Zur Homepage der Dissertation

Decentralizing Energy Generation - Policy Recommendations for Germany

vorgelegt von

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List of Abbreviations

CCGT	Combined Cycle Gas Turbine
CO_2 equivalents	Indicator for global warming potential, comprising CO_2, CH_4, N_2O, SF_6, PFC and HFC
E&C	Engineering & Construction
EEX	European Electricity Exchange, Frankfurt
I&C	Information & Communication
LDC	Local Distribution Company, "Kommunalversorgungsunternehmen"
LNG	Liquified Natural Gas
NMVOC	Non-Methane Volatile Organic Compounds
NTC	National Transmission Company, "Verbundunternehmen"
OTC	Over-The-Counter, or bilateral deals
PEMFC	Proton Exchange Membrane Fuel Cell
PR	Progress ratio: In the learning curve concept the residual cost after one doubling of cumulated output
RDC	Regional Distribution Companies, "Regionalversorgungsunternehmen"
SO_2 equivalents	Indicator for acidification potential, comprising SO_2, NO_x, HCl, HF, NH_3 and H_2S
SOFC	Solid Oxide Fuel Cell
SOFC ultra	Ultra efficient electricity generation system, combining SOFCs and microturbines and expected to reach electric efficiencies of up to 70%
T&D	Transmission & Distribution

TA Luft	Technische Anweisung Luft
TOPP	Indicator for tropospheric ozone production potential, combining CO, CH_4, NMVOC, NO_x
Ultra DIPP	Ultra-efficient DIstrict Power Plant

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1 Introduction

1.1 OVERVIEW

Deregulation, Yello, micro power, fuel cells, "KWK-Gesetz", "Atomausstieg", Kyoto protocol - the German energy industry underwent significantly more change in the last decade than in all the time since the Second World War. And this could be just the start.

The next 10-15 years will determine if one of the world's leading economies and Europe's biggest energy consumer will be able to re-define its energy industry and use the benefits of innovation in order to combine long-term sustainability with current welfare. And chances are that decentralization plays an important role.

The first part will provide a fact-based evaluation of decentral energy generation from a macroeconomic point of view. Both cogeneration and decoupled technologies will be compared against the most modern incumbent technologies on their economic and ecologic performance. Thereby, five common structural defects of previous studies will be avoided.

The result will look rather different from the recommendations currently articulated loudest.

The second part will analyze the strategic interests of energy players concerning the previously derived technology recommendation applying a game theoretic framework. It will point out possibilities for the state to leverage those private interests in order to implement his technology vision at minimum cost and resistance.

1.2 A FUNDAMENTAL QUESTION FOR HUMANKIND

"Energy" is perhaps the most important notion of the universe. It is one of the three fundamental physical values that always seem to be conserved[1]. Greek for "potency", it measures the ability of a system to work[2].

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[1] Therefore, the term "energy generation" is in fact wrong. Energy can neither be generated nor lost in a narrow physical sense. The popular use of the term energy refers to the transformation of especially chemically stored

It is fundamental to our wealth: One kWh of electricity equals 10 hours of intense human work, but it costs only 15 ct. The same amount of human work would cost at least €150. If we had to pay humans to generate the 48 MWh of primary energy an average German uses per year[3] we would have to pay more than an additional €7 millions per person and year. Cheap energy lets us all live like millionaires!

One the other hand our current way of generating energy is responsible for some of the major harm that affects humans and other life forms on the planet. The associated emissions destroy house facades, churches and monuments. They cause headaches, asthma, skin diseases and cancer. They desolate forests and landscapes, perforate the ozone layer, cause irreversible changes of our climate and devastate entire regions with nuclear radiation.

The question of how to supply every human being with sufficient energy and doing so in a sustainable way is definitely one of the current big issues of humankind, on one level with topics like nutrition, health and education.

1.3 STUDY SCOPE

Energy is often classified into three forms: primary energy, secondary energy and tertiary or useful energy[4].

Primary energy relates to all kinds of energy that are found in nature, both fluent and stored forms. Fluent forms originate from nuclear fusion in the sun, nuclear fission on the earth's core or kinetic energy from the earth's movement and manifest in sunlight, wind, water streams in rivers and seas and geothermal heat. Stored forms comprise fossil or nuclear fuels, biomass or tidal waves.

Tertiary energy is the form that provides the actual benefit to its consumers: light, heat, cold, mechanical energy or electricity used in electric devices like computers.

Secondary energy relates to intermediate forms like diesel, steam and once again electricity[5].

This study is going to deal with heat and electricity. While heat regularly would be classified as tertiary energy form, electricity could be both seen as secondary and tertiary one, being a source for mechanical energy, light, heat and driving electronical applications. More important than being at the same level of a very

---

energy in fossil fuels to other, more useful forms like light, heat or electricity. In following, the term "energy" will be used in its popular sense and especially stand for electricity and heat.

[2] see http://www.agnu-haan.de/993_ene1.htm and [DIT-1], page 3

[3] [BMW-1]

[4] see [DIT-1], page 28f. The entire classification system is not mutually exclusive and can only serve as a broad concept.

[5] Depending on the application, electricity would also be referred to as end energy.

general framework is to assess whether the suggested structure is sufficiently mutually exclusive and collectively comprehensive and to what extent it covers the problem.

Table 1 shows that the structure in this study is indeed both mutually exclusive and collectively comprehensive. The relevance of the study scope will be discussed next.

[GEI-1] structures end energy demand into heat, mechanical energy, light and Information & Communication (see Table 1). As this study regards heat and electricity only and will also concentrate on small applications[6], roughly a third of Germany's end energy demand ends up in the focus (see Table 2).

Electricity will also drive the largest part of non-automotive mechanical energy applications. Furthermore, some of the key technologies to be evaluated are also applicable for industrial purposes. So, another third of the demand is partially affected by this research.

Only the energy demand for traffic is discussed little, though both combustion engines and low temperatures fuel cells are technologies that are and will indeed be used both in automotive and electricity generation. Nevertheless, this study does not contain an assessment of different technologies for the transportation sector.

End energy form	Households	Commercial	Industry	Traffic
Heating	21%	7%	2%	0%
Process heat	4%	4%	18%	0%
Light	0%	1%	0%	0%
I&C	1%	0%	0%	0%
Mechanical energy	2%	3%	5%	30%

Table 1: End energy in scope of study (1/2)

Relevance	Share
Focus	39%
Affected	32%
Apart	30%

Table 2: End energy in scope of study (2/2)

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[6] Households and Commercial

Widening the view from end energy to primary energy, the technologies considered in this study also affect losses and consumption in the energy sector itself. Only the non-energetic energy usage would clearly stay out of scope. So, out of the German demand for primary energy, more than half is clearly under focus of this study and more than two thirds are strongly concerned (see Figure 1).

Limiting the scope of the study to Germany initially might seem a dramatic reduction of significance: Germany consumes only 4% of the world's primary energy.[7] On the other hand, most analyses for Germany are equally valid for other areas with similar climate and settlement structure, for example in Europe or North America.

Secondly, Germany influences the international energy sector far more than with the share of its consumption. Engineering companies like SIEMENS, Lurgi or Enercon, utilities like RWE and E.ON or car manufacturers[8] like Daimler Chrysler, BMW, VW or Porsche have dominant positions in the world's markets. Germany is at the technologic forefront of fuel cells, CCGTs, micro cogeneration, wind and solar power. It therefore could play a crucial role in developing the solutions for the world's energy problems.

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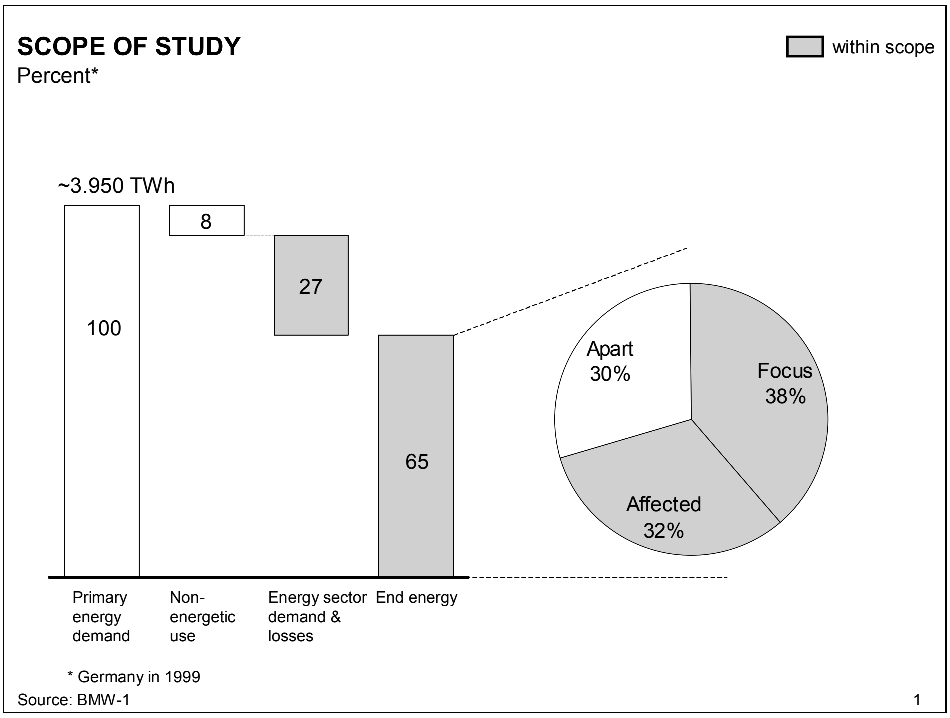
[7] [BMW-1], page 36 for 1997

[8] Car manufacturers are linked to the energy sector in two ways: one, they produce the products that supply 30% of our end energy, second, they develop and build reciprocating engines and fuel cells, that can also be used in other sectors to generate electricity and heat.



* Germany in 1999

Source: BMW-1

Figure 1: Primary energy in scope of study

The following study hence is extremely relevant for the German energy system and beyond that has a wider significance for other energy markets especially in moderate climates.

1.4 A NEW PARADIGM FOR ELECTRICITY GENERATION?

So far, a better ecological performance has been associated with either "bigger" or "more expensive". Three reasons suggest that this might change:

¶ *Technological development:*

Fuel cells are becoming viable for the mass market. They work on a fundamentally different physical principle than current electricity generation technologies and achieve emission levels that are orders of magnitudes lower than for comparable incumbent technologies. They also reach astonishing levels of electric efficiency. Additionally, they have much smaller minimal sizes and scarcely any scale effects in their ecologic performance.

¶ *Business practice development:*

Constantly evolving production technologies, especially the Toyota Production System, have made large-scale production incredibly efficient. Mass production of generation capacity might therefore proof to be more cost efficient than huge power plant projects. Investment cost for power from CCGTs averages to around €500/kW_e. Cost for power from car engines amounts to only €50/kW thanks to a learning curve over hundreds of millions of units[9].

¶ *Tapping into new resources:*

Decentral technologies could tap into new resources free of charge. The waste heat of the transformation process could be used for heating and warm water. And, solar energy locally heating roofs, soil, air and water today could be used as well.

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[9] Of course, regular car engines do not provide electricity, but mechanical energy. Hybrid motors are under development though and the difference's order of magnitude is astonishing.

Decentral technologies might hence succeed to become both less pollutant and cheaper than incumbent, central technologies and change today's paradigm of ever larger plants and extensive distribution systems to a world of small, decentral units.

1.5 HUGE STRATEGIC IMPLICATIONS FOR INDUSTRY PLAYERS

The impact on our current energy industry structure could be huge and certain players seem to be able to profit more on a distributed generation paradigm than others:

- Decentral technologies could reduce entry barriers in terms of know how, capital and regulator relation. This would both raise competition amongst generators and could shift bargaining power downstream.
- Upstream generation and transmission companies would face lower volume due to a higher share of renewables and improved efficiency.
- There also could be more competition between the gas and the electricity grid. Heating can be done using electric heat pumps instead of gas boilers or households could produce their own electricity with natural gas in cogeneration PEM fuel cells.
- The sale of decentral technologies and their maintenance could redefine the relation between retailers and their customers and become an important tool for the acquisition and retention of consumers.

Is a multi-billion € industry worldwide confronted with revolution[10]?

Are there any technologies that mid-term could become both economically[11] and environmentally superior to others?
If so, who would be the winners and losers in the related markets, if those technologies would be widely applied?
And, how can the state support the application of those technologies in a smart way, considering the market players' interests? Or, in other words, are there any innovative policy tools, that are highly efficient, low cost, that increase national welfare and reduce ecologic harm at the same time?

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[10] The magnitude of the implications induced "*The Economist*" to write a cover story on the decentralization of energy generation with the title "The Electric Revolution" [ECO-1].

[11] From a national economic point of view

2 Technology evaluation

A couple of basic innovations and advancements in the field of energy generation are arriving at the market and they do so roughly at the same time. They are based on numerous physical principles, but the electricity generating ones have one thing in common: their minimal size is several orders of magnitude below that of the current central facilities that generate 90% of today's electricity. This smaller minimum size allows those units to be deployed decentrally and therefore to tap into local renewable sources or to use heat that is now wasted.

But also central technologies get steadily improved. They benefit from scale effects both in terms of ecology and economy and they have proofed reliable over a long time.

Is decentral generation better than central one from a national economic point of view? What should be the technologic vision of the German government concerning the generation of electricity and heat? Are there technologies that are both ecologically and economically superior to others?

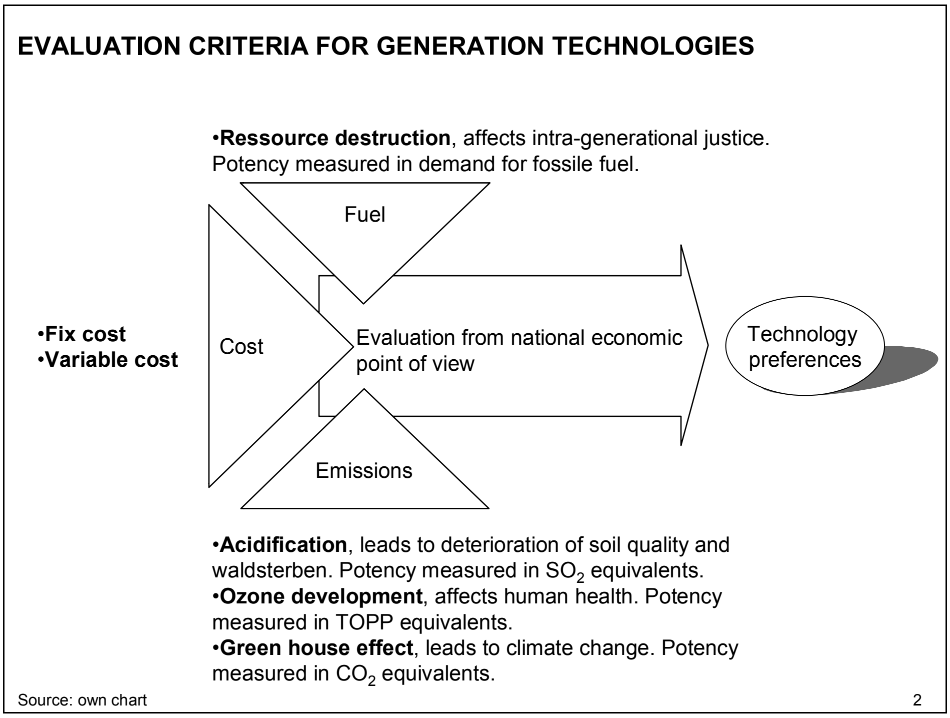
An accurate macroeconomic analysis suggests the support for high-temperature fuel cells and heat pumps. On the other side, the unconditional support for cogeneration technologies does not make sense. Concerning pure renewables, photovoltaics still need research more than market introduction support, but solar thermal collectors could become a viable source of heat.

2.1 EVALUATION CRITERIA

The following chapter will compare energy technologies according to three dimensions: cost, emissions and resource consumption (see Figure 2).

Unfortunately, a lot of analyses were made from a private perspective, but are nevertheless used to evaluate their national economic performance. Others contain systematic errors. So, subsidies and PR worth dozens of billion EUROS are granted based on inaccurate analysis.

A correct macroeconomic analysis has first to carefully identify decision-relevant aspects and second to elaborate the true options to be compared.



EVALUATION CRITERIA FOR GENERATION TECHNOLOGIES

•**Ressource destruction**, affects intra-generational justice. Potency measured in demand for fossile fuel.

•**Fix cost**
•**Variable cost**

•**Acidification**, leads to deterioration of soil quality and waldsterben. Potency measured in SO_2 equivalents.
•**Ozone development**, affects human health. Potency measured in TOPP equivalents.
•**Green house effect**, leads to climate change. Potency measured in CO_2 equivalents.

Source: own chart

Figure 2: Criteria for technology generation

2.1.1 Cost

Energy supply causes cost for fuel, generation, transmission and distribution. Retail costs shall be neglected in this study, as they depend more on the market structure than on the generation technologies used.

Not all cost components are equally relevant for investment decisions, though. Furthermore, the state has a different perspective than private investors.

Hence, some guidelines have to be followed when analyzing relevant cost from a macroeconomic perspective: It should regard cost and not prize, neglect electricity distribution grid fees and avoid certain business ratios. Furthermore, there are some issues about the assessment of labor and capital costs.

2.1.1.1 Cost, not prices

First, it is important to look at costs, not prices. The differences are taxes and margins. Both only have redistributional effects within the same economy and therefore are not relevant for the economic analysis. While taxes can be measured rather easily, assessing margins is generally more difficult. At least, one can assess cost for gas import[12] and electricity generation.

2.1.1.2 The decision-relevant part of grid costs

Secondly, the decision-relevance of grid costs has to be considered carefully.[13] Grid costs consist basically out of construction, maintenance and transport losses. The latter are variable and always have to be accounted for. The other parts are fix and only matter for electricity transmission and gas distribution.

One could argue that grid investments are sunk, once spent, and therefore do not have any decision relevance. Whether the infrastructure is used or not, they never can be recovered anymore, no matter what. In the long run, though, grids have to be maintained and renewed. Those maintenance costs amount to those of complete re-investment over time.

Then, the electricity distribution grid[14] is always necessary in an urban area. Even in the case of decentral electricity generation it is still needed for peak shaving, feed-in of excess energy and back-up purposes. The value of electricity is so high, that you would not risk being without it.

If the electricity distribution grid is necessary anyway, its cost are only decision-relevant if the technology in question would require it to be bigger and therefore more expensive.

This is rarely the case, as grid capacity is normally much higher than the regular consumption and therefore does not need to be increased.[15] Even in that case, the absolute relevance would be little. Bigger grids are only a little more expensive than smaller grids and therefore the marginal grid costs are little.[16] Therefore, electricity distribution does not have to be considered in the macroeconomic cost.

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[12] In reality, there are different import prices for gas that is used for electricity generation and for heating. The figures published by [BMW-1] give a weighted average.

[13] [VDI-1] shows how little politicians often understand of costing and business in general, even in high ranks. Klaus Moeller, the Minister of Energy and Ecology in Schleswig-Holstein is cited, that lots of cogeneration plants would have to stop production, because of competition of conventional plants, that are written off. Capacity costs of existing plants are sunk and hence not decision-relevant. The decision whether to operate them or not is not influenced by depreciation.

[14] medium and low voltage

[15] At least within certain boundaries

[16] At least for grids to be constructed or heavily repaired.

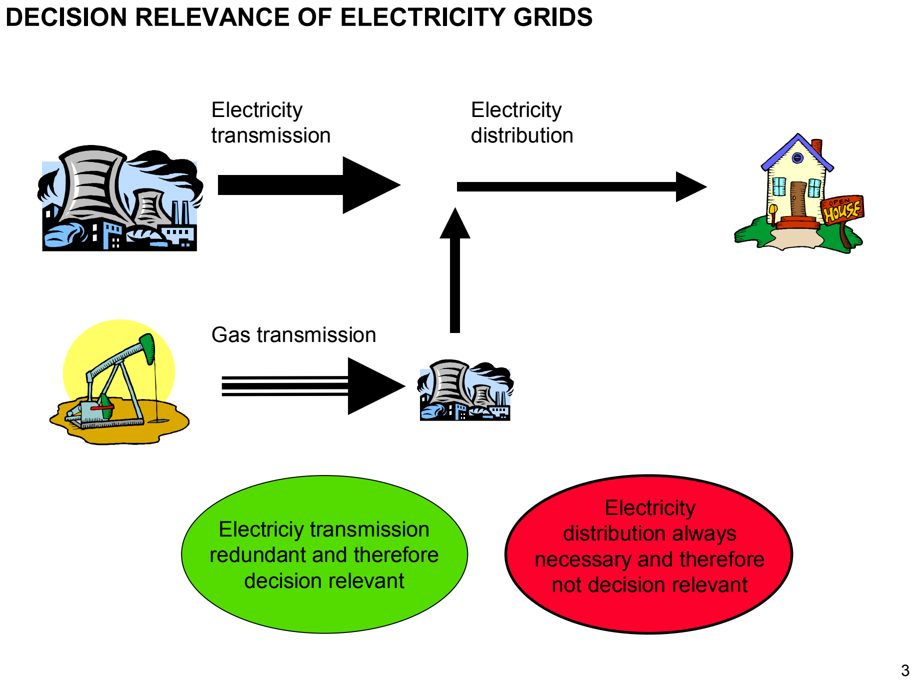

Figure 3: Decision relevance of electricity grids

In contrast to distribution grids, electricity transmission grids[17] are not indispensable, though. They are only needed in central scenarios to transport energy from large central plants to the consumers. Decentral alternatives might generate electricity locally from gas and use micro grids to exchange excess energy between adjacent consumers only[18] (see Figure 3).

The situation for gas grids is opposite. In some way, transmission lines will always be needed. They either transport natural gas to large central plants or to the distribution grids supplying decentral, gas-fired alternatives. Their costs do not have to be accounted for.

The gas distribution grid could become obsolete, though, depending on the amount of heat needed. While little amounts of heat can be supplied by solar energy, using solar collectors or heat pumps, bigger amounts and backup for big consumers has to come from applications connected to gas-, electricity- or district heating grids.

---

[17] high voltage

[18] In most cases, they still would make sense, though, due to their relatively low cost share. Furthermore, without them, regulation and reserve power ("Regelenergie") would have to be provided locally, as well, which would cause additional efforts.

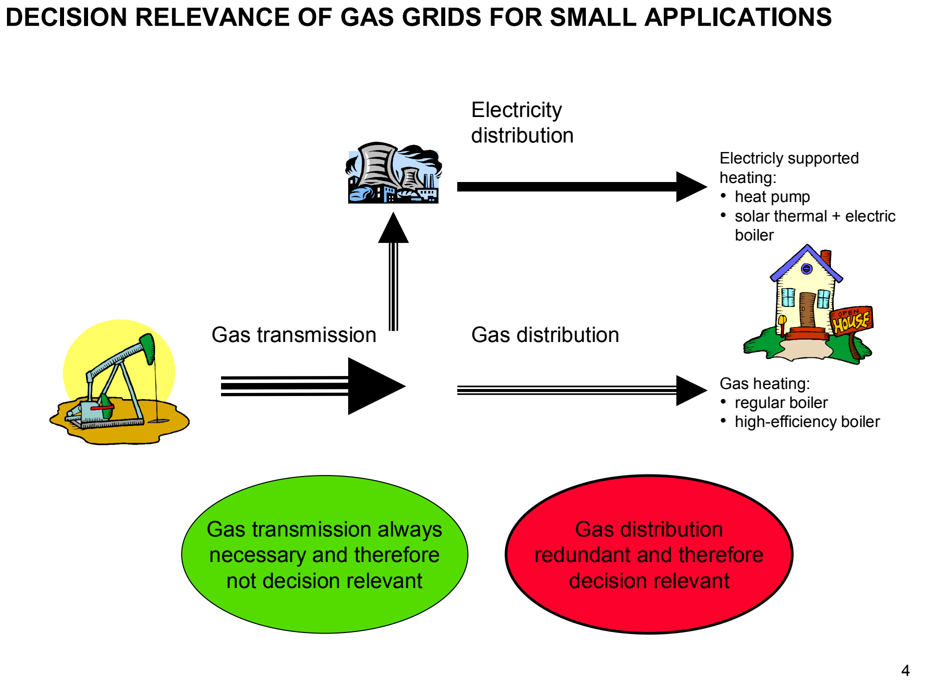

Figure 4: Decision-relevance of gas grids for small applications

Using precious electricity for heating is in most cases neither reasonable from a financial, nor from an ecological point of view. Hence, while most industrial and commercial customers with high heat demand need a gas grid connection, small residential buildings complying with modern isolation standards do not. They can be supplied with warm water, heating and process heat for cooking and baking without a gas grid connection. Then, the costs for a gas distribution grid are decision relevant and have to be accounted for. The height of the cost might be reduced in the future though, as new materials make gas grids less expensive[19] (see Figure 4).

Variable cost for the electricity grid are basically due to transport losses. Those can be roughly neglected for transmission and amount for roughly 5% in the distribution grid[20]. Transport losses in gas grids can be neglected both for transportation and distribution.

Summarizing, only the grid costs that are definitely decision-relevant are those for investment in electricity transmission grids and losses in the electricity distribution system. Then, there are two different cases: one considering gas distribution costs, for instance when supplying small, modern residential houses, and another case, where a gas grid connection is needed anyway and therefore is not accounted for.

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[19] see [SCHM-2]

[20] [DIT-1] estimates 3,5%, GEMIS suggest higher values of around 7%. See also [PFA-6], page 50.

Other grid costs, especially for electricity distribution, must not be considered in a macroeconomic analysis.

2.1.1.3 Investment cost of heating capacity

This thesis discusses four alternatives to heat generation with regular gas boilers. Only one of those, namely high-efficiency boilers, can fully replace regular ones, though. Hence, only one of them gets investment cost credits for replacing regular boilers.

The other, cogeneration units[21], heat pumps and solar thermal collectors, are too expensive to be dimensioned for peak demand. They are also not reliable enough. So, regular boilers are still needed for backup and peak demand.

High-efficiency boilers though can totally replace regular boilers and therefore get a bonus on the full capacity cost replaced.

The other technologies that only partly substitute boilers, only receive a benefit amounting to the marginal boiler cost of the capacity replaced. The marginal cost of boilers is negligible though, due to high economies of scale.

In some cases, though, electricity supported technologies like solar collectors and heat pumps can fully replace a regular boiler. This is the case for small and well-isolated residential buildings. Their heating energy demand is so little, that a boiler with gas grid connection would not make sense. The heat that cannot be supplied by the collectors, especially during cold winters days, could be produced with electricity. This is more expensive and environmentally inferior.

2.1.1.4 Opportunity cost of capital and labor

Capital costs make up for a dominant share of generation, transmission and distribution costs. Labor costs influence operation and maintenance costs and, indirectly, capital costs.

Choosing the macroeconomic opportunity costs of labor and capital needs some reflection.

One could argue, that in times of unemployment, the opportunity cost of labor is, at least[22], zero. A more refined approach would have to compare the profiles of jobs created with those of the currently unemployed. Only where they match, opportunity cost would be zero. Even that is only a short-term view: in the long

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[21] reciprocating engines, Stirling engines, PEM fuel cells, microturbines

[22] Not regarding the value of professional training and general welfare losses due to redistribution.

run, those people might be missing when employment grows or be lacking as skilled labor or entrepreneurs in emerging industries. Then, again, macroeconomic opportunity cost would be greater than zero.

Generally, the problem of macroeconomic labor opportunity cost should not be mixed with that of decentralizing energy generation. Subsidizing microeconomic labor cost should only be done with caution, because it can cause friction and lead to misallocations. Labor cost will hence fully be accounted for in this study.

Microeconomic capital opportunity costs differ largely between players, due to different credit rating and taxes. A good assessment of macroeconomic capital opportunity cost is to look what a nation pays to foreigners for loans with a similar duration: long-term government bonds. The risk associated with business activities is at least in Germany higher than that of government bankruptcy. The currently 5% interest rate on long-term government bonds is therefore a lower boundary.

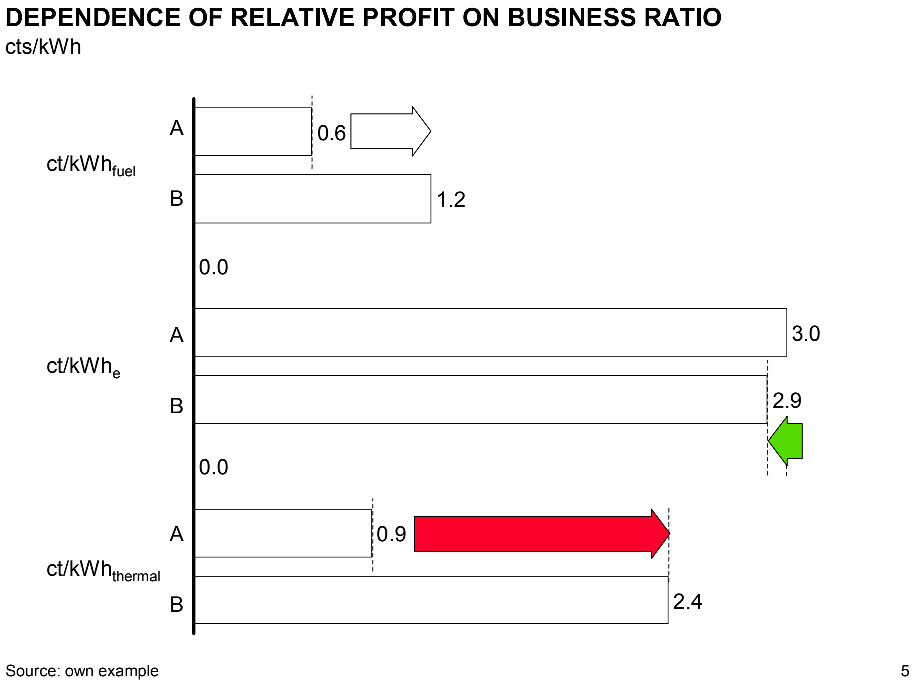
2.1.1.5 Base for comparison

Finally, one has to be cautious on what basis to compare electricity-, heat- and cogeneration units. Relating the same financial result to electric output, heat output or fuel input can lead to very different conclusions. The following example demonstrates that.

Parameter	Dimension	A	B
Efficiencies	Electric (in %)	20%	40%
	Heat (in %)	70%	50%
	Total (in %)	90%	90%
Fuel cost	Ct/kWh_{fuel}	1,0	1,0
Output value	Ct/kWh_{e}	4,0	4,0
	$Ct/kWh_{thermal}$	1,15	1,15

Table 3: Parameters of mock-up cogeneration units

Two different mock-up cogeneration units shall be compared. They have the same overall efficiency, but different ones for electricity and heat. For simplicity reasons, only variable costs and benefits will be compared. Table 3 gives an overview on the parameters for this example.



DEPENDENCE OF RELATIVE PROFIT ON BUSINESS RATIO

cts/kWh

Source: own example

5

Figure 5: Distortion effect of business ratios

Each unit burns natural gas and generates heat and electricity in a certain ratio. When calculating profit, the value of heat and electricity generated is accounted for with a bonus. Unit A, for instance, generates 0.2 kWh of electricity and 0.7kWh of heat per 1 kWh of gas. The profit therefore is the value of the heat generated (1.15ct x 70%), plus that of electricity (4.0ct x 20%), minus the cost of gas burned (1ct). That results to a profit of 0.6ct/kWh$_{fuel}$.

Figure 5 shows the profits for both machines, referred to different bases. The result is astonishing:

Just by changing the basis for comparison, their difference in competitiveness can be made look bigger or smaller. Even more, the same machine can be made look cheaper or more expensive than a reference machine. Choosing the reference means choosing the result to a large extent. This effect gives way to manipulation, but is not discussed in public. Interestingly, current pro-cogeneration literature often bases analysis on kWh$_{e}$.[23]

The explanation for that is, that A and B have very different fuel consumptions and run-times (see Table 4) when referenced to kWh$_{fuel}$ or kWh$_{thermal}$. Depending

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[23] see for instance practice examples in [SEN-1]

on the choice of the reference, one or the other is running longer and therefore accumulates more margins.

The effect gets much bigger, with the electric efficiency getting a little smaller[24], due to the behavior of a "1/x" function with x being close to zero.

	Fuel consumption or runtime (index = 100)	
Business Ratio	**A**	**B**
kWh_e	500	250
$kWh_{thermal}$	140	200
kWh_{fuel}	100	100

Table 4: Fuel consumption in each reference scenario

The implications of this effect are huge. It seems that the worse the electric efficiency of a cogeneration unit is, the lower its electricity generation costs are. That does not make sense, of course, and is only due to an increased runtime and fuel consumption.

Nevertheless, the cogeneration lobbies managed to make tax exemptions unconditional of electric or overall efficiencies[25]. The risk is, that "tax exemption burners" gain ground. Those are machines with low electric efficiency, that still manage to make a little margin due to high subsidies and that due to their hidden higher runtime suddenly look more competitive than they actually are.

As a result, the reader should always have a look on electric efficiencies when profits are displayed in ct/kWh_e and on thermal efficiencies when they are shown in ct/$kWh_{thermal}$.

For comparisons in this study, the reference basis will be neither kWh_e nor $kWh_{thermal}$, but kWh_{fuel}. It shows what value can be derived from the same amount of natural gas. It can also be applied to non-cogeneration devices for heat and electricity. Only pure renewables cannot be compared that way, because they do not need fuel. They will be evaluated on kWh of output energy.

Another meaningful reference is "margin per emission unit", that will be looked at in some cases as well.

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[24] In case of referrencing to kWh_e.

[25] see for instance [BUN-1]

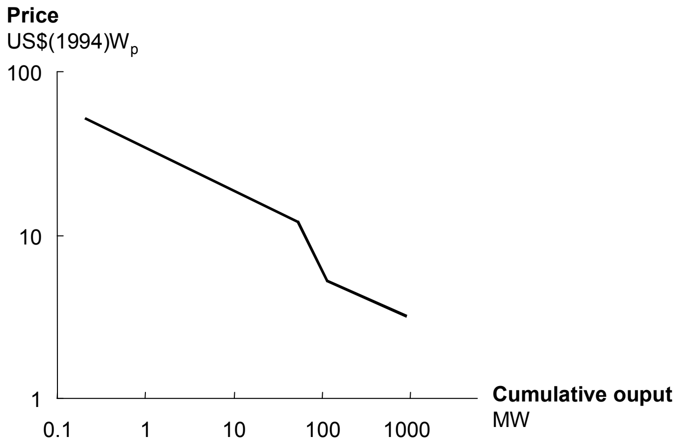
In any case, the calculation of profits or margins needs reference prices for heat and electricity. For electricity, the decision-relevant cost for CCGT-generated electricity is taken, for heat that of high-efficiency-boiler-generated heat.

2.1.1.6 Learning curve effects

Another pitfall, that reduces the meaningfulness of policy recommendations is, that only current investment costs are compared. But as some technologies will become cheaper quickly, projections for future cost have to be made as well. Comparing mature and new technologies at current cost cannot lead to a macroeconomic proposal on what technology to use long-term. Over product lifetime, investment costs go down as experience grows and processes are improved.

This phenomenon is generally referred to as "learning curve" and has been first discovered by T.P. Wright in 1936 for the aviation industry.[26] The learning curve suggests, that production costs are reduced with every doubling of cumulative output by a certain factor, for instance 20%. This can be used in order to make projections about cost development (see Figure 6).

LEARNING CURVE OF PHOTOVOLTAIC CELLS



Source: [AGF-2], p. 269, values estimated from graph 6

Figure 6: Learning curve of photovoltaic cells

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[26] see [SAN-1]

This study will both compare current costs, but also look at costs after a certain amount of cumulative output, assuming a specific learning curve.[27]

In order to do so, two factors have to be assessed: the current cumulative output and the learning factor. While initially the scope was limited to one producer only, the concept can be expanded to entire industries. In that case, the question of the market scope occurs. In some industries, like photovoltaics, learning probably happens on a global scale, other markets, like cogen reciprocating engines, are more fragmented and isolated. In the following, only the German market will be regarded. The resulting inaccuracy is limited though, as not only the current output seems smaller, but also the production rate.

Second, the learning rate is extremely difficult to assess and would be dependent on the market structure as well, in case of an industry wide application. [PFL-1] proposes a very sophisticated approach when dealing with technology evaluations when no clear, discrete input parameters are available. He assumes functions for several input parameters[28], not discrete values. Those functions are mathematically folded and result in a probability distribution for profitability. This approach is not better, though, than the quality of the worst input parameters. This is why in the following, the lack of accuracy in cost calculations is regarded as structural problem. Results will be considered more on a "fuzzy" approach, looking whether there are big differences or clear gaps.

2.1.2 Emissions

Energy generation causes emissions over the entire value chain of exploration, transportation and combustion of fuel, as well as during the production process of transformation units and their respective parts and raw materials. Hence, also renewable energy generation causes emissions.

Those emissions can harm buildings and other materials, ecosystems, climate and human health and general welfare. Those affected by them neither can choose not to be harmed nor get compensated in most cases. This is why emission reduction has such a high political interest.

What emissions are relevant and have to be considered in the evaluation of different technologies? How can they be aggregated into clear, easy and meaningful parameters, best into money?

This study will concentrate on three parameters: CO_2-, SO_2- and TOPP-equivalents. Any aggregation beyond that, especially a conversion into cost is not regarded meaningful, even misleading. The cost of emission reduction, on the

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[27] [SAN-1] and [AGF-2] have already used this thinking in order to assess the potential of several energy generation technologies.

[28] Other parameters are highly variable between different applications as well.

other hand, can be measured and compared between different technologies. Again, the harm of emission cannot be put into costs, but the costs of reducing emissions can be compared.

The analysis of ecological impact is very complex. Quite a few different parameters are important, like efficiencies, type of fuel, cleanliness of combustion and value chain effects. The "ÖkoInstitut" in Darmstadt, Germany, has set a kind of "industry reference" with its technology evaluation tool "GEMIS"[29]. This tool will be used for analyzing effects over the entire value chain and for calculating emission equivalents. On the other side, using GEMIS has a few disadvantages: it is very complex, input parameters do not always reflect the same degree of accuracy as the complexity of calculations suggest and some of the above principal errors in technology analysis are hard to get rid of in GEMIS. This is why basic emission calculation will be done with a simple, self-made model.

2.1.2.1 Emission types

Energy generation leads to a wide range of emissions: gaseous, liquid or solid ones, noise. Most relevant in this case are gaseous emissions, that have lots of known and yet unknown effects, like global warming, waldsterben, asthma, damage to buildings, etc. Science clustered some of the substances with similar chemical effects to aggregated parameters, like CO_2 equivalents. The damage of those clusters as a whole is analyzed subsequently.

SO_2-, CO_2- and TOPP equivalents occur in public discussions most often and will be used in this study. They also cover the most important effects of energy generation emissions. Each of those three emission classes has a different main object of damage[30]:

- The CO_2 equivalent indicates the green house potential and the respective impact on world climate. It is subject to the Kyoto protocol. The CO_2 equivalent is an aggregation of CO_2, CH_4, N_2O, SF_6, PFC and HFC.[31]
- SO_2 equivalents indicate the acidification potential and thereby especially the damage to forests, biosphere and to buildings and materials. They are aggregated out of a mix of the following gases[32]: SO_2, NO_x, HCl, HF, NH_3 and H_2S.

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[29] please refer to http://www.oeko.de/service/gemis/

[30] see also [MAS-1]

[31] see GEMIS Index

[32] see GEMIS Index

- TOPP (tropospheric ozone production potential) equivalents indicate the threat to human health by summer smog. It is the quantification of the potential of four gases (CO, CH_4, NMVOC, NO_x) to produce ozone close to the surface that can affect the human respiratory system.

In the simply model, only the three most important substances will be regarded: CO_2, SO_2 and NO_X. Those are the ones most discussed in literature and public. Even manufacturers' emission specifications normally do not go further than that. The results are later compared to the more comprehensive approach of calculating equivalents[33].

Similar to the calculation of financial viability, the question of the right comparison base arises: It could be "SO_2 savings per" $kWh_{thermal}$, kWh_e, kWh_{fuel} or € of profit, revenue or cost? As with the calculation of financial viability, the choice can lead to distortions. This is why for cogeneration technologies, kWh_{fuel} will be taken as ratio. Pure heat or electricity technologies will be referred to that as well and to sometimes also to output numbers.

2.1.2.2 The choice of fuel and reference technologies

Another issue already encountered when calculating cost, is that of reference values. A generation unit causes emissions, but on the other side saves some as well, because the amount of heat and electricity it generated does not have to be produced elsewhere. If it replaces machines that are dirtier than itself, it saves emissions in a certain way. The question is what reference technologies should be taken. Here, again, the choice determines the result[34]. This study will take gas-driven CCGTs as reference for electricity[35] and modern standard gas boilers for heat.

Current literature suggests often taking coal plants as reference for electricity generation.[36] Both the reasoning and the result are wrong and lead to serious misallocations.

The argument for coal plants as electricity generation reference for cogeneration units is that a cogeneration unit in practice produces electricity at roughly the same times as a coal plant.[37] Someone, who argues in that way, implicitly compares two options:

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[33] using GEMIS

[34] see also [LUX-1]

[35] Of course, CCGTs can be operated in cogeneration as well and obviously they are more efficient if the waste heat is used, too. The question is whether they are superior to other technologies even when used for electricity generation only.

[36] For instance, see [ENE-5] for "Ökotest" study finding that heat pump electricity consists by 85% out of coal power. [PFA-3] argues that co-generated power replaces centrally coal-fueled electricity generation

[37] see for instance [ENE-5]

a. Install new cogeneration units or

b. Run an existing coal plant and run some existing boilers that otherwise would stand still or be dismantled[38]

This choice is silly, for three reasons. First, it compares new investment with old capacity. New investment in both heat and electricity generation capacity (e.g. a reciprocating engine) has to be compared with new investment into heat and electricity generation capacity (e.g. CCGT and heat pumps) - and nothing else.

Second, it cuts out a number of options that seem more promising than both of the previous[39], for instance:

c. Install new boilers and a new CCGT plant

d. Install new heat pumps and a new CCGT plant

e. Install solar thermal collectors and photovoltaic panels

A couple of other options are thinkable. Anyway, the restriction of options to the one that is preferred and one or more obviously silly ones is not correct.

The argument is not valid for a third reason: closing down coal capacity is not necessarily an option. This decision is not taken on the basis of emissions or cost. Coal plants have been kept alive until today due to fuel price risk hedging and, above all, politics: miners proofed to have strong lobbies in certain areas, especially in the Ruhr. Hence, replacing coal plants with cogeneration units or any other gas-driven technology on a significant scale is probably not an option.

How should the reference technology be determined correctly, then?

[PFA-3] says that there is an irresolvable methodical problem with the question of the reference technology. He basically argues that it is not possible to determine how a generation park would look like if there had not been investments into certain (co-generation) plants.

This is true for a historic view: what did certain investments into decentral co-generation technologies achieve? This is not true for a future-oriented view, though. In that case, there is a free choice of either decentral or central technologies as there is a free choice for co-generation units or decoupled generation of electricity and heat.

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[38] [VDI-1] cites lobbyists and politicians, including a Minister, that even go beyond that: they base their recommendation of conventional gas-driven cogeneration units on a comparison with **new** conventional coal plants. This is an example, that shows that the discussion about cogeneration often is more motivated by the will to make political tricks or financial profit, than to find the true optimal technologies.

[39] It is not my intention to polemize, but it reminds me of a German way of describing decisions that leave out important options: choosing between black plague and polio.

One way of finding the best generation technologies could happen in two steps, ceteris paribus: first, find the best technologies for each fuel, and then, second, compare the best technologies of the different fuels.

Once done, would the winning technology be used and the others not? No, because fuel is selected not on the basis of emissions only, not even on the basis of today's cost, but for political and risk hedging reasons as well. It involves aspects of ethics, party politics, international agreements, supply security and international cooperation.

- For instance, it leads to ethical questions like weighting a small risk of nuclear devastation[40] against the more or less sure damage of the biosphere by CO_2 emissions.
- It involves very tangible party-political interests: Coal mining used to have a very strong lobby at the Ruhr[41], lignite offers thousands of jobs in areas with high unemployment in Eastern Germany. Germany is also the world's biggest lignite consumer[42] and leader in related technology. Nuclear energy is a red rag for the environmental movement while it enjoys strong support from the energy lobby.[43]
- Furthermore, Germany received "indicative targets" from the European Commission for electricity generation from renewable sources: in 2010, renewable energy should have a 12,5% share [NEW-1]. Furthermore, Germany signed the Kyoto protocol.[44]
- The aspect of supply security, both long and short term, is important as well. Long-term, there are very opposing views, especially on the availability of oil and gas.[45] Short term, oil supply has been threatened several times already, as most reserves are concentrated in the Middle East. The impact of for instance the first oil crisis on Germany's

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[40] [LUG-1] argues that after September 11th, the risk of nuclear catastrophies has become much larger. None of the currently running nuclear plants could withstand a hit by a passenger airplane. The International Atomic Energy Association does not oppose this statement [CHA-1].

[41] German coal costs three times as much as the market price [DEL-3]. Nevertheless, it has been subsidized for decades now with several billion € annually, on a declining level. The current reduction will be from € 5 billion to €2.5 billion until 2005 [HBL-1]. Additionally, the so-called "ecological tax reform" exempted coal from taxes that oil and natural on the other side have to pay [GAI-1].

[42] see [SCHI-2]. Current technological advances, like the RWE "BoA" significantly improve the cost and environmental position of lignite.

[43] [CHA-1] and [UEX-1] see the danger of nuclear energy strongly increased after Sept 11th. The Nuclear Control Institute in Washington demanded anti-aircraft guns installed at nuclear power plants. But also the vast number of licenses to use radioactive material should be reduced: in North Carolina alone, 650 universities, industries and hospitals use radioactive materials. [LUG-1] clarifies the scientific background more detailed and gives an overview on the evolution of security standards in the nuclear plants that have been built at different times, but are still running today. In his opinion, nuclear reprocessing plants are the easiest and most disastrous targets.

[44] By the way, [PRI-1] states that 50% of Germany's targets could be reached by replacing coal with nuclear or renewable energy.

[45] For a discussion on oil reserves see [ALL-2], [EID-18] or [EID-4]

> economy has been severe.[46] Consequently, supply security is of interest to both governments and private companies. But natural gas is not more secure. On the contrary: while OPEC holds only 47% of know oil reserves, the eleven biggest gas exploring countries hold 71% of gas reserves.[47] A national energy policy therefore has to make sure to at least keep options on different fuels.

So, the choice of fuels is to a large degree independent of SO_2, CO_2, and TOPP emissions. And it takes place before a decision on technologies. For lignite, coal, nuclear and waste, only central applications have to be considered[48]. Decentral options are valid only for natural gas and to some extent for oil and biomass. Biomass will not be dealt with, as the potential seems too small to cover for a major share of Germany's energy demand. This study will focus on natural gas, as it is more promising and cleaner than oil.

So, this study will analyze the following question: For the amount of natural gas that we decide to take for our primary energy supply[49], which are the technologies that make best use of it, both in terms of cost and emissions? The reference is the current benchmark systems for natural gas: a decoupled CCGT as reference technologies for electricity and a standard boiler for heat. The study therefore only compares a selected set, not all possible energy generation technologies.

2.1.2.3 The non-sense of internalization

Some people try to further aggregate the above emission parameters and in the best case come up with clear money equivalents. This would allow them to place exact taxes on different units and to make clear trade-offs between "cheap" and "dirty". This so-called "internalization of external effects" does not make sense though and probably even is misleading.

Emissions are caused by someone, but harm someone else. This person cannot decide not to be harmed; neither does the originator compensate him. This is called "external effect". Microeconomics try to internalize those costs, that means to assess their welfare impact in terms of money and then to transfer it from the subjects to the objects of damage. In both theory and practice, this is not possible, though.

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[46] [GIN-1] addresses the risk deriving from the world's largest oil reserve owner's (Saudi-Arabia) social instability, [PLE-1] introduces the notion of political capital that is paid along with money for our dependency on Middle Eastern oil. Our policy options in dealing with regimes over there are reduced; the Gulf War was a very tangible outcome of that. [REM-1] estimates the cost of the latter at €100/capita in Germany, which has been paid by taxpayers, not the oil consumers.

[47] For a discussion of the market power of those eleven countries, that are associated in the GEFC (Gas Exporting Countries Forum), see [WET-1] and [HAN-2]

[48] Despite a very surprising news headline of a renowned international press agency, that the Japanese Atomic Energy Research Institute finances the development of a 200kW micro reactor for office and apartment buildings

[49] For political and strategic reasons, independent from ecologic and short term economic aspects

A brief critique of the assessment logic follows. For a more comprehensive discussion see [MAS-1][50].

The assessment follows a three-step approach: identification of external effects, quantification and monetarisation.

Identification is still rather feasible. [MAS-1] comes up with a wide variety of effects ranging from ugly views of huge power plants to higher rates of cancer. In total, he identified eight different objects of damage (buildings and materials, human health, psychological harm, animals and plants, biodiversity, soil and water, landscape, intergenerational distribution justice) and causes for their respective damage. Though still some causes are yet undiscovered or only under suspect,[51,52] further research likely will identify the causes for most external effects.

Quantifying the cause-effect-relations is much more difficult. Highly non-linear effects are expected for instance if soil contamination reaches certain thresholds. Climate and whether are other non-linear, even "chaotic"[53] systems. Quantifying the impact of green-house gases on changing climate zones or the number of extreme weather situations and their respective damage is probably not possible, even in principle.

The monetarisation of these effects poses the biggest problems, some of them irresolvable. In theory, every person affected should get reimbursed the exact value that damage meant to him. This individual value can never be found out, because there is no possible market solution: a resident cannot choose not to be damaged and reimbursed by a near-by plant. In other words, exclusiveness of consumption is not guaranteed and a market is principally not possible. The setting of re-imbursement values can only be done on a centrally planned economy base, which will nearly always leave a group of people underpaid.

To what level did studies set the standard price for human life, for instance?

- ¶ Some took the so-called human-capital approach to set the price of life to the value of lost production. That means life of unemployed or retired people would come close to zero.
- ¶ Others took salary premiums of dangerous jobs as an indication for the willingness-to-pay for a reduced risk of death. Does this mean that we all have to accept to value our lives at the same level mercenaries or soldiers

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[50] Especially the dedicated chapter on principal monetarisation problems, pages 313ff. For articles describing and being in favor of the approach refer to [FRI-1] and [VDI-2]

[51] [MAS-1], page 42. Buildings and materials also undergo natural aging processes. It seems to be sometimes difficult to separate those from damage done by pollution.

[52] [MAS-1], page 75. For instance, the impact of SO_2 on human health is difficult to isolate from that of other emissions, as people normally get exposed to a "cocktail" of different emissions.

[53] in a mathematical sense

> of the Foreign Legion do? Does the value of life depend on current unemployment rates, educational standards and level of social security? What about children working in Indian fire working plants - should their "salary premium" set the value of life?

Why do we pay 80% of lifetime health expenses in the last year of a persons life and put people into prison when they, deliberately or carelessly, kill others and then on the other hand allow "flat fees" for human life?

I think the above made clear that the value of life is something very individual and there is no way of making people communicate their true preference structure. The monetarisation of external cost does not make sense. Worse, it even can be misleading. The biggest study ever on external effects, the "ExternE Program" of the EU[54], derived the external effects of producing electricity from natural gas at an additional 30% of production cost.[55] The authors very well describe the limitations of that approach and the assumptions they had to make and that this figure can only set a minimum and be a rough approach, better than nothing. But what will reach the public and what will be cited in other publications is only "30%". All of those reservations will be lost to the vast majority. Who will actually know about all the silly assumptions being made for instance for the value of life? The smallest part. Most people will think or be made believe that if taxes for natural gas amount to 30% of production cost, or around 1ct/kWh, everything would be all right[56]. And this is why the discussion of internalization is even dangerous: it draws away attention and political will to reduce external effects, as they seem to be paid for.

Furthermore, the results are meaningless, even if the method would be all right. [MAS-1] found differences of factor 50 between several studies comparing certain kinds of external effects[57]. Even the "ExternE" study itself comes up with huge ranges, like 2ct/kWh to 58ct/kWh for electricity from fossil fuels[58]. Whether natural gas gets taxed by one, 50 or ten ct/kWh, makes all the difference. Whether electricity from fossil plants gets taxed by two or 58ct/kWh, makes all the difference. The bandwidth is too wide in order to come to meaningful results.

Deciding about a cost level from below which external effects would be justified therefore is not possible. There is no way around continuously reducing them and looking for closed cycles. On the other hand it is feasible to compare the cost of different emission reduction measures, at least for a single emission type, not along several variables at the same time, in a narrow, mathematical sense. The

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[54] see [EUC-1], [EUC-2]

[55] [EWI-1]

[56] Another problem would later be the distribution of that money. Today, it is the state that receives it, or better, the people that profit from the state spending it - not those being harmed by the external effects.

[57] page 119, for instance on calculating the impact of a nuclear emergency

[58] [EUC-1], page 78, with no or high assumption for cost of global warming.

study will take a more "fuzzy" approach and look for clear champions, technologies that are "much" better in certain parameters and only "little worse" in others. The results in practice anyway vary so largely, that anything else would be pseudo-precise.

Summarizing, the technology comparison will include three different kinds of emissions: CO_2-, SO_2- and TOPP-equivalents. They will be regarded separately as further aggregation or monetarisation does not make sense.

2.1.3 Resources

Our current energy system consumes huge quantities of fossil fuels. On the one hand those amounts will be lost for future generations. On the other hand, those generations also profit form the technological advances our current economy creates.

What is the amount of fuel usage we are entitled to and when do we infringe against intra-generational justice? A quantified answer probably does not exist, so here as well, we have to reduce our current consumption and look for cycle processes.

The problem of intra-generational justice has been discussed in the finance already. There as well, future generations have to bear the effects of state debt, but they also profit from the infrastructure and human capital built for it. There, the conclusion was, that incurring debt in order to invest in sensible projects is all right; incurring debt for consumptive purposes is not.

The equivalent thinking for fossil reserves suggests that using fossil fuel is only justified when done to build up renewable generation capacity or when used for improving efficiency for instance with isolation. Today, by far the most energy is used for consumption though. We have to reduce that and leave next generations with a more sustainable way of generating and using energy.

Measuring resource consumption can be done rather pragmatically. The only fossil fuel regarded is natural gas. Therefore, fuel consumption is proportional to CO_2 emissions and apart from that is basically independent of the conversion technology. The issue of intra-generational justice is hence addressed in that parameter already and will not occur separately again.

2.1.4 Other benefits

There are a couple of other aspects that have to be considered, most of them related to safety and national welfare. Some are clearly in favor of decentral generation, others on the side of the most efficient technology, which still has to be determined.

Decentral generation definitely improves the security of the energy system at the level of generation and transmission.

Concerning generation, it smoothens the availability curve of capacity and related price spikes. Stoppages or regular maintenance plant closures do not affect a large unit from time to time, but continuously a number of micro units. This can be calculated with a low statistical variance. For the same reason, vulnerability to terrorism and war is reduced.

Concerning transmission, decentral generation reduces the risk of grid failure. Especially electricity grids can be damaged due to natural disasters, terrorism or war. A decentral generation system has clear advantages as gas transmission grids are underground and hence less exposed to natural or destructive forces. Specific decentral generation technologies like photovoltaics or solar thermal collectors even further reduce the impact of grid failure as they use locally available renewable energy that does not require transmission.

The most efficient generation technologies, central or decentral, enjoy a couple of other advantages.

Firstly, a reduced usage of natural gas increases our supply security and reduces our exposure to rising gas prices. The market structure will change significantly when Great Britain will convert from a net producer to a net importer of natural gas before the end of the decade.[59] [SCHM-2] states, that the United States as well will become net importers within nine years, with a huge impact on global LNG markets. The resources of the current EU will expire in not more than 18 years. The impact of tightening oligopolies on prices could be significant. The political dependency on current supply countries like Russia or Algeria[60] and future supply countries from the Middle East will grow. [REM-1] refers to that as "political cost", that take the form of concessions are even war.

Secondly, resource efficient technologies increase national welfare, as they reduce fuel imports and might on the other side even become subject to export.

2.1.5 Metric

Economic and ecologic results can vary to a reasonable extent depending on specific applications. Also, the future development can only be assessed roughly. Calculations hence cannot come up with exact results, but can only indicate an order of magnitude.

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[59] See [HOM-2] for an analysis of reserve capacities for natural gas. See [NAL-1] for the huge impact the entry or exit of a player can have on the supply and demand balance and the market outcome.

[60] 90% of all German natural gas imports currently come from five countries: Norway, The Netherlands, Russia and Algeria

In the following, "fuzzy" notions will be used frequently in order to assess the order of magnitude of results (see Table 5) and not to distract the reader with pseudo-exact details.

Very unprofitable	**Clearly unprofitable**	**(Close to) break even**	**Clearly profitable**	**Very profitable**
<-50%	<-50% to -10%	(-10%) to 10%	10% to 50%	>50%

Table 5: Fuzzy metric for result assessment

2.1.6 Conclusion

A couple of central and decentral generation technologies for electricity and heat will be compared on the basis of decision-relevant macroeconomic cost and three different types of emissions. Those four parameters will not be integrated into a single result function, but the comparison will be done in a fuzzy logic approach, looking for pareto-optimal solutions.

Cost comparison will include two different scenarios, one for micro residential applications at recent isolation standards putting a gas grid connection at stake and another scenario for all other applications with higher heat requirements that will in any case need a gas grid connection.

Cost comparison will also consider both current cost and expected future cost, using cost projections based on learning curve theory.

2.2 ENERGY GENERATION TECHNOLOGIES

The previous chapter has defined the criteria under which the emerging decentral technologies will be evaluated. This chapter will select the technologies to be compared, as well as the reference technologies, that define the current state-of-the-art.

2.2.1 Definition of decentral generation

What is "decentral generation"? [WEL-1] distinguishes between "decentral"[61] and "distributed"[62] electricity generation, at least in German language. In his view, "decentral" refers to the generation-side and means that it requires a certain location. Hydropower, for instance, is generated where the river is, independently from the energy demand at that place. "Distributed", on the other hand, is supposed to refer to the demand-side, saying that generation takes place close to where demand is, whatever "close" means. He defines distributed generation to be below 20-30 MW.

In English language, he says, the above differentiation is not made. In the US, people use the term "distributed generation", in the UK "embedded generation" and in neither country, there is a term for what he calls "decentral generation".

The distinction between generation- and demand-side seems long-winded, though, and it is not true, that the term "decentral generation" is not used in English. In fact, in the probably most popular US article on distributed generation[63], "The Economist" does use the term "decentralized generation" and it uses it synonymously for "distributed generation" or "micro power". In order not to confuse the reader, in this paper, the terms "distributed", "embedded" and "decentral" generation will be applied all homonymously, referring to generation "close" to demand.

There are definitely different degrees of closeness and each capacity limit will be somehow artificial[64]. "20-30 MW" seem to be rather central when supplying 20-30.000 households as opposed to 20-30.000 1kW-fuel-cells. A less artificial definition could be that decentral generation takes place, wherever the electricity is distributed on the voltage level it is consumed at without transforming it for transportation reasons.

	kW_e	**$kW_{thermal}$**
Domestic	<10	<100
Commercial	10-500	100-5.000
Industrial	500-5.000	5.000-50.000

Table 6: Sub segments of distributed generation

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[61] "dezentrale Erzeugung"

[62] "verteilte Erzeugung"

[63] [ECO-2]

[64] The US DoE takes 30MW_e, [Datamon DG], Goldman-Sachs assumes 1-5 MW_e [GS Power Tech],

For pragmatic reasons, though, in this paper a simple upper threshold of $10MW_e$ will be taken. Furthermore, three sub segments are defined: domestic or "micro power", commercial and industrial (see Table 6). The focus of this work will be on the first two segments.

2.2.2 Technology selection

This study will evaluate the most promising emerging decentral and gas-driven electricity and heat generation technologies[65]. A few pure renewables will be regarded as well, for two reasons: first, solar thermal collectors and photovoltaics occupy a significant mind share in discussions, and second, it calibrates the ecologic performance of the gas-driven technologies, which are currently widely perceived as benchmarks. The study therefore only compares a selected set, not all possible energy generation technologies.

Among natural-gas-driven technologies, reciprocating engines, microturbines, Stirling engines and fuel cells are most promising.

- Reciprocating engines have been used for more than a hundred years. The small ones are normally based on car engines that have been adjusted to run on natural gas and equipped with a generator and a heat collection device. For cogeneration applications, they are available for some ten years. Their electric efficiency is rather low and cost still a problem. Larger units are much better performing.
- Microturbines have been developed recently, based on aircraft turbine technology. They are air bedded and only have one moving part. Therefore, they are extremely reliable and easy to maintain. A very continuous combustion leads to little NO_x emissions.
- Stirling engines are a rather old technology that never made it to large numbers. They work on a temperature difference between a source of heat and one of coldness. The heat source can be solar energy or combustion of fossil fuels[66]. It then works on an external combustion. NO_x emissions are very low as well, thanks to a very controlled combustion, especially using new FLOX® technology[67].
- Fuel cells. Out of the different kinds of fuel cells, two representative ones with high prospects are considered: PEMFC[68] and SOFC[69]. PEMFC are low temperature fuel cells targeting smaller applications. They

---

[65] This includes electric heat pumps running on electricity that has been generated on natural gas.

[66] Which would be external, as opposed to most other devices that normally would have internal combustion.

[67] Flameless oxidation, suppresses peak temperatures in the flame. See www.flox.com.

[68] Proton Exchange Membrane Fuel Cell

[69] Solid Oxide Fuel Cell

benefit from R&D expenses and, perhaps later, high manufacturing volumes in the car industry[70]. SOFC operate on high temperatures. Ultra-efficient hybrid systems of SOFC and microturbines will reach electric efficiencies of up to 70% [JOP-1]. In the following, those systems will be referred to as "SOFC ultra".

At this point, the term "cogeneration" needs a clarification. Cogeneration is a thermodynamic principle that can be applied to basically all electricity generation technologies. Even with a SOFC ultra with 65% electric efficiency waste heat can be recuperated and used. In that case, the difference is small, though. The opposite is true for a microturbine operating at 27% electric efficiency.

Therefore, microturbines, reciprocating engines, PEMFC[71] and Stirling engines will be referred to as "1/2 cogeneration technologies" or just cogeneration technologies, SOFC and CCGT either as "2/1 cogeneration technologies" or just electricity generation technologies.[72]

A few renewable technologies are considered as well:

¶ Photovoltaics. Perhaps the most famous, generic and easy-to-grasp technology. Research experiments with different efficiency/cost trade-offs and materials. The break-through has not been achieved yet.

¶ Solar thermal collectors. Much more economic than photovoltaics and in southern countries already cost efficient, they still face economic problems in Germany, due to the high heat demand in winter and the little sunshine throughout the year.

¶ Heat pumps. They are not 100% renewable, but use electricity (or gas) to extract solar energy that is stored in the ground[73]. This technology had a boom period in the early eighties, but at that time disappointed customers with unreliability. Up to now, they did not recover from that.

Water and wind energy require certain locations and are limited in potential, at least in Germany. Additionally, their economics make them central technologies.

For the same reasons, special gases, geo-thermo-electric energy, wave and solar-thermo-electric plants are not considered. Neither are bio fuels.

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[70] [GUA-1] even suggests a hybrid role of fuel cells as both car engines and, in the evening when the driver has come home, as decentral electricity plant.

[71] PEMFC might become something in the middle, a "1/1-" cogeneration technology in the future.

[72] The figure describes the rough ratio of electrical and thermal efficiency.

[73] Other heat pumps take energy from different sources. While water is not available everywhere, the heat capacity of air is normally too little to run heat pumps in wintertime. Exhaust air from buildings is a viable source for heat pumps, though.

Concerning unit capacity sizes, reciprocating engines cover the largest spectrum. For the model, a micro and a medium one are taken in order to cover the whole bandwidth[74]. PEMFC can be scaled to any size, but first products will be targeted at the domestic segment[75]. Stirling engines face a similar situation. Both PEMFC and Stirling engines are not yet on the market, at least not in Germany[76]. Microturbines currently target the range from $30kW_e$ up to $200kW_e$ and will most likely continue to do so, due to their specific physics[77]. A mini-power micropump will be analyzed. PV can principally cover all three segments, but is referred to only in the micro power segment. This is where the highest demand is and where first competitive niche applications are (remote power). SOFC ultra will not get smaller than medium-power[78].

2.2.3 Summary

Five gas-driven electricity-, heat- and cogeneration- technologies and three renewable technologies will be evaluated and compared amongst themselves and against the current incumbent benchmark technologies boiler and CCGT.

To some extent, those technologies serve different consumer segments. So, some emerging technologies might only target niches markets.

According to their electrical and thermal efficiency, cogeneration technologies can be classified into "1/2-" and "2/1-" cogeneration technologies.

Table 7 gives an overview of the technologies chosen for the model.

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[74] For overviews on the German market for cogeneration and especially reciprocating engines see [EUM-1], for sales figures and [FFM-1] for cost data.

[75] For expected product features and time schedule for one of the most promising project see [VAI-1]

[76] In the US, The Stirling Company has already products on the market, designed for backup power, not co-generation, though (Interview with The Stirling Company, April 2002). In Germany, SOLO Stirling Engine is for instance developing a co-generation unit targeted at the micro-power segment. For a more comprehensive overview on R&D activities on Stirling engines in Germany and some other countries, see [KÜB-1].

[77] Interview with Capstone (USA), April 23, 2002. See also [FAZ-8].

[78] [JOP-1] states that SIEMENS Westinghouse is designing hybrid systems starting at $220kW_e$ up to 2-3 MW_e.

Decentral			**Central** *(>10MW$_e$)*
Micro power (<10kW$_e$)	*Minipower (10-100kW$_e$)*	*Medium power (0,1-10MW$_e$)*	
Reciprocating engines Stirling engines PEMFC Photovoltaics	Microturbines (Reciprocating engines)	Reciprocating engines SOFC ultra	CCGT
Pure heat generation: Regular boilers, high-efficiency boilers, heat pumps (driven by gas-fueled electricity), solar thermal collectors			

Table 7: Classification of technologies in comparison model

2.3 TECHNOLOGY EVALUATION SCHEME

The previous chapter has stated the technologies that are going to be evaluated and outlined the criteria to do so. In the following, the actual comparison will be done. Which are the technologies that make most sense from a holistic, macroeconomic perspective? Heat pumps and SOFC ultra will turn out to be the best ways to use natural gas and to bridge the way to a fully sustainable energy system.[79]

2.3.1 Current financial viability

Are decentral generation technologies financially viable from a macroeconomic perspective? The following paragraph analyses their financial performance, starting with the calculation of reference values for electricity and heat.

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[79] Shell basis his energy scenarios on the thought that natural gas will be used to gap the next 20 years, until renewable technologies can take over cost efficiently [SHE-1].

2.3.1.1 Reference cost for electricity

The macroeconomic electricity costs consist of the cost for generation, transmission and the losses during distribution. The distribution grid costs are not decision relevant. The reference price is hence calculated at 4,4 ct/kWh$_e$ [80].

The generation costs consist of costs for fuel, depreciation and O&M.

The fuel costs are estimated to the natural gas import costs. This is a good estimate for gas opportunity costs. The fact that gas is normally imported on long-term take-or-pay contracts could suggest to estimate opportunity cost at zero, but growing demand and so far untouched markets like car fuel will prevent importers from sunk cost on a large scale and for a long time.

Another issue is that natural gas is also exploited in Germany, so opportunity costs could be different from that of mere import costs. Firstly, the biggest share of our natural gas is imported; only 20%[81] are exploited in Germany. Secondly, on a long-term view, own production definitely substitutes import, so opportunity costs for German gas should be set to import costs.

	O&M (ct/kWh$_e$)	**Fuel** (ct/kWh$_{fuel}$)	**Electric effic.** (%)	**Invest** (€/kW$_e$)	**Lifetime** (hrs)	**Runtime** (hrs/a)
CCGT	1,2[82]	0,76[83]	55%[84]	400[85]	80.000	4.000

Table 8: Parameters for CCGT generation cost calculation

All necessary values for the calculation of depreciation can be found in Table 8. The annual full-load hours ("runtime") depend on the type of customer. Technology comparisons should always be based on the same customer structure and therefore on the same runtime. In practice, decoupled units will have more full-load hours than cogen ones, though, as they are not restricted to matching of heat and power demand.[86]

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[80] This is more or less equal to the wholesale price for large customers in April 2002 [EID-20]

[81] [SCHU-3]

[82] [AGF-2] takes a variable part DM/MWh 10 and a fixed part of DM/kWa 55 for a CCGT connected to a district heating system. The same values are assumed in this paper for a de-coupled CCGT.

[83] [BMW-1], page 30, for 1998

[84] see [VDE-1]. [NIE-1] refers to a new world record set by a 400MW unit in Mainz: 58%. In that case, another 22% can be used thermally. The overall efficiency is with 80% lower than that of reciprocating engines.

[85] [VDE-1] gives a price range from €400-€500/kWhe. As cost, not price is looked for, the smaller boundary value is taken.

[86] Heat storages and variable heat/power ratios can reduce this impairment.

Cost item	**Unit**	**Cost**	**Comment**
Generation	Ct/kWh$_e$	3,3	See text
Transmission fee	Ct/kWh$_e$	1,0	See VIK overview 1/2001 in [KÄS-1]
Transmission losses			Included in transmission fee
Distribution fee	Ct/kWh$_e$		Not decision relevant
Distribution losses	Ct/kWh$_e$	0,1	Estimated according to GEMIS[87]
Total	Ct/kWh$_e$	4,4	

Table 9: Calculation of reference electricity costs

The central reference system has to cover all cost that would not occur in a decentral system. The electricity transmission grid could be significantly reduced if electricity was produced locally. Therefore, reference cost has to cover transmission fees as well. [KÄS-1] gives an overview on current transmission fees that range from slightly below 1.0 ct/kWh$_e$ to nearly 2.0 ct/kWh$_e$. Those prices should include cost for transmission losses and profits. As profits do not make part of macroeconomic electricity cost, they should be deducted. As no better database is available, transmission cost is estimated at 1.0 ct/kWh$_e$, the lower end of this price bandwidth.

The distribution grid costs are not part of the macroeconomic electricity cost, but losses have to be accounted for, as a decentral structure would significantly reduce distribution volume and related losses.

Table 9 gives an overview on the electricity reference cost calculation. This is the current value of the decision-relevant part of macroeconomic cost for electricity generated from natural gas.

2.3.1.2 Reference cost for heat

A similar calculation is made in order to derive reference heat costs. The reference technology in this case is a regular gas boiler that is installed decentrally at the consumer.

Cost are calculated for two different cases:

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[87] GEMIS estimates medium voltage losses to 14% per 100km and average length of German medium voltage in distribution to 5km. The respective values for the low voltage grid are 600% per 100 km and a length of 500m.

¶ Moderate and high demand - "substitution"[88]. Those applications need both a connection to the gas distribution grid and a boiler for backup and peak supply. If a cogeneration unit is installed, the boiler can be reduced in size, but not entirely replaced. The cogen unit therefore only saves marginal boiler costs, which are rather low. For example, a hotel could install a reciprocating engine. Due to spikiness of demand and the importance of heat supply, they still would have a regular boiler and not entirely depend on the reciprocating engine.

¶ Low demand - "replacement". Those applications do not require a gas grid connection and the boiler can be replaced entirely. Small demand peaks can be supplied by electricity. For example, a low energy house could get supplied entirely by a heat pump. No gas grid and no boiler would be put in place.

Table 10 gives an overview on the parameters necessary for reference cost calculation.

Fuel import costs are the same for both cases; losses for the gas distribution grid are close to zero. Thermal efficiency for regular gas boilers is estimated to 92%, losses occurring in the building itself are technology-independent and therefore not considered.

O&M cost are considered fix and rather independent from size [GAS-2]. Marginal costs are hence zero.

Investment costs in the case of mere substitution equal the marginal boiler costs[89], in the case of full replacement they amount to the sum of the full boiler and gas distribution grid. Compared to central electricity generation, the gas distribution grid can become obsolete in cases with little heat consumption, for instance small houses at current isolation standards. For those cases, grid cost has to be considered. Information is much more restraint on gas grid cost than it is for electricity grids[90]. A rough estimate for grid capacity cost is €100/kW$_{\text{fuel}}$. This is a very low estimate. Avoiding the installation of gas grids by using electric heat pumps is probably even more economic in reality than it seems already.[91]

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[88] The regarded technologies concern basically household and commercial applications. Industrial heat demand would in most cases refer to different technologies. In a lot of cases, CCGTs in cogeneration mode would then be the best choice.

[89] €2045 for a 11kW unit, €2531 for a 30kW unit, see [GAS-2]

[90] Combining information from [KÄS-1] and GEMIS leads to a rough assumption for gas grid costs of 0,34 ct/kWhtherm. Those grid costs are fixed, but this calculation takes the per unit cost at base consumption.

[91] Calculating the present value of gas grid tariffs [HAN-1] on a very conservative base (30 years, 10% interest, 50% operating costs, 12000kWh/a) leads to a value more than four times higher. So, either margins are outrageous, or grid capacity cost is much higher.

	O&M (ct/kWh$_{therm}$)	**Fuel** (ct/kWh$_{fuel}$)	**Thermal effic.** (%)	**Invest** (€/kW$_{therm}$)	**Lifetime** (hrs)	**Runtime** (hrs/a)
Substitution - residential	0,00	0,76[92]	92%	25	24.000	2100
Substitution - commercial	0,00			25		6000
Replacement	0,68			285		1300

Table 10: Parameters for heat reference cost

Lifetime for all units is estimated at 24.000 hrs, but low energy demand applications have fewer full-load hours. Regular households normally run for 1600 annual full-load hours ("runtime") for heating and another 500h/a for warm water[93], better isolation standards reduce heating requirement at least by half[94]. Runtime for commercial applications of course varies significantly with the application. The reference cost for one commercial application with a high and constant heat demand has been calculated as well. The result is rather similar to substitutional residential applications, though[95]. Therefore commercial and residential heat costs will not be regarded separately in the following.

Table 11 shows the results: The heat reference cost for capacity that partly substitutes reference infrastructure is 0.9 ct/kWh$_{thermal}$. The value is significantly higher, when the entire costs for the reference system can be saved.

2.3.2 Substitution (in ct/kWh$_{therm}$)	**2.3.3 Replacement** (in ct/kWh$_{therm}$)
0,9	3,3

Table 11: Heat reference cost for different cases

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[92] [BMW-1], page 30, for 1998. This is also in line with [HAN-1], page 164.

[93] [MAT-1] calculates with 2200 hrs/a, [EAE-1] with 1800 hrs/a or 2000 hrs/a (p. 183, 203, 223).

[94] [LAM-1] estimates end energy demand for heating to drop by half in the next decades. See [FEI-1] for overview on isolation standards until 1995: low energy houses account for one third of the energy demand of current houses, half of the 1984 standards and two thirds of the 1995 standards. In 2002, new standards have been put into place, "EnEV", that changed accounting procedures and now refer to primary energy demand. [LUT-1] estimates the reduction impact of EnEV 2002 to 25% compared to 1995 and 2/3 to the average building stock.

[95] This is because marginal costs of commercial boilers are extremely low. The possibility to reduce it in size thanks to a cogeