taxation, the CHP bonus and any other levies in Germany (concession levy, renewable electricity levy and CHP levy).

A broader diffusion of micro cogeneration can result in economic benefits for the electricity network, including savings of transmission and distribution losses, the deferral of upgrades of the electricity network or the relief of local bottlenecks in the distribution system (IEA 2002). As power from micro cogeneration is mostly consumed on-site and hardly fed into the medium voltage level, it can be expected that micro cogeneration will mostly have positive economic benefits for the electricity network (Arndt et al. 2004). Certainly, by today, these benefits are difficult to quantify. As a conservative assumption, we estimate that with 20% percent of low voltage power being generated by micro cogeneration or other distributed technologies, overall transmission and distribution costs would be reduced by about 5% in the long-run. We consider these economic benefits in calculations from an societal perspective. In the operator's perspective, we calculate with the actual tariffs in Germany, including the CHP bonus (see Table 3 above).

4.4 Heat and electricity supply costs

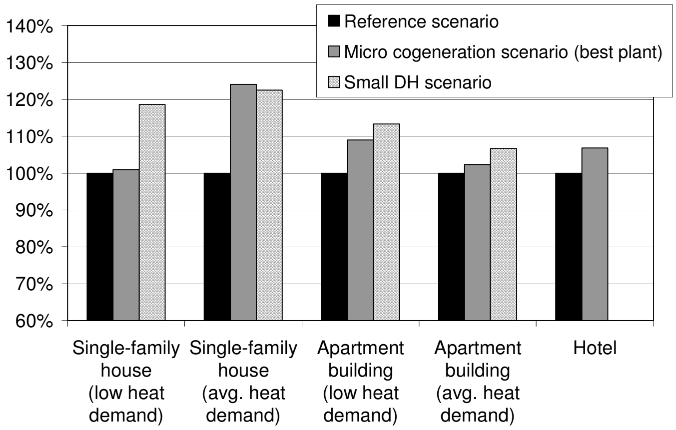
Total heat and electricity supply costs from an operator's perspective and from a societal perspective are illustrated in Figures 3 and 4 below.

Figure 3. Costs of heat and electricity supply from an operator's perspective



Source: Own calculations.

Figure 4. Costs of heat and electricity supply from a societal perspective



Source: Own calculations.

These figures provide some interesting results:

- Micro cogeneration can be economically feasible for operators, but are in most cases not yet economically favorable from a societal perspective. From an operators perspective, the costs of micro cogeneration are similar to or lower (up to about 10%) than the reference scenario. However, from a societal perspective (without consideration of environmental external effects), the application of micro cogeneration is only in the single-family house with low heat demand an economically attractive option.
- From the operator's perspective, micro cogeneration plants are particularly promising when they are able to fully replace boilers. This is the case for the single-family house with low energy demand, where micro cogeneration technologies are able to meet the peak heat demand without an additional

boiler. In case of all other buildings, an additional boiler for peak demand is required next to the micro cogeneration plant, which increases the costs of heat supply.

- Low electric efficiency is not an economic disadvantage for operators of small micro cogeneration plants, as it better reflects the heat and electricity demand characteristics of small buildings, and – more essentially – it leads to significant tax advantages. In Germany, heat generation in boilers is subject to natural gas taxation, while heat generation in a CHP engine with 70% overall efficiency is exempt from natural gas taxation. This legislation cuts particularly the costs of CHP engines with low electric efficiency, reducing marginal electricity generating costs by almost 50% in the case of the small Stirling engine. However, this taxation effect is not environmentally sensible, as the taxation advantage increases with lower electric efficiency. In this light, it may be necessary to reconsider the criteria for natural gas tax exemption in Germany.
- *Small heat and electricity grids with CHP (reciprocating engines) are for operators a good option for apartment blocks, but less appropriate for areas with lower heat density, such as in case of single-family houses with low energy demand.* A major cost advantage of small grids is the significant lower investment costs per capacity and operating costs per kilowatt-hour of larger reciprocating engines. For this supply option, a major barrier is the economic risk that some electricity costumers would prefer to be supplied by other electricity companies. In this case, electricity needs to be fed into the gird, with respectively lower revenues for the operator.

