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Explaining the lack of dynamics in the diffusion of small stationary fuel cells[1]

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Abstract:
Using the reaction of hydrogen with oxygen to water in order to produce electricity and heat, promises a high electrical efficiency even in small devices which can be installed close to the consumer. This approach seems to be an impressive idea to contribute to a viable future energy supply under the restrictions of climate change policy.
Major reasons currently hampering the diffusion of such technologies for house energy supply in Germany are analysed in this paper. The barriers revealed, include high production costs as well as economic and legal obstacles for installing the devices so that they can be operated in competition to central power plants, beside others in tenancies.

Keywords: fuel cell; diffusion process; valuation of environmental effects; technological innovation
JEL classifications: K12,O33,Q51,Q55

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1. Introduction

The technical principle of the fuel cell was discovered in the early 19th century and has been applied since about 1960 in US aerospace projects. Using electricity and heat directly produced during the reaction of hydrogen and oxygen to water, suggests a simple, efficient and environmentally friendly methodology for cogeneration.

However, although technologies for the application of fuel cells for mobile and stationary energy supply have been developed for several years yet, the devices are still in the pilot phase. This includes the application of small stationary fuel cells (SSFC) for house energy supply via combined heat and power production which is particularly interesting because of the large heat market in that area, the technical possibility to build small fuel cell devices with high electrical efficiency, and the required replacement of aged power plants within the next years representing about one third of the installed electric power in Germany.

In the following, the reasons for the lack of dynamics in the diffusion of SSFC plants are analysed interdisciplinarily, mainly in the case of Germany, by taking relevant environmental, economical and legal aspects into account.

2. An interdisciplinary methodology of technology assessment

The question why fuel cell technology is entering contemporary systems of stationary electricity and heat production so slowly – despite of its potential for energy efficiency –clearly is an *interdisciplinary* one. As explained in this paper, related obstacles turn out to be technological, economic and legal problems. These barriers have to be overcome in order to improve the environmental quality of future energy supply by introducing fuel cell-based systems, among other environmentally-friendly options. Finally, appropriate and reliable solutions are to be worked out with respect to the relevant levels of political decision making and acting, thus enabling their implementation.

Following this outline the core disciplines are: engineering, economics and jurisprudence. They should be complemented by sound competences covering necessary sustainability issues and related policy aspects as well as profound experience in technology assessment (TA). The latter is indispensable because interdisciplinary work requires specific methods and structures which will improve *appropriate integration* of the above-mentioned disciplines (Decker and Grunwald, 2001). The successful integration promises additional cognitive and practical benefits for the excellence and meaningfulness of the interdisciplinary effort instead of merely adding disciplinary views as a whole with low coherence and possibly inconsistent results.

Other central prerequisites of interdisciplinary work are *excellence* and *neutrality*: The regular study work should be based on efforts by relevant experts that are preferably renowned scientists from universities and independent research institutions. Nevertheless, this experts approach may be blamed for being blind for public demands, especially by advocates of participatory TA (Aune et al., 2002; Simonis et al., 2000). However, many participatory TA projects often suffered from specific structural and methodological deficits, thus leading to poor results with short-lived validity (Hanekamp, 2001; Gethmann, 2002). Instead, the relatively long amortization periods of energy infrastructures and possible locked-in dilemmas of the future require sufficient orientation on mid-term to long-term scales as well as forward-looking decisions on related energy questions. Therefore, the authors pled for an *experts approach*, in this field, promising high levels of *trans-subjectivity* of overall study results, thus fostering their justification – especially in the long term (Gethmann, 1999).

Moreover, interdisciplinary work in the demanding contexts of technology assessment aims at evaluating the chances and risks of research and development for the society. The consulted experts should therefore be also able to take up perspectives beyond the scientific horizon in favour of the applicability or connectivity of results with respect to corresponding decisions of the actors. This *trans-disciplinary perspective* can be reached at best by experienced experts having a sufficient overview. Finally, the constitution of a corresponding experts group necessarily demands for ability and willingness to cooperate from each group member. The chosen experts are expected to both find interest beyond their disciplinary scope and to tolerate discussions of their own propositions and methods. Finding and obligating the "right" experts is thus a sensible part in preparing an interdisciplinary project which might determine about its later success.

The constitution of related *interdisciplinary working groups* provides the appropriate means to enable the above-mentioned integration of the relevant disciplines. Its effectiveness depends highly upon the achievement of tight meeting cycles which allow for iterative development and refinement of propositions by the project group. So it can be reasonably expected that the developed propositions turn out to become increasingly adequate and meaningful to scientific policy advice. Supporting procedures like regular external reviews by independent external experts or boards as well as discussions of interim results by means of dedicated workshops and scientific conferences lead to further *quality enhancement* of the final study results with respect to their validity to the society.

Finally, urgent questions on favourable technologic developments require early scientific assessments of today's chances and disadvantages of emerging technologies. Thus, organizing the efforts of technology assessment in terms of *temporary projects* makes sure that the results will be available for policy advice in a reasonable period of time. They may contribute to rational choices on options like the application of fuel cells and virtual power plants as contribution to a future European power supply.

3. The technical efficiency and environmental potential of the SSFC

Fuel cells provide a very efficient conversion of primary energy to electricity by using the electricity flow in the reaction of hydrogen with oxygen to water, the so-called reverse electrolysis of water. During the process, for efficiency purposes the heat produced should ideally be consumed close to the devices, e.g. for the house energy supply.

While in future new central fossil power plants may show efficiencies of about 46 to 48 percent (coal and lignite) and even up to 58 percent (natural gas), the typical electrical efficiency of small fuel cell systems is currently at about 30 percent, aiming at about 35 percent. However, using additionally the thermal energy in the flue gases, for fuel cell types working at high temperatures, electric efficiencies of up to about 60 percent could be reached, even for small devices designed for households – SSFC (s. e.g. Ceramic Fuel Cells, 2009). Furthermore, future central power plants using fossil fuels will prospectively require a capture and storage option for CO_2 which will reduce the electrical efficiency by about 10 percentage points. Anyhow, the main advantage of producing electricity in the object is that the devices can easily be integrated into the house energy system to heat rooms and water. In this way a total energy efficiency (electricity and heat) of up to 90 percent can be achieved. Compared to other so-called micro-CHP, like motor-powered micro-CHP and stirling engines, especially the electric efficiency reached is much higher (Droste-Franke et al., 2009). This is an important advantage of fuel cells, as the typical heat demand of buildings will decrease in future and electricity is an energy form of higher quality than heat, because it can easily be transported and transformed into all other forms of energy without any major losses.

In order to analyse the environmental performance of small fuel cell devices, the whole energy system needs to be taken into account. Thus, the analysis is subdivided into the performance with respect to two aspects: firstly, the provision of energy for specific supply tasks in defined objects and, secondly, the production of one kilowatt hour of electricity in comparison to other technologies. The assessment is based upon results from detailed life cycle analyses carried out by Krewitt et al. (2004). In the evaluation, impacts were considered which have been identified to be the most important regarding energy conversion technologies: both, effects due to climate change and due to the pollution of the atmosphere. The bottom-up methodology of impact pathway assessment, starting from emissions, estimating concentration increases, applying concentration-response functions for effects and using specific monetary values is followed which has been developed within the EU funded ExternE project series (European Commission, 2004).

As a consequence of restrictions in the data for human health effects it had to be assumed that the major effects are caused by fine particles, which was supported by earlier estimations (e.g. European Commission, 2004, Droste-Franke, 2005). Further restrictions in the available data on emissions required assumptions for the impact of different types of secondary particles built through chemical reactions with emitted gases in the atmosphere which are set in a way that the results represent upper values. An overview of the concentration response functions and monetary values applied here can be found at EcoSenseLE (2009). Climate change effects were valued with 70€/tCO_2 as best estimate supplemented with 20 and 280€/tCO_2 for the sensitivity analysis based on Krewitt and Schlomann (2006), Downing et al. (2005), and Watkiss et al. (2005). To estimate ecosystem damages, a value of 1,800 €/t$SO_{2\ equiv}$ was derived from avoidance costs estimates (Amann et al., 1998, Droste-Franke et al., 2006). Damages due to acid rain on materials and agricultural crops are estimated to be only about 390€/tSO_2 for Germany (EcoSenseLE, 2009) and were only considered in the upper value of the sensitivity analysis.

One main result of assessing environmental damage costs for specific supply tasks was that fuel cells with current efficiencies but a higher lifetime of 40,000 hours would perform well, even if natural gas was used. In general, three operation modes can be distinguished: following the heat demand of the object, following the electricity demand of the object, and following externally set schedules. From the perspective of the environmental performance, the fuel cell heating plants should be operated following the heat demand of the object, because in that case most electricity is produced and, as a consequence of this, most electricity from the grid is substituted which was produced by means of facilities having worse environmental performance than the SSFC.

FIGURE 1 OVER HERE

The results of the calculations per kilowatt hour electricity produced for the best estimates are shown in figure 1. SSFC perform similarly to motor-powered micro-CHP and stirling engines, better than fossil fired central power plants, but worse than technologies using renewable energy sources. This ranking does not substantially change with the sensitivity analysis of the evaluation of impacts due to climate change. Estimates for carbon capture and storage (CCS) technologies adjusted to the valuation applied here with about 1.7 to 2.5 cent/kWh_{el} are in the same range as for micro-CHP devices. However, air pollution damages for these technologies assessed to about 0.8 to 1.4 cent/kWh_{el} are much higher and even dominating the results which were estimated to be 0.10 to 0.15 for SSFC (s. figure 2) (Friedrich, 2008).

FIGURE 2 OVER HERE

The competitiveness concerning greenhouse gas emissions in the context of agreed targets for CO_2 reduction is essential for the future viability of SSFC. In comparison to heating systems this may already be lost in 2015 due to efficient heat pumps and increasing renewable energy in the electricity mix. Regarding the production of electricity, as long as the heat of at least one central power plant is not further used, small fuel cell systems are competitive with respect to greenhouse gas emissions. Is the heat of all fossil plants used, the efficiency of the SSFC needs to be higher than that of the other power plants (Jungbluth, 2007). If CCS is applied in all plants, the fuel applied for SSFC has to be switched from natural gas to renewably generated combustibles to remain competitive to the central power production. However, it has to be decided whether advantages of CCS technologies concerning greenhouse gas emissions outweigh the disadvantages in the protection of ecosystems caused by air pollution and other environmental effects.

Due to the analysis of environmental effects, SSFC can be implemented competitively if they are generally operated according to the heat demand of the supply object and are able to replace at least a share of central fossil power capacity.

4 Obstacles for the fuel cell

4.1 Network aspects and resource problems

Network aspects

Due to physical requirements concerning the stability and curve of voltage in order to keep minimum quality criteria so that the electrical current can still be used for devices e.g. in households, in- and output of electricity into the grid have to be equal at any time. In order to ensure this equality, the input of electricity is mainly managed on so-called balancing energy markets.

The following aspects should be provided by balancing the flows of current (Handschin et al., 2003, Franz et al., 2006): overall safety, keeping the voltage level, and keeping the ideal course of voltage. These should be guaranteed even if the input from peripheral plants is increasing.

In order to assure human, grid and technology safety, recent protection concepts need to be updated because changes in load and direction may disturb the technical activation processes for the respective protection measures. Furthermore, isolated networks may occur and may even be intended, but are currently not considered in the safety concepts.

Concerning the voltage level legally defined ranges need to be kept. For this purpose, typically at the transformer from the medium to the low voltage level, the voltage is set to a value slightly higher than the value which is targeted at the consumer. In case peripheral plants feed electricity into the grid, the voltage level will increase at the consumer and thus, the maximum value could be exceeded at the transformers. This problem can already occur with a small number of facilities, specifically in regions with low current capacity. The situation can be improved by providing idle power in the plants themselves as well as by regulating voltage automatically at the transformers or at the inverters of the individual devices oriented at the actual load and feed-in situation.

Deformations in the voltage course can be avoided by using intelligent inverters. Furthermore, the provision of short-circuit power can help to stabilise the grid. Most of the measures for grid stabilization can be provided by technical upgrades in the grid infrastructure and at the facilities. However, a provision of idle power in a correct way and well-directed in the short term requires a specific operation concept for the individual plants. If this is provided, the maximum electric capacity which can be installed at a certain location of the grid can be increased and, thus, the grid can be stabilized. Therefore, decentralized power plants like SSFC will rather support than hamper a secure grid operation, if they are installed accordingly.

The balancing energy markets in Germany are installed and organized on the level of transmission networks and subdivided into three sub-markets, primary, secondary and tertiary or minutes reserve. The most promising market for SSFC is the one for minutes reserve, because power needs to be initialized only within 15 minutes which has been proved to work with SSFC (European Commission, 2005), and the announcement is only one day in advance (ÜNB, 2007). In order to supply energy on the balancing energy market, a prequalification procedure has to be passed. One major barrier in this area is the minimum power of +/-15 MW which has to be guaranteed for a duration of some hours (VDN, 2007). The requirements can be met by combining thousands of small SSFC together with larger CHP in a so-called virtual power plant. However, in contrast to central power plants, these devices feed electricity into the distribution grid and, therefore, technically it could make sense that a share of the balancing energy is traded at the same place without the long way round over the transmission grid. Thus, electricity fed into the distribution grid by small fluctuating renewable energy sources could already be balanced close to the sources. Furthermore, other grid services for the distribution grid should adequately be compensated for. Legal regulation exists and seems to be sufficient, however, markets have not yet been developed so far. How this development could be stimulated adequately without installing organizationally inefficient structures requires further analysis.

Resource Problems

With respect to applied energy resources, SSFC are very flexible in general. Several fuels can be reformed to hydrogen automatically at high temperatures in the fuel cell or by means of additional devices, depending on the type of fuel cell device applied. Beside natural gas also biogas and hydrogen as well as liquid fuels like methanol can be used, requiring the respective specific equipment, of course.

In contrast to the flexibility in fuels, certain materials are currently required for the production of SSFC. If these are not managed sustainably, production could become more expensive or economically unfeasible in future. Rare materials used in SSFC are listed in table 1 with decreasing material intensity, i.e. material applied per kW_{el}, per reserve availability and per lifetime of the plant. The most intensively used material is yttrium oxide. The second highest material intensity (zirconium oxide) is at a factor of ten lower than this. Rough estimations on the basis of international statistics and projections (IEA, 2007, VDEW, 2007) show that with a provision of 1 percent of the world-wide electricity consumption in households by SOFC heating plants, the share of yttrium oxide resources used for these SSFC would exceed 10 percent in about fifty years.

TABLE 1 OVER HERE

The situation is more severe concerning the reserves-to-production ratios of the applied material. Particularly, yttrium and manganese show high decreases between 1996 and 2008 for the reserves-to-production ratios (s. figure 3) which Steger et al. (2005) defined as indicator for non-sustainable resource use. Most of the other materials also either show high decreases or low levels of reserve-to-production ratios. The reserve-to-production ratios of chromium, zirconium oxide, copper, manganese, nickel, and yttrium are below or at about 60 years. This value is seen as particularly critical, because approximately that duration will be required to restructure an energy system which was called by Steger et al. (2005) “time of safe practice”.

FIGURE 3 OVER HERE

Further criteria for the usability of materials are absolute prices and relative price changes. The development on the market shows that especially platinum group metals show very high prices. The highest price changes between 2001 and 2006 were observed for nickel (460 percent) and copper (350 percent). An increase in prices of more than 100 percent was observed for bauxite, chromium, iron, manganese, platinum, and zirconium oxide. To a large extent these have been generated by strong demand in the so-called BRIC-countries: Brazil, Russia, India, and China. High regional concentration in reserves as well as in delivery and production contributes to uncertainties concerning the economic availability of rare materials. Following the literature, past problems were discussed particularly in the context with Russia, China, Ukraine, Pakistan, and India (Behrendt et al., 2007). Large regional concentrations of reserves in only two countries of 86 to 98 percent can be found for chromium, lithium (China: 13 percent), and platinum group metals (Russia: 9 percent). With respect to the delivery and production chain a concentration of 72 to 99 percent is observed for platinum group metals (platinum: Russia: 13 percent; palladium: Russia: 44 percent), zirconium oxide, and yttrium (China: 99 percent). For palladium additionally about 50 percent of production and delivery is performed by only one Russian firm (Norilsk Nickel).

By applying the indicators concerning the change in the reserve-to-production ratio and the critical limit of “time of safe practice” designed for the evaluation concerning sustainable resource use, none of the material is currently managed sustainably. Yttrium and manganese are particularly critical with this respect. Concerning potential problems through high prices or high price changes and high concentration of reserves or delivery and production, primarily, again yttrium but also platinum group metals have to be mentioned. Before planning with the technology of SSFC in the long run, high recycling rates or the development of unproblematic substitutes for these materials, particularly for yttrium should be aimed at.

4.2 Market imperfections, joint products, multiple markets, complementary systems, multiple networks, and environmental externalities

If an innovation is technically and perhaps economically efficient and possibly environmentally preferable it should enter and penetrate the market. If it does not, an explanation for this requires some resort to the analysis of market imperfections – market power, ill-defined property rights and uncertainty-insurance problems from incomplete markets – which may delay diffusion (Arrow, 1962) in our case in regard to the stationary fuel cell. Alternatively, one may want to cast into doubt the efficiency of the technology for reasons to be specified. We will discuss both classes of reasons in this sub-section[2].

Market power

Energy systems are currently highly centralized in the sense that a few power stations provide electricity for many firms and households. In some countries (like Germany and the UK; see Brown et al., 2007) the state of (de-)regulation is such that there are regional monopolies of electricity supply with or without competitive fringe. Besides the legal situation large scale technologies may support monopolistic situations, because only a low number of firms can get into the market (Horstmann and Markusen, 1992). In contrast, stationary fuel cells could produce electricity in private buildings, each on a small scale, and deliver electricity supply in a highly decentralized way (see above and also Hendry et al., 2007). If access to the electricity network is free this supply could undermine the monopoly of current suppliers. Of course, current

[2] We will not discuss practical management problems that can easily be solved like informing customers although we have discussed them broadly in our project (Droste-Franke et al. 2009).

monopolists may not be interested in this competition and therefore may not be interested in support for the diffusion of the fuel cell – unless other reasons exist and prevail – and may try to raise costs of producing or using fuel-cells.[3] Their impact on political developments may therefore be a barrier to the diffusion of the stationary fuel cell.

The amount and timing of electricity supply of many fuel cells can be coordinated through virtual power stations (see section 3). In case monopolists can get a grip on these virtual power stations or a monopoly on crucial parts of their components, a situation of bundling may happen to occur. This monopoly could possibly be used to block entry of virtual power stations jointly with that of fuel cells. Alternatively, it could be used to get a monopoly on the electricity supply from fuel cells. However, these are only theoretical possibilities for which there is little evidence so far. If there are local monopolies for the supply of gas, they also may be interested in the application of fuel cells and getting an impact on their market.

Property rights

In regard to ownership of innovation, property rights are by-and-large well arranged in developed countries. Those in regard to environmental issues are often not well arranged. If a technology can help solving an environmental problem whereas a property rights solution remains imperfect, subsidization may be justified in order to compensate for the contribution to the environment.[4] In regard to CO_2 environmental policy has installed the European Union Emission Trading System (EU ETS), but so far this covers only industry and electricity production and not other sectors like traffic and households. The fuel cell has the advantage of being very efficient in its use of natural gas and therefore may emit less CO_2 than other techniques (see section 3). If used with hydrogen this advantage would be even larger. If used with biogas it can help resolving some waste problems. Moreover, it produces less noise and vibration (Brown et al., 2007). Thus, subsidies would be justified for environmental reasons. In

[3] Partnerships with utility companies mentioned by Hendry et al. (2007) do not predetermine strategic behavior in any way.

[4] Subsidies are price measures though and their effectiveness is limited by the implied consumer rents (see Kemp, 1995, 230-2).

case of the fuel cell the interviews carried out among industry firms in Germany[5] during our project (Droste-Franke et al., 2009) indicate that a lack of subsidization is not seen as a problem by fuel cell developers and therefore not a barrier for the diffusion of fuel cells.

Denied free access and contracting of CHP technologies could be a serious entry barrier for the fuel cell (see section 4.3 for an extensive discussion).

Uncertainty-insurance problems

Uncertainty about the success of research and development cannot be insured because of the obvious hazard of effort reduction. The remaining risk would then provide an incentive to reduce research and development activity and its financing to sub-optimal levels. Instead, subsidies to research and development activities can provide the required additional incentive that drives the activity to the desired level. As stated above, a lack of subsidization is not perceived to be a problem in Germany because of specific legal regulations (see section 4.3.) and available research subsidies.

Lack of technical and economic efficiency

An obvious direct reason for a lack of diffusion is a too high market price, which may stem from too high costs, including fixed and upfront costs. Interviews with practitioners in our project (Droste-Franke et al., 2009) emphasize that the stationary fuel cell is simply too expensive. Beside others, the best mixture of components has not yet been found. Costs of the production process themselves may decrease according to the concept of learning curves.[6] In spite of the installation of some hundred systems in the USA and Japan the PAFC did not get down sufficiently much in units costs and industry concentrated more on the PEMFC in 2000 and the SOFC in 2002.[7] Since 2004 PAFCs have new components and lower replacement costs (Hendry

[5] Fuel cell research in the Netherlands has moved to mobile fuel cells using hydrogen in the last decennium (Suurs et al., 2009).

[6] For products that are not yet on the market estimation is not possible and therefore parameters of other products must be used (see Taanman et al. 2008). For recent development regarding learning curves see Cantono and Silverberg (2008).

[7] Many more have been installed in mobile devices like boats, caravans, special bikes, etc. But these niche market segments are not the topic of our paper.

et al., 2007).

Besides the technical mixture of components their prices matter, too. Our analysis of resources used in components of the fuel cell discussed in section 3 shows that some of these resources are likely to become fairly expensive in the future, because they are also demanded strongly by other production processes. On the other hand, not only direct costs and component prices matter but also price developments related to competing technologies do. Oil price increases will be more damaging to other technologies and therefore support the diffusion of the fuel cell. In case of carbon pricing (the EU ETS or carbon taxes in Norway, Switzerland and soon probably also in France), if small stationary fuel cells or natural gas as fuel are included, increasing prices for tradable CO_2 permits will be a disadvantage for them in comparison with wind and solar energy unless it is driven by hydrogen generated from renewable energy sources, but an advantage in regard to oil and coal driven technologies unless the latter use carbon-capture-and-storage technologies. Therefore it is unclear whether pricing of carbon contributes to the limited success of the fuel cell. Here is an obvious overlap between property rights issues (see section 4.3) and resource prices (see section 3) with the economic aspects of this section.

A third reason for a too high price of the fuel cells is the compatibility in regard to several aspects of complementarities. The reason is that due to the cogeneration of heat and electricity the fuel cell provides joint production, it serves two markets and the corresponding technical systems, it is linked to two networks because it needs network connections for gas inputs and electricity outputs, and it has several environmental externalities (CO_2, NO_X, SO_2). Moreover, high costs for one of the joint products imply high costs for the other. Price policies of firms have to take the effects on both products into account. The prospects of the fuel cell depend on all circumstances in regard to its own markets, networks and environmental externalities, but also those of all competing technologies as well as all related environmental, energy and technology policies which have an impact on its price relative to that of other technologies. For example biomass-driven technologies have benefited strongly from the absence of environmental policies in Indonesia which allow for cheap production of palm oil[8]. All of this is important for innovations because in order to get selected they must fulfill these compatibility requirements.

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[8] Palm oil also serves several markets (food, energy, wood), is linked to two complementary systems (land ownership, slash and burn), several networks (food and wood trade transport, electricity), and several environmental externalities (water use, CO_2, methane, crowding out of other crops).

On the other hand, innovations in one aspect make innovations in complementary aspects more profitable.

One further complementarity is that among fuel cells themselves. Coordination of the energy supply from many fuel cells through virtual power stations may reduce the costs and fluctuations of energy and heat production.

A shortcoming of the fuel cell currently is that in the chain from production to the use of hydrogen there are large energy losses of about 79% indicating that the price of electricity inputs in the production of hydrogen has to be about one fifth of that from the electricity produced through the burning of hydrogen in the fuel cell. This lack of being economically efficient in regard to the environmentally preferable hydrogen use is a serious drawback for the attractiveness of the fuel cell. One idea to get such cheap electricity as input of hydrogen production is to use wind energy at times with little electricity demand and correspondingly low spot-market prices employing wind-hydrogen-system techniques, stationary or mobile ones (e.g. on a ship).

For the time being technical efficiency problems, the expected development of resource prices, and some features of the law discussed in the next section seem to be more important than market imperfections. Once they are solved it remains to be seen whether entry problems with or without relation to monopolistic market structures play an important role.

4.3 Legal barriers

The legal framework conditions in Germany with regard to the diffusion of small stationary fuel cells is influenced by numerous legal aspects and regulations passed by various governmental bodies such as international law (in particular the UN's Kyoto protocol), European[9] and German environmental and energy laws, state law and even municipal building law. These will be analysed with respect to potential barriers in the following.

[9] In December 2008 the European Community concluded a new "green package" and passed directives regarding renewable energy (2009/28/EG), emissions trading schemes (2009/29/EG), geological carbon storage (2009/31/EG) and a decision to curb greenhouse gas emissions by the member states (406/2009/EG).

Governmental Funding Systems

In principle, a lack of subsidization does not seem to be an obstacle for the diffusion of fuel cells, because of the various subsidizations, which were advanced through the enactment of the Meseberger-climate decisions recently this year. The facility operator is entitled to feed electricity into the nearest low-voltage grid and the network operator is obliged to pay a minimum payment for this input. The payment for electricity fees can be carried out according to the "Act to protect the Generation of Electricity from Cogeneration Facilities" as amended (KWKG, 2009) or, if regenerative fuels are used, according to the "Renewable Energy Sources Act" as amended (EEG, 2009). The KWK-bonus which is a part of the feed-in-reward pursuant the KWKG is now independent of feeding the electricity into the national grid so that producers get the bonus also in case of self supply. Still that bonus has an overall cap (ca. € 600 Mio)[10] which has often been criticized.

The expanding of the promotion of CHP plants leads to a set of legal and policy problems with respect to the constitutional financial system (cf. Salje, 2008), an equitable and consistent legal system, interdependency with other governmental funding systems and the market distortions they could produce, which requires further analysis. Further regulations that are important here are the electricity and energy taxes (eco taxes) and their exemptions, the Act on Granting Priority for Renewable Energy Sources for Heat Supply (EEWärmeG), the Act on Energy-Saving Buildings (EnEG), the Emissions Trading Act as well as investment incentive programmes (e.g. KFW-Programm). Furthermore, obstacles include the complexity and hassles of the regulation system (Ekart and Heitmann, 2009) and more importantly the absence of harmonizing the exemptions of energy and electricity taxes (Otto and Krzikalla, 2004) such as income taxes and the turnover tax.

Problems in law of tenancy

Germany's tenancy law poses a serious barrier for the distribution of fuel cells and other micro-CHP facilities, especially for the allocation of costs and benefits of such an investment in climate protection as well as the current formulation of typical tenancy agreements and conditions.

[10] Recapitulatory: Beschlussempfehlung und Bericht des Ausschusses für Wirtschaft und Technologie zum dem Gesetzesentwurf der Bundesregierung eines Gesetzes zur Förderung der Kraft-Wärme-Kopplung, BT-Drucks. 16/9469, S. 11.

Particularly in the rental housing market there are miscellaneous barriers for the installation of stationary fuel cells. These are very important in consideration of the fact that the vast majority of Germans lives in rental housing (Ekardt and Heitmann, 2009).[11]

With respect to the *heat supply* of multi-family homes, it is important to clarify the extent to which investment and operation costs can be allocated between the tenant and the landlord in the pertinent order ("Heizkostenverordnung" ─ ordinance on the allocation on heating costs). Currently this must be negotiated between the contractual partners. Thus, legal uncertainties do exist representing the first barrier. The second one concerns questions and legal restrictions regarding the *electricity supply* of multi-family homes by the landlord through the use of fuel cells: The landlord has to establish an electricity supply contract with every tenant[12] and all other duties as any "normal" energy supplier pursuant the Energy Industry Act (EnWG) along with accompanying statutory orders.

The third barrier for fuel cells with respect to the tenancy law concerns the allocation of investments and operation costs in the case of an ecological modernization of an old building with fuel cells. The landlord must pay the costs of investments up front while the tenant benefits from lower operation costs usually paid by him. The questions discussed are whether a conservation of primary energy is adequate to constitute a claim to increase the base rent even if it does not save any costs to the tenant (§§ 554, 559 BGB) (Börsinghaus in Schmidt-Futterer, 2006, § 559, Rn. 80). This dispute seems to be clarified recently by a judgment of the Federal Court of Justice (BGH, 2008) in favour of the exclusive conservation of primary energy. A legal clarification would be helpful to avoid residual legal uncertainties. The next important point would be to clarify which investment costs can be allocated to calorification and thereby results in base rent increase pursuant to § 559 BGB. [13]

A further set of questions and barriers in regard to tenancy law is posed by the transfer of the fuel-cell plant operation to a special (non-utility) firm providing this service (contractor) that supplies the heat and electricity to the tenant for a value typically including all operation costs

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[11] The situation and the legal barriers are very similar in the case of freehold flats.

[12] Some producers have designed model contracts for their customers.

[13] In the literature both the uncertainty and the time of the amortization (mind. 10 a.) result from the claim pursuant § 559 BGB not to give any incentives to the landlord to invest in energy-saving modernizations.

and corporate profits. Considering the organizational efforts required to allocate and implement micro-CHP facilities in multi-family homes for the transfer of heat and electrical supply, a contractor would seem to be the most efficient solution, particularly if they are to be integrated into virtual power plants. As seen above, from the environmental perspective, this is the preferred operation mode. The implementation of such services involves a highly procedural effort with many legal uncertainties, not only regarding tenancy law, especially in older multi-family homes (Hack, 2003). Despite a judgment of the BGH (2007) considered as seminal in the German “Contracting-Industry”, several unsolved legal questions remain. The detailed nature of the terms in the tenancy agreement required to authorize the landlord to replace the heat supply without abating the base rent remains to be clarified, particularly with regard to older leases.[14]

Network aspects

Access to the electricity network free of discrimination is a basic requirement for the diffusion of small stationary fuel cells. CHP-facilities are entitled to a preferential connection to the nearest low voltage grid (§ 4 KWKG) and to feed their generated electricity into this grid at any time. If the grid capacity is deficient, the grid operator must expand the network immediately.

Some literature (Krewitt et al., 2004, Brandt et al., 2006) expresses doubts about free access in the future for cases of insufficient grid capacity based on the mechanism of capacity distribution by the “priority principle”[15] according to the KWKG and the preference of electricity from renewable sources. In the amended EEG 2009 this system has been replaced by a new “feed-in-management” which currently applies only to plants with a rating higher than 100 kW, but indicates the legislative approach to this problem. According to the management system, CHP- and regenerative energy facilities are equivalent. The feeding-in limitation is affected due to pending grid overloads and concerns the main polluters only, independent of any principle priority. If this is applied, the grid operator is still obliged to pay the feed-in-reward deduced by the saved expenses of the CHP-operator. This creates some new problems for CHP-facilities such as compensation for atypical damages (e.g. backup heat supply of a tenant, customer claims for heat due to non-performance). Furthermore, this “feed-in-management” is not equivalent to

[14] Furthermore, the judgement regards in this case a kind of communal heating.

[15] Priority of the plants that are connected earlier.

the virtual power plants concepts described above. The function of the feed-in-management system is to ensure the network reliability merely until the network expansion is complete. The well-established mechanism currently in place may prove to be a barrier for virtual power plants and thereby for FC plants in the future. According to the current status, the KWKG and EEG have several components that may establish micro-CHP-facilities primarily as individual plants and thus may hamper realization of virtual power plants (Droste-Franke et al., 2009)[16.] One essential issue for the diffusion of fuel cells is the design of the regulation of utility grid access fees. A frequently disputed question in this context is the design of incentive regulations so as to exclude incentives that discriminate local generators by introducing appropriate regulation of cost-plus and incentive elements as well as elements of quality regulation (Bauknecht et al., 2009). Furthermore, the realization of benefits from grid management through the integration of micro-CHP-plants may be perceived by the grid operator as an option that can only be attained by the regulation of access fees. Essential issues in this context include "quality regulation" and the avoidance of grid access fees if the transmission grid is not used (Droste-Franke et al., 2009). In this subject further analysis is required.

5. Policy Recommendations and conclusion

The analysis of the lack of dynamics in the diffusion of SSFC devices integrated over relevant scientific disciplines reveals the following aspects which should be considered for their further technological development and market implementation:

- Significant cost reduction must be achieved for SSFC plants. Relevant aspects are the mixture of components, the market conditions for rare material required for production and various complementarities.

- Regulations of the tenancy market should be clarified, legal uncertainties should be removed and the operation of SSFC and other micro-CHP as well as the provision of heat and electricity to tenants should be simplified.

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[16] At first the amended EEG 2009 requires wind-power plants to utilize techniques for better grid integration and create an incentive to adduce ancillary services by an "ancillary-service-bonus".

- Funding seems to be sufficient, but the current system supports primarily the installation of individual plants. Further incentives should be given for implementing the facilities so that they can be operated in a coordinated way, e.g. in virtual power plants, and, thus, can be used to provide grid services in competition to central power plants which is recommended from analysing environmental and electricity network aspects.

References

Amann, M., Bertok, I., Cofala, J., Gyarfas, F., Heyes, C., Klimont, Z., Makowski, M., Schöpp, W. and Syris, S. (1998) Emission Reduction Scenarios to Control Acidification, Eutrophication and Groundlevel Ozone in Europe. Report, *22nd Meeting of the UN/ECE Task-Force on Integrated Assessment Modelling*. IIASA, Laxenburg (Austria)

Arrow, K.J. (1962) Economic Welfare and the Allocation of Resources for Invention. In: Nelson RR (eds) *The Rate and Direction of Inventive Activity: Economic and Social Factors. National Bureau of Economic Research*, Princeton/NJ, pp. 609–625

Aune, M., Berker, T. and Sörensen, K. H. (2002) *Needs, roles and participation. A review of social science studies of users in technological design*. NTNU Trondheim

Bauknecht, D., Bokelmann, H., Evers, E., Frey, G., Horst, J., Leprich, U. and Schrader K. (2009) Optimierungsstrategien für Netzbetreiber. *Energiewirtschaftliche Tagesfragen* **59**, pp. 56-58

Behrendt, S., Scharp, M., Kahlenborn, W., Feil, M., Dereje, C., Bleischwitz, R. and Delzeit, R. (2007) *Seltene Metalle, Maßnahmen und Konzepte zur Lösung des Problems konfliktverschärfter Rohstoffausbeutung am Beispiel Coltan.* Texte 08/07, Umweltbundesamt, Berlin

Brandt, M., Frey, G., Gross, B., Kimmerle, K. and Leprich, U. (2005) *Analyse und Bewertung von Instrumenten zur Markteinführung von stationärere Brennstoffzellen*. Endbericht (Projekt Nr. 85/05) im Auftrag des Bundesministeriums für Wirtschaft und Arbeit, Saarbrücken

BGH (2007) Judgment of the 27th of June 2007, Federal Court of Justice -VIII ZR 202/06, Karlsruhe

BGH (2008) Judgment of the 24th of September 2008 - (Federal Court of Justice) VIII ZR 275/07, Karlsruhe

BGR (2007) *Rohstoffwirtschaftliche Steckbriefe für Metall- und Nichtmetallrohstoffe.* Stand 01/07, BGR, Hannover

Brown, J.E., Hendry, C.N. and Harborne, P. (2007) An emerging market in fuel cells? Residential combined heat and owner in four countries, *Energy Policy* **35**, pp. 2173-2186

Buchmann, F. and Hirschmann, M. (2009) Die Novelle des KWK-Gesetzes, *Recht der Energiewirtschaft* **7**, pp. 204-211

Cantono, S. and Silverberg, G. (2008) *A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies*, UNU-MERIT WP 2008-025

Ceramic Fuel Cells (2009) *Achieving 60% Electrical Efficiency.* Status: September 2009.

Decker, M. and Grunwald, A. (2001) Rational technology assessment as interdisciplinary research. In: M. Decker (ed) *Interdisciplinarity in technology assessment*. Springer Berlin/ Heidelberg, pp. 33-60.

Downing, T., Anthoff, D., Butterfield, R., Ceronsky, M., Grubb, M., Guo, J., Hepburn, C., Hope, C., Hunt, A., Li, A., Markandya, A., Moss, S., Nyong, A., Tol, R. and Watkiss, P. (2005) *Social Cost of Carbon: A Closer Look at Uncertainty.* Final project report. Stockholm Environment Institute, Oxford

Droste-Franke, B. (2005) *Quantifizierung von Umweltschäden als Beitrag zu Umweltökonomischen Gesamtrechnungen.* Doctoral thesis (Universität Stuttgart), OPUS Stuttgart

Droste-Franke, B., Bickel, P., Greßmann, A. and Friedrich, R. (2006) *Überblick über den Stand der Forschung zu externen Umweltkosten.* Endbericht zu Baustein 3, FKZ 203 14 127, Umweltbundesamt. IER/Universität Stuttgart

Droste-Franke, B., Berg, H., Kötter, A., Krüger, J., Mause, K., Pielow, J.-C., Romey, I. and Ziesemer, T. (2009) *Brennstoffzellen und Virtuelle Kraftwerke. Energie-, umwelt- und technologiepolitische Aspekte einer effizienten Hausenergieversorgung*. Springer, Berlin Heidelberg
Executive Summary: *Fuel cells and virtual power plants. Energy, environmental and technology policy aspects of an efficient domestic energy supply*. Graue Reihe No. 47, Europäische Akademie Bad Neuenahr-Ahrweiler

Eckardt, F. and Heitman, C. (2009) Energetische Sanierung im Altbestand und das EEWärmeG , *Recht der Energiewirtschaft* **4/5**, pp. 118-126

EcoSenseLE (2009) *EcoSense Lookup Edition v1.3.* Status August 2009, by B. Droste-Franke, P. Bickel, and P. Preiss, IER/Universität Stuttgart

European Commission (2004) *ExternE, Externalities of Energy – Methodology 2005 Update.* EUR 21951, Directorate-General for Research, Brussels

European Commission (2005) *The Virtual Fuel Cell Power Plant, System Development, Build, Field Installation and European Demonstration of a Virtual Fuel Cell Power Plant, Consisting of Residential Micro-CHP's.* Final Technical Report, European Fuel Cell Project NNE5-2000-00208, Brussels

Franz, O., Wissner, M., Büllingen, F., Gries, C.-I., Cremer, C., Klobasa, M., Sensfuß, F., Kimpeler, S., Baier, E., Lindner, T., Schäffler, H., Roth, W. and Thoma, M. (2006) *Potenziale der Informations- und Kommunikations-Technologien zur Optimierung der Energieversorgung und des Energieverbrauchs (eEnergy).* Studie für das BMWi, FhG Verbund Energie, wik-Consult, Bad Honnef

Friedrich, R.(2008) *External and social costs of electricity generation*, presentation 20th-23rd August 2008, Erice

Gethmann, C. F. (1999) Rationale Technikfolgenbeurteilung. In: A. Grunwald (ed) *Rationale Technikfolgenbeurteilung. Konzepte und methodische Grundlagen.* Springer Berlin/Heidelberg, pp. 1-10.

Gethmann, C. F. (2002) Scientific policy consulting and participation. *Poiesis & Praxis. International Journal of Ethics of Science and Technology Assessment*, **1** (2), pp. 151-159.

Hack M. (2003) *Energiecontracting*. Recht und Praxis, München

Handschin E., Horenkamp W., Wiesner T. (2003) *Integrationsprobleme von Brennstoffzellen in elektrischen Netzen.* ETG im VDE, AG V1.1, Dortmund

Hanekamp, G. (2001) Scientific policy consulting and participation. *Poiesis & Praxis. International Journal of Ethics of Science and Technology Assessment*, **1** (1), pp. 78-84.

Hendry, C., Harborne, P. and Browne, J. (2007) Niche Entry as a Route to Mainstream Innovation: learning from the Phosphoric Acid fuel Cell in Stationary Power, *Technology Analysis & Strategic Management*, **19** (4), pp. 403-425

Horstmann, I.J. and Markusen, J.R. (1992) Endogenous Market Structures in International Trade (Natura facit saltum). *Journal of International Economics* **32** (1/2), pp. 109–129

IAEA (2005) *Energy Indicators for Sustainable Development. Guidelines and Methodologies.* IAEA, UN DESA, IEA, Eurostat, EEA Vienna

IEA (2007) *Online Energy Statistics of the International Energy Agency.* Status: 25.4.2007, IEA

Jungbluth, C. H. (2007) *Kraft-Wärme-Kopplung mit Brennstoffzellen in Wohngebäuden im zukünftigen Energiesystem.* Doctoral thesis (RWTH Aachen), Series „Energietechnik“, vol. 59, Forschungszentrum Jülich

Kemp, R. (1995) *Environmental Policy and Technical Change,* Maastricht University Press.

Krewitt, W., Pehnt, M., Fischedick, M. and Temming, H. V. (eds.) (2004) *Brennstoffzellen in der Kraft-Wärme-Kopplung, Ökobilanzen, Szenarien, Marktpotenziale.* Erich Schmidt Verlag, Berlin

Krewitt, W. and Schlomann, B. (2006) *Externe Kosten der Stromerzeugung aus erneuerbaren Energien im Vergleich zur Stromerzeugung aus fossilen Energieträgern.* Expertise in charge of BMU, Stuttgart

Maibach, M., Sieber, N., Bertenrath, R., Ewringmann, D., Koch, L., Thöne, M. and Bickel, P. (2007) *Praktische Anwendung der Methodenkonvention. Möglichkeiten der Berücksichtigung externer Umweltkosten bei Wirtschaftlichkeitsrechnungen von öffentlichen Investitionen.* Research project in charge of Umweltbundesamt, Förderkennz. 203 14 127, FiFo Köln and Infras Zürich

Otto F., and Krzikalla N (2004) Der Einfluss von Steuern, Abgaben und Umlagen. In: K. Schrader, M. Hartmann & N. Krzikalla: *Praxishandbuch der Kraft-Wärme-Kopplung,* Köln

Salje, P. (2008) Möglichkeiten und Grenzen zur Freistellung von eigenerzeugtem Strom von der EEG-Umlage, *Infrastrukturrecht* **5**, pp. 102-106

Schmidt-Futterer, W. (2006) *Mietrecht*: Kommentar, 9. Aufl. München

Simonis, G., Martinsen, R. and Saretzki, T. (2000) Die TA-Landschaft in Deutschland – Potentiale reflexiver Techniksteuerung. *Politische Vierteljahresschrift. Politik und Technik,* Spec. Issue 31/2000, pp. 425-456.

Steger, U., Achterberg, W., Blok, K., Bode, H., Frenz, W., Gather, C., Hanekamp, G., Imboden, D., Jahnke, M., Kost, M. Kurz, R., Nutzinger, H. G. and Ziesemer, T. (2005) *Sustainable Development and Innovation in the Energy Sector.* Springer, Berlin Heidelberg

Suurs, R.A.A., Hekkert, M.P. and Smits, R.E.H.M. (2009) *Understanding the build-up of a Technological Innovation System around Hydrogen and Fuel Cell Technologies*, Innovation Studies, WP 09.10, Utrecht

Taanman, M., de Groot, A., Kemp R. and Verspagen, B. (2008) Diffusion paths for micro cogeneration using hydrogen in the Netherlands. *Journal of Cleaner Production* **16** (1, Suppl. 1), pp. 124–132

ÜNB (2007) *Informationen zu den Märkten für Regelleistung.* Internetplattform zur Ausschreibung von Regelleistung, Status: 30.11.2007, Deutsche ÜNB, Berlin

USGS (2009) *Mineral Commodity Summaries.* U.S. Geological Survey, Reston

VDEW (2007) *Stromwirtschaft nutzt vielfältigen Energiemix. Gesamte Netto-Stromerzeugung in Deutschland in Milliarden Kilowattstunden (kWh).* Appendix to press release, 21st February 2007, Verband der Elektrizitätswirtschaft e.V., Berlin

VDN (2007) *Transmission Code 2007, Netz- und Systemregeln der deutschen Übertragungsnetzbetreiber.* Version 1.1, August 2007, Verband der Netzbetreiber e.V. beim VDEW, Berlin

Watkiss, P., Anthoff, D., Downing, T., Hepburn, C., Hope, C., Hunt, A. and Tol, R. (2005) *The Social Cost of Carbon (SCC) Review – Methodological Approaches for Using SCC Estimates in Policy Assessment.* Final Report, AEAT, Oxon/UK

Table 1 Resource use for the production of different fuel cell power plants (source: Krewitt et al., 2004)

Fuel Cell System	**Used material, ordered with decreasing material intensity**[a)]
PEMFC-micro-CHP	*nickel*, platinum, iron, chromium, manganese, aluminium, copper
SOFC-micro-CHP	*yttrium oxide, zirconium oxide, lanthanum oxide, chromium*, iron, nickel, aluminium, copper, manganese

a) Materials are ordered by decreasing material intensity. Materials with a material intensity larger than the maximum value of other comparable CHP plants are marked in italic.

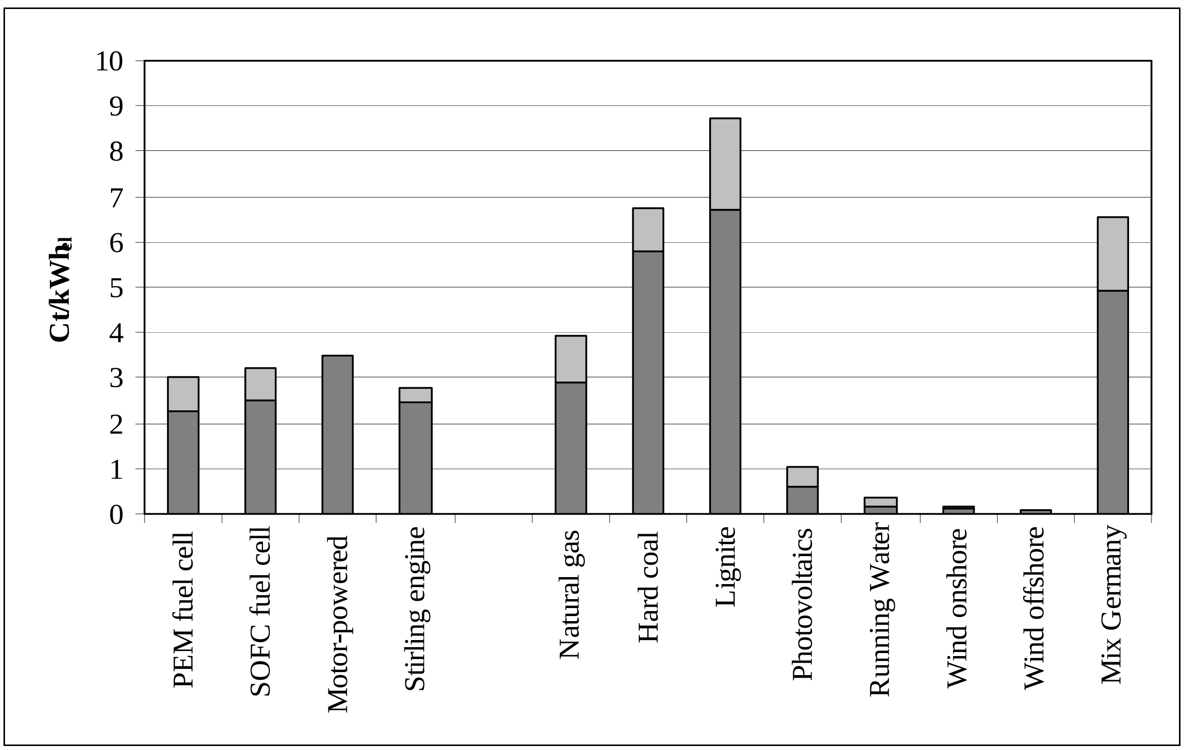

Figure 1 Best estimates of specific environmental damage costs considering *air pollution and climate change* effects from different options of power technologies, the light ranges show variations in technologies (based on Krewitt et al., 2004, Krewitt und Schlomann, 2006, Maibach et al., 2007)[2]

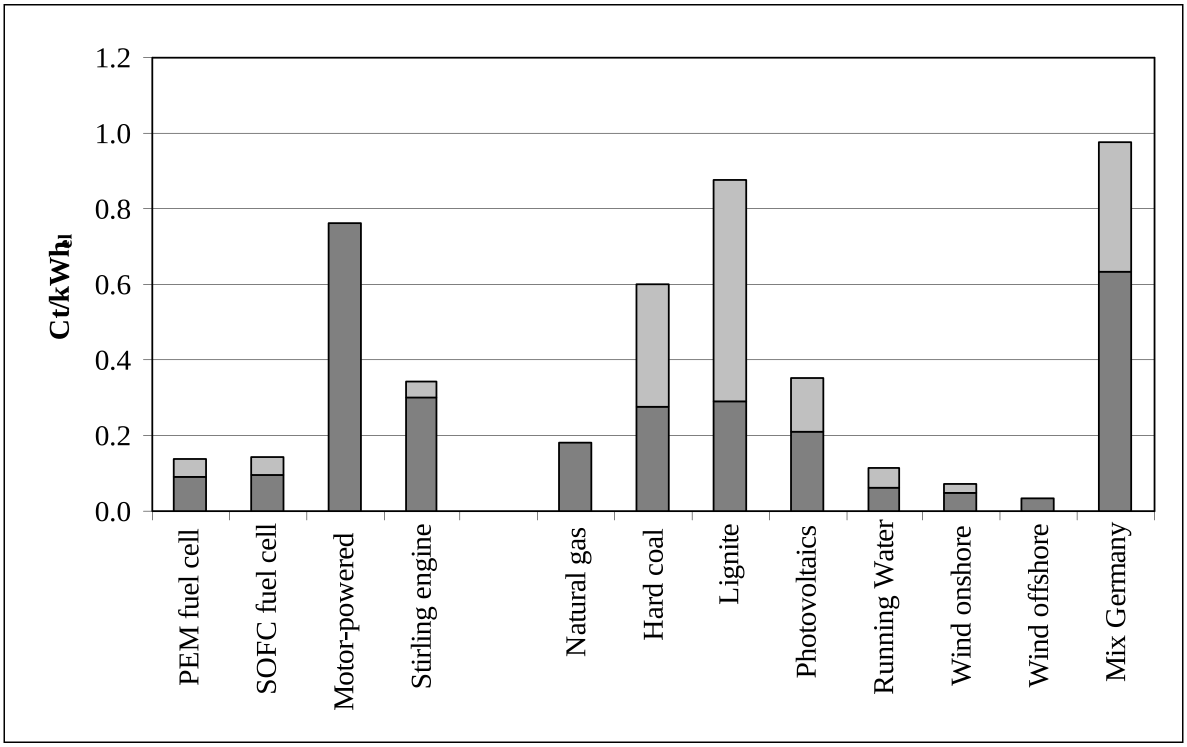

Figure 2 Best estimates of environmental damage costs due to *air pollution* from different options of power technologies, the light ranges show variations in technologies (based on Krewitt et al., 2004, Krewitt und Schlomann, 2006, Maibach et al., 2007) [17]

[17] Low and high estimates are derived from different assumptions concerning energy efficiencies for the various technologies; the electricity mix in Germany is varied as follows: mix 2010 in Germany based on Krewitt et al. (2004) or current electricity mix in Germany with the assumption that nuclear power is assessed like lignite as worst variant concerning external costs remaining in the market.

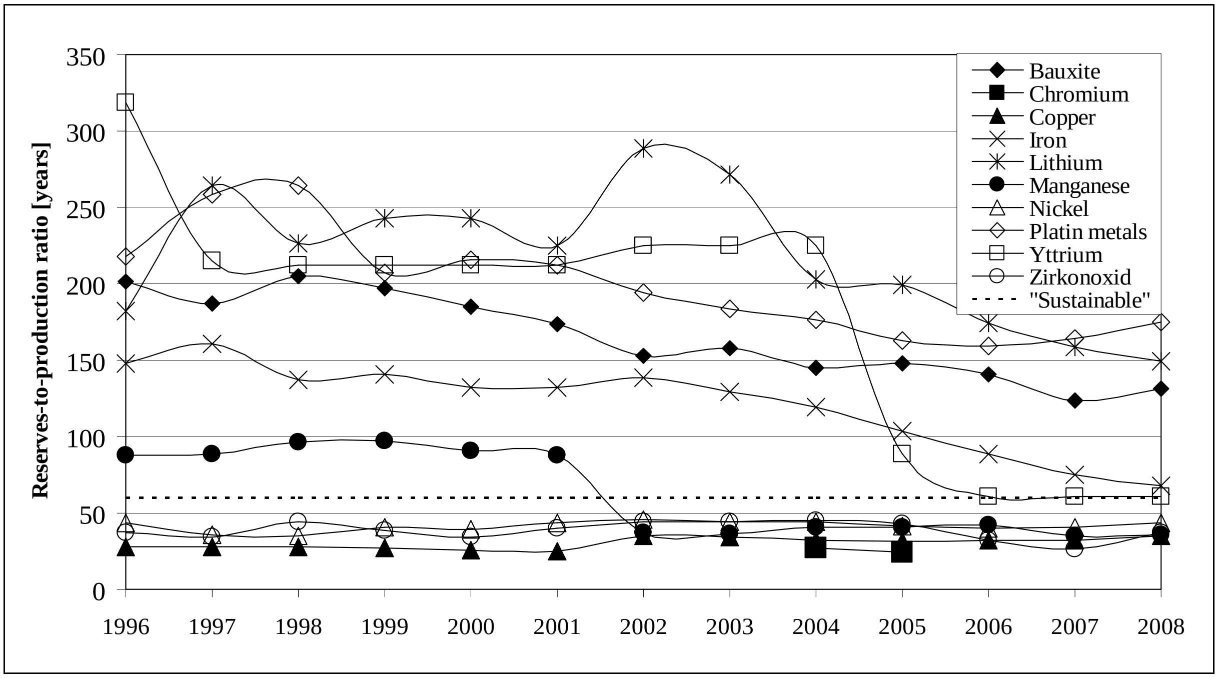

Figure 3 Time series of reserves-to-production ratios and time of safe practice (60 years) named as “sustainable” (source: USGS, 2009)

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