All in all, the analysis shows that micro cogeneration plants can be economically viable for operators, but that the viability substantially depends on the plant type and on the specific conditions of the facility. For single-family houses, replacing a boiler with Stirling engines seems to be an economically attractive option. For apartment buildings, a small heat and electricity grid is likely to be economically the most efficient solution. In the case of hotels and commercial buildings, the advantage of a micro cogeneration plant, compared to the reference case, may be smaller, as such customers enjoy lower electricity prices.

However, the economic attractiveness of micro CHP for operators builds largely on a number of regulatory advantages. This includes the exemption from electricity and natural gas taxation, the payment of a CHP bonus for electricity fed into the grid and the avoidance of concession levies and grid charges for electricity generated on-site. From a societal perspective, without consideration of taxes, levies and subsidies, none of the analyzed micro CHP technologies is yet economically viable. Heat and electricity supply costs are for most technologies substantially higher compared to heat supply by a boiler and electricity purchase from a utility. Also greenhouse gas abatement costs are relatively high, amounting to about 100-250 EUR per ton of CO_2 equivalent. Consequently, investment costs would need to decrease further and efficiencies should be further improved to make micro CHP a viable option from a societal perspective.

5 Dynamics of micro cogeneration diffusion in Germany

Real markets are a complex issue. Institutions, market structures, economic and other interests affect the introduction of a socio-technological innovation like micro cogeneration. As we have shown, the current market share of micro cogeneration is relatively small compared to its potential. In the remaining paper, we explore the apparently unreceptive environment in Germany to date. We look at markets and actors and ask whether – from their perspective – the setting is favorable for introducing micro cogeneration on a larger scale.

The mid- to long-term potential for introducing micro cogeneration strongly depends on the strategic interests and attitudes of the actors which are necessarily involved in a move towards micro cogeneration or even a generally more decentralized generation. Economic viability is one important factor to determine their interests. However, to explain real world decisions about investment in technology development and diffusion, this is not sufficient. Motivations – and also disincentives – stem from several sources. Micro cogeneration potentially affects the economic interests of a number of players; their individual attitude towards micro cogeneration will depend on whether they perceive themselves as winner or as loser of a larger-scale introduction of micro cogeneration.

A first core aspect is the *institutional context* as described above. Institutions matter – this proposition raised by New Institutional Economics theorists is still valid and yet often ignored when trying to explain the function and outcomes of market interactions (Williamson 1985). Indeed, innovative behavior cannot be explained in a satisfying manner without taking into consideration the institutional framework which is shaping it. Institutions are motivating or discouraging action. Vice versa, the actors considered with the respective innovation may also motivate changes of the institutional framework. A second aspect is *cooperation*: The implementation of micro cogeneration entails cooperation between the actors. Some of them are crucial for its implementation, others may be marginal or replaceable. In any case, the functioning, style and forms of cooperation may motivate – or discourage – further engagement in micro cogeneration. A third aspect is *intrinsic motivation and strategic attitudes*: Decision making on future investment and innovation is not purely "rational" but also a function of expectations and risk assessment of individuals within their respective company and industry environment.

These aspects are all interlinked; they build the focus of the following assessment. To derive the eventual prospective for diffusing micro cogeneration, a closer look at the setting, motivations and the resulting strategies towards micro cogeneration is taken. For this purpose, a set of interviews with relevant actors has been carried out and evaluated.[2] Key actors were asked for their attitude towards decentralized energy technologies, cooperation with other actors of the innovation cluster "micro cogeneration", and external factors like the institutional setting which are influencing their attitudes and strategies.

5.1 Energy market setting relevant for micro cogeneration

To sketch the setting of the energy markets as far as it is relevant for micro cogeneration, we briefly assess recent developments in Germany. The EU directive on energy market liberalization led to significant changes in the structure of the German electricity market; effects in the gas market are less momentous so far. In 1998, monopolistic regulation of the electricity supply industry was replaced by competition on all levels. Market liberalization led to substantial changes in the structure of the German energy industry. The market is now dominated by four vertically integrated electricity companies, which also own major gas companies and shares in all levels of electricity and gas supply. This trend towards mergers between gas and electricity utilities is important for the prospects of micro cogeneration; electricity and gas markets are more closely interwoven than they used to be.

All in all, competition on the grid-bound energy market is rather stagnating, and newcomers are rare. Only about 5% of household customers changed their supplier, together with 7% among commercial customers (VDEW, 2004). Liberalization has led to a sharp decrease in electricity prices, which made the operation of existing, and the installation of new CHP plants more difficult. However, electricity prices, in particular for households, have started to rise again and are expected to mount even further over the next few years. In addition, emissions trading is likely to further increase the cost of conventionally produced electricity and thus improve the competitiveness of micro cogeneration due to the higher value of avoided electricity demand.

In terms of policy support for micro cogeneration, German legislation has enhanced its economic competitiveness, in particular by exempting micro cogeneration plants from electricity and natural gas taxation, but also by introducing a bonus for electricity fed into the grid. Thus, after the first shock of liberalization, the general institutional framework for micro cogeneration has improved considerably, which is possibly the major reason for the steady increase in sales numbers observed during the last few years.

5.2 Tackling high transaction cost and small margins

Despite its economic feasibility in a considerable number of cases, and even with the public support schemes listed above, micro cogeneration did not yet take off the ground in Germany. This is essentially a consequence of high transaction cost which are hardly compensated by the small margins that can be gained with micro cogeneration to date. Transaction cost are composed of costs caused by information and search processes as well as negotiation cost until the actual supply and/or service contracts are signed. For Germany, this includes

[2] The interviews took place from June to December 2004 in the form of qualitative, face-to-face or telephone interviews on the basis of a standardized interview guideline The interviewees are senior employees from the micro cogeneration industry, from large electricity companies as well as local / regional energy suppliers and grid owners, and also representatives of the gas industry, third party financing companies, and independent experts in Germany.

- search and evaluation cost, i.e. the cost of assessing the respective heat and electricity needs and of choosing the appropriate micro cogeneration technology.
- implementation and maintenance cost: Micro cogeneration technologies require specific skills and hence supplementary training for technicians. At present, the share of accordingly skilled technicians is relatively small: Firstly, they used to focus on either elecricity or heat supply systems, and secondly, micro cogeneration technologies differ in their engineering and system characteristics, which represents a supplemental challenge.
- negotiations with the grid owner: Connecting a cogeneration plant to the grid costs a fee which is to be paid to the grid owner. It furthermore implies negotiations about the feed-in remuneration, compensation for avoided network grid use, disconnection options for critical load situations and grid bottlenecks, and about tariffs for supplemental electricity purchased from the grid. These procedures were more or less standardized for small cogeneration, however, they remain a source of uncertainty and risk, as will be shown below.
- authorization from the Federal Agency for Economy and Export Control (*Bundesanstalt für Außenhandel, BAFA),* in order to qualify for the bonus payments for electricity fed into the grid as granted by the CHP law. The related administration fee amounts to € 75 per cogeneration unit, which in many cases is hardly compensated by the bonus payments received in one year.
- continuous reporting demands: To receive the ex post exemption from energy taxes, the owner of the micro cogeneration unit has to collect detailed information about the unit, including yearly and monthly input and output data. If not generated automatically, this is a time-consuming task.
- contracts with electricity customers: In the case of apartment buildings, for example, supplemental contractual issues become apparent as the electricity generated in the micro cogeneration unit is supposed to be sold to the tenants. In existing buildings, long-established tenants cannot be obliged to change their supplier in order to buy the "home-made" power. This poses significant risks to the viability of the micro cogeneration unit.
- further legal aspects: In case of third party financing companies, property rights of and access to the micro cogeneration plant have to be listed as easement in land registers. For small micro cogeneration plants this might be a prohibitive barrier, as transaction costs are considerable and as many property owners dislike the idea of easements associated to their properties. Hence, it appears more likely that small micro cogeneration plants are owned by the property owners, while they may be installed and/or operated by energy service companies or utilities. Also, the negotiation of a heat and electricity supply contract with the property owner may cause significant transaction costs for third party financing companies.

Altogether, compared to a conventional heating and electricity supply agreement, micro cogeneration involves a complex and costly procedure which is rewarded very little. Also, the feed-in bonus and other compensations do not cover the electricity generation cost, with the effect that micro cogeneration operators can install plants only in buildings with sufficient electricity demand. As a result, many heat potentials for micro cogeneration without sufficient electricity demand are not used for cogeneration. This applies, for example, to the apartment buildings cited above, where third party financing companies or property owners can not bear the risk that tenants in the building prefer to be supplied by other energy supply companies. High transaction cost and the related institutional setting are therefore a major barrier to the diffusion of micro cogeneration.

5.3 The actor's perspective: strategy, motivation and institutional setting

5.3.1 Micro cogeneration developers

Measured by the number of units sold since liberalization of the energy markets, micro cogeneration actually booms, at least in its niche. The handful of German technology developers and engine building firms engaging in this market experience an increasing interest in their products. Senertec promotes its reciprocating engine named *Dachs* since 1996 and sold its 10,000th unit in 2004. Power Plus started with marketing the *Ecopower* reciprocating engine in 1999 and has been implementing some 1000 motors since. The *Stirling* engine build by Solo has been tested on about 30 locations in Germany so far. A steady increase of sales volumes from the mid-1990ies until now can be observed, with about 50 per cent more plants being installed in 2004 compared to 2002 (Pehnt et al., 2006). Last but not least, various fuel cell developers are still in the process of testing and improving their respective fuel cell designs. A number of units have been installed as part of field trials, among them approximately 100 Sulzer Hexis 1 kW fuel cells, around 20 Vaillant 1 kW units as part of the Virtual Fuel Cell Power Plant field trial, partially funded by the European Union, and some 5 kW units from RWE Fuel cells.

The strategies of these developers are substantially different. Senertec is the most successful and well-known vendor of micro cogeneration units so far – so successful that its production capacities seem undersized: in 2004, the delivery time lag after ordering a *Dachs* amounted to about 6 months. Senertec aims at a production and delivery of 3000 units per year. For this purpose, a sophisticated distribution system was set up, with 30 so-called regional centers all over Germany, and around 280 sales partners with cooperation agreements, as well as framework contracts concluded with energy companies and third party financing companies. The *Dachs* is marketed to household customers with life style brochures, a *Dachs* fan club and so-called *Dachs* parties, i.e. information evenings in the house of a *Dachs* operator for "fans" and potential buyers. Power Plus started later into the market of reciprocating engines and could not copy the *Dachs* success yet with its Ecopower. In the future, they hope to benefit from the established distribution system of Vaillant, one of the large boiler companies in Germany, which purchased Power Plus in early 2004. In parallel, Vaillant also develops its own small-scale fuel cell. Stirling developer Solo operates in a different (non-household) market segment and is still in a testing phase of its technology in which they approach local utilities and other prospective customers. It also remains to be seen whether foreign Stirling firms will enter the German market. First WhisperGen engines are currently being tested in Germany. Their developers are keenly observing the German market, in search for the best starting points for their marketing initiatives.

In terms of their ownership, it is interesting to note that originally independent technology developers like Senertec and Power Plus, and a number of fuel cell developers equally, have been purchased by other boiler or CHP technology firms. In the case of Senertec, the British Baxi Group – also a fuel cell developer – is interested in the elaborated German distribution network of Senertec. Just like Senertec itself, they may argue that the more micro cogeneration is being disseminated – regardless the respective technology or firm – the higher is the recognition in society and thus the chance to sell further units of their own original technology.

The cooperation between traditional boiler companies and micro cogeneration manufacturers appears promising, as micro cogeneration plants could be marketed as a "better" boiler which also produces electricity. Such a marketing strategy may simplify the deployment of micro cogeneration for various reasons. Firstly, consumers are mostly unaware of CHP and often do not properly understand it. However, they could be informed on micro cogeneration plants easily, when they need to replace a boiler and boiler manufacturers also offer micro cogeneration plants. In addition, micro cogeneration is economically particularly promising and much easier to install, if the micro cogeneration plant fully replaces the boiler.

5.3.2 Gas supply industry

Micro cogeneration is mostly fuelled by natural gas. Likely allies and drivers for the introduction of micro cogeneration to the market could hence be found among gas suppliers. Before liberalization, the gas industry has solely been focusing on the heat market. Modern gas-fuelled technologies like the high efficient condensing boiler allowed them to gain an increasing share of the heat market. The image of gas as a clean heating energy, combined with the advantages of a grid-connected energy delivery (no need to order and bunker energy), offer good marketing arguments for acquiring new customers. Today, 46.6% of German private households use natural gas for heating; in new residential buildings, the market share is as high as 75% (BGW 2004). In order to further increase their gas kilowatts sold, gas companies also invested in the development of cogeneration since the 1980s. At the same time, this was a means for entering the market for electricity generation.

Indeed, many gas companies are accurately observing innovation activities with respect to small cogeneration technologies. They check promising technologies – like the small WhisperGen Stirling engine or fuel cells – on location and negotiate framework contracts with engine developers, with the objective to obtain better conditions in terms of unit prices and maintenance service packages. Both sides benefit from this form of cooperation. Some gas utilities make use of their own contracting subsidiary to implement small and medium size reciprocating machines for industrial customers and larger domestic buildings. In other cases, external contractors support implementation.

However, not every gas company encourages small cogeneration. In fact, the ownership structure seems decisive. With its acquisition of the national gas importer and long-distance transport company Ruhrgas, for example, the electricity company E.ON pursues the strategy to gain access to the gas grid and to local heat market. The electricity market, however, is not in the focus, as it is supplied by other E.ON subsidiaries. Other gas supply units are likely to face similar internal strategic decisions. On the municipal level, the picture is more mixed, again depending on the respective business concept (see below the section on local energy companies): Integrated companies will compare the advantages of increased gas sales with the losses through decreasing electricity sales.

All in all, the gas supply industry is indeed a "natural ally" and invests in implementing micro cogeneration as long as it is not constrained by its stockholders or – in case of multi utility companies – by the other business areas like electricity generation. Besides, similarly to the local electricity industry, the gas industry is currently tied up with other issues: Liberalization and regulation of the gas transmission grid are the real issues at stake; micro cogeneration plays a rather subordinated role.

5.3.3 Large electricity companies

Traditionally, the focus of the established large-scale electricity industry has been on larger generation units and a centralized supply system. A certain path dependency in strategic decision management in favour of large power stations may thus be presumed. In an increasingly competitive environment, however, electricity companies would need to carry out substantial changes in their operations and make use of technological innovations. The response of the German electricity industry to liberalization was hence to reduce operating costs including manpower, capital expenditure and routine maintenance.

At the moment, micro cogeneration would need a better economic performance to be attractive to energy utilities and customers equally. In the mid to long term, learning effects and economies of scale could be expected to improve the performance and release a number of advantages that micro CHP may have for large electricity companies. In principle, from an investment and operational perspective, micro cogeneration involves lower incremental and strategic risks because the initial investment is small. Micro cogeneration could be a strategic tool for customer retention and offer attractive business opportunities to energy companies when they shift their profile towards an energy service company.

This argumentative route is currently being followed by E.ON UK, the former PowerGen and UK's second largest energy retailer, which ordered 80,000 Stirling machines with the ultimate objective to equip (and commit them to the energy company) up to 30% of the UK households with micro cogeneration in the year 2020 (WhisperTech 2004). However, the features of the UK retail market differ substantially from the German market, in particular with respect to heating needs – German houses are much better insulated – and to the quality of maintenance services – in Germany, the service network functions well, so that a full-service package is not as attractive to private households as in the UK. This is a major reason for E.ON Germany not to follow the UK example.

At the same time, the development of distributed generation technologies is being well observed by German electricity companies. All major and many medium-size energy companies are involved in developing or at least observing and testing possible micro cogeneration technologies. These activities overwhelmingly focus on fuel cells. RWE has its own subsidiary "RWE fuel cells", E.ON tests small units on location in cooperation with its regional and local subsidiaries, and EnBW checks fuel cells with pioneer operators. Image campaigns support the vision of self-sustaining energy cycles and decentralized power supply. By focusing on fuel cells, all of them advertise decentralized generation as a scenario which will only become relevant in the remote future while they ignore other micro cogeneration technologies which are nearly or already commercially available.

From the perspective of large utilities, this strategy seems consistent. They are not interested in implementing decentralized structures; they rather focus on their traditional path of central generation plants. In parallel, observing the market allows them to participate in a potential niche development and to receive signals of an emerging trend towards decentralized generation as early as possible. For the time being, the utilities avoid the transaction cost which would occur in the case of a too early commitment to decentralized generation structures. All the same, this strategy prevents them from business risks such as losses of revenue to new (decentralized) market entrants and stranded assets in form of under-utilization of their existing assets. In any case, distributed generation is not in the focus of the major companies with regard to the upcoming reinvestment cycle in Germany.

5.3.4 Local energy companies

Other potential allies for micro cogeneration could be expected among the large number of local companies in Germany. Competition with the large, cross-regional energy companies is an explicit challenge for them. Customer retention activities are hence an effective objective on the local level of the German electricity supply system, in particular with respect to medium-size customers like hotels, public baths or small businesses. Local energy companies with both a power and a natural gas grid but little own generation capacities should have good reasons to promote micro cogeneration, in order to increase their sales in natural gas, as gas offers a higher margin. However, the margin is still comparatively small, so that the economic incentives are low to engage in a "new" technology. Some invest for the reasons mentioned above, in particular for customer retention reasons. Altogether, however, only a small share of local energy companies is active in the area of small-scale cogeneration yet. In a survey of investment activities in the field of cogeneration, only 20% of the local utilities answered that they intend to invest in cogeneration smaller than 50 kW_{el}, and some 11% also consider fuel cells as a future option (VKU 2003). An investigation by the consultant Ernst & Young in cooperation with the electricity industry association VDEW among German municipalities stated that 65% of the interviewed decision makers in local utilities consider fuel cells to be a particularly important generation technology of the future, along with cogeneration (58%) (Ernst&Young 2003). Conversely, the future relevance of distributed generation in general is estimated to be comparatively small. This probably reflects a down-to-earth assessment of the market potential of fuel cells and other small-scale electricity generation technologies: Local energy companies regard the operation of fuel cells on a local level as a complement to their bulk energy suppliers, so as to be slightly more flexible. They do not yet see it as a significant building block of their own future distributed generation park. Still, local energy companies currently focus on issues other than on micro cogeneration – the upcoming new regulation entity and the unbundling directive keep them more than busy.

5.3.5 Energy contracting and energy service companies (ESCOs)

In terms of diffusion of micro cogeneration, third party financing or contracting companies as well as ESCOs play a crucial role – their concepts may even be the most advantageous way to introduce it to the market. While most of the actors assessed above have little economic advantages from introducing micro cogeneration, a number of different additional commercial opportunities opens up for ESCOs as operating company of micro cogeneration units. ESCOs – in the denotation used here – are companies that offer energy services to final customers by means of implementing the technology on site and acting as a link to the original supplier of energy (mostly gas or electricity). They are able to overcome typical problems like information and skill shortage, delivery or operation and maintenance risks and the like. They benefit from bundling knowledge and contacts to the relevant administrative and financing institutions and they apply standard contracts and are able to negotiate a quantity rebate with the technology industry. All in all, they are thus able to realize higher margins than individuals in implementing micro cogeneration. It is therefore likely that ESCOs will be not only initial market entrants but also the principle long term players. This may also be an underlying reason for medium- and large-size energy companies to having a subsidiary ESCO company.

5.3.6 Distribution network operators

Distribution Network Operators (DNO) are at the lynchpin of a broader diffusion of micro cogeneration as they are the point of connecting the units to the electricity network. In Germany, the high-voltage transmission grid is owned by the "big four" electricity companies. The unbundling directive requires network operation to become legally independent, and the large companies unbundled their businesses already. However, as long as the ownership structures remain unchanged, the incentives for DNO to act fully independent are small. In fact, DNOs and vertically integrated electricity supply companies in general have often used technical connection requirements to discourage distributed generation (IEA 2002). Jörß (2003) additionally reports procedural prolongations, unjustified financial requests and other negative experiences of distributed generation operators with DNO. These "policies", however, vary considerably from company to company and over time (Jörß, Jorgensen et al. 2003).

With regard to the network operation as such, recent advances in power conversion and information technologies allow for the coordination of a large number of small feed-in points to the electricity grid. A widely decentralized electricity supply may also physically disburden the electricity grid; the diversification of generation feed-in points would theoretically help to improve the quality of supply and to reduce the risk of brown- or blackouts. Network operators may thus see the potential for avoiding investments in grid expansion and upgrading in the mid to long term. Supplemental cost, however, may arise from the need to maintain voltage levels and other technical problems related to large numbers of micro cogeneration in an area.

Economically, micro cogeneration plants reduce DNO revenue without decreasing costs significantly, at least in the short term. Even in a longer term, though, it is uncertain whether cost savings due to deferral of upgrades or capacity reductions will compensate losses of revenue. As regulation of network tariffs will in principle be based on cost recovery, these increased costs per kWh delivered could be compensated by higher tariffs. However, the ongoing discussion in Germany is about how to *decrease* network tariffs, and DNOs may fear that the new regulation office will follow that route and not accept further increases in tariffs. DNOs may also worry that losses of revenue due to on-site power generation are larger than the expected cost reductions in the electricity grid. Besides, the DNO is burdened with keeping the balancing power and reserve capacities. The related costs, again, remain with the DNO and are paid by the remaining customers. The DNO also faces supplementary administrative costs, related to the German feed-in and compensation system for electricity from CHP (and renewables). The DNO is responsible for paying the CHP law bonus to the owner of the micro cogeneration unit, and then applies for compensation from the respective balance area.

Altogether, to date, there are no incentives for a DNO to support micro cogeneration. The issue of economic incentives for decentralized generation in general should therefore be taken into account in the regulation of DNOs (Leprich 2004; Leprich and Thiele 2004). For example, an appropriate redesign of grid charges that rewards connecting decentralized generation units may allow to remove the existing disincentives.

5.3.7 Consumers and customers

To justify their disinterest in promoting distributed generation systems, energy companies argue that small and private consumers, albeit fascinated by the fancy or "high tech" fuel cell, are not interested in on-site cogeneration yet. Indeed, as has been demonstrated, the German electricity and heat retail markets follow different routines as – for example – the UK. Supplier change rates are small, and full service packages are not as attractive. Also, Germany has an elaborated system of service companies to maintain the existing boilers, and customers are usually not particularly interested in installing a new technology as long as the old technology is still running well and when economic advantages are not significant. Only a comparatively small number of consumers conscious for environmental and critical about market power of the large energy companies may value micro cogeneration as a contribution to a decentralized and environmentally sound energy supply. In general, however, the size and the respective economic attributes of micro cogeneration technologies do not suit to individual private households yet.

No technology can succeed in the market without taking user or consumer perspectives into account. In particular, *pioneer* users play an important role in the diffusion of new technologies by testing them and giving feedback to manufacturers, by spreading the word and acting as multipliers. An assessment by Fischer (2005) reveals that pioneers of micro cogeneration come from a well educated, established middle-class population with good income. Their lifestyles are rather traditional, they are usually families living in their own houses in rural areas or small towns. Their education is very often of a technical nature, spurring interest in new technologies. Striking is their relatively high age and the almost complete absence of female pioneers. Pioneers are environmentally conscious and show a keen technical interest, hoping to solve environmental problems by means of innovative technology. They trust their own ability to solve technical and environmental problems and want to make their own contribution. Many of them already possess "green" energy technologies like solar heat or heat pumps, or efficient household appliances. These technologies might serve as a "door opener" for micro cogeneration. Even Pioneers wish their home energy system to be cost-effective, reliable, and user-friendly, at least in the long run. In these domains, they spot deficits in fuel-cell-based micro cogeneration. They are willing to give an immature technology a chance, but strongly point to the necessity to remedy the deficits in order to reach a mass market. Other micro cogeneration technologies might perform better in this regard; but, on the downside, especially reciprocating engines are sometimes perceived as being "dirty". Pioneers tend to be very positive about their technology, willing to promote it and function as communicators and multipliers. We suppose they are successful in doing so, because they are well integrated and respected in their respective communities (Fischer 2005).

Restrictions to the adoption and promotion of new micro cogeneration technologies, such as fuel cells and Stirling engines, are uncertainties about cost and performance. Helpful tools to overcome these barriers are reliable information, especially personal experience, contract arrangements, and support schemes. However, to convince other target groups, massive technological development to increase reliability is necessary as well as cost reductions. Today, the area of larger apartment buildings, hotels, public baths, and other small businesses appears to be a more promising market for micro cogeneration. Here, energy and heat demand reach levels in which energy service packages are attractive for both sides the energy supplier and the customer, and in which third party financing subsidiaries and independent contractors and energy agencies find an attractive – albeit niche – market for implementing micro cogeneration.

5.4 Barriers and measures for disseminating micro cogeneration

In the literature on systems of innovation, three fundamental functions of an appropriate institutional setting for innovation diffusion are usually distinguished: they ought to reduce uncertainty, to manage conflicts and cooperation, and to provide incentives (Preissl and Solimene 2003, p. 27). In other terms: Good institutions reduce the existing transaction costs and risks of the real-world context. They should help to overcome informational barriers to the implementation of novelties, they help to handle contractual issues, and they stimulate the respective markets and thus market introduction by setting the right incentives.

Our case study for micro cogeneration has shown that the institutional setting does not meet these functions yet. A number of institutional and regulation aspects would have to change if micro cogeneration is to gain a significant market share. *First*, uncertainty in terms of implementation procedures and economic risks involved by investing in micro cogeneration is still high. Bonus payment and the obligation to accept electricity fed into its grid are supportive, however, a number of contentious issues with respect to technical and administrative details of grid access create uncertainty, and the related transaction costs are an effective barrier. Both the administrative and network connection procedures would need to be standardized and transparent. Moreover, to reduce information and search cost, micro cogeneration would need a broad spreading of authoritative and independent information about products and systems. *Secondly*, there is no sufficient management of conflicts yet; negotiations are bilateral, and court decisions are an expensive way to regulate conflicts. This specifically concerns the relationship of potential micro cogeneration operators and DNOs. Even with the new German regulatory body it is not certain whether the DNO will have a sufficient incentive to foster distributed generation. Even with a regulator, the prevailing ownership structures to which all DNO belong, are still unfavorable for micro cogeneration. The large energy companies are likely to make use of their market power, while small independent generators do not have the financial background to survive long legal disputes. Here, the *complete* unbundling and implementing an independent system operator for the transmission grid may be the best solution, combined with a regulation of grid use tariffs and procedures that gives sufficient incentives to the DNO to connect decentralized generation (Leprich and Bauknecht 2003; Leprich 2004). *Thirdly*, the economic incentives are comparatively small for inducing actors to invest in micro cogeneration. Here, economic viability and creating a level playing field for different sustainable technologies are the issue. If government intends to foster an on-site, decentralized energy supply, it would have to improve the framework conditions so as to make it more attractive for potential investors.

On the other hand, any further increase of feed-in remuneration and other support schemes for micro cogeneration should also consider effects on alternative technologies for a sustainable energy sector transformation. It would not make sense to foster micro cogeneration at the expense of other, more sustainable energy technologies such as district heating or thermal solar collectors, when the latter are more suitable from both the economic and ecological perspectives. Most notably, only highly-efficient cogeneration should benefit from the exemption from natural gas taxation; this should be accounted for in the next revision of the German law on mineral oil taxation. Currently, public support schemes provide a number of economic incentives for micro cogeneration (exemption from natural and electricity taxation, CHP bonus, grid charges, concession levies), whereas public support for – for example – thermal solar collectors varies strongly between regions in Germany. Future German policies towards sustainable energy systems (i.e. public support programs, the revision of the CHP law) should therefore aim at providing a consistent framework, i.e. to supply similar support for technologies with similar environmental benefits.

6 Conclusion

The framework for micro cogeneration has changed considerably in the past years in Germany: A number of new technologies such as Stirling engines are emerging which are expected to be brought onto the market in the next years. Although liberalization has lowered electricity prices, regulatory reforms such as electricity and natural gas taxation or the law to promote CHP provide substantial economic incentives for micro cogeneration. The installation of micro CHP plants is already economically viable in many cases but often impeded due to disincentives which originate from the institutional setting and cause high transaction costs.

Micro cogeneration could become particular attractive in single-family houses, where the cogeneration plant could fully replace the boiler. However, from a societal perspective, micro cogeneration is not (yet) beneficial. With some technologies, energy savings and emissions reductions as compared to separate generation of heat and electricity are still limited, due to their low electric efficiencies. To make micro cogeneration a beneficial innovation for society, investment costs need to be further decreased and energy efficiency should be increased, for instance by using the latent heat in the flue gas.

In addition, the setting of the market, i.e. the network of actors involved in implementing micro cogeneration in Germany is not favorable. Besides the micro cogeneration developers themselves, only parts of the gas industry and some third party financing or energy service companies are interested in fostering micro cogeneration. The natural gas industry is interested in micro cogeneration – as long as it is not owned and dominated by the electricity industry. The electricity industry follows its traditional path of central electricity generation. Local utilities see some potential in distributed generation; yet, a clear strategy towards fostering micro cogeneration could not be found. Distribution network operators (DNOs) currently do not have much of a motivation to facilitate distributed generation, as the existing economic (dis)incentives and ownership structures do not provide incentives to connect distributed generators. DNOs may become new incentives to facilitate the connection of micro cogeneration depending on the evolution of an incentive-based regulatory scheme by the new German regulator. In any case, there are currently only few incentives and thus drivers active in introducing micro cogeneration, so that it is likely to remain for some more time in its market niche.

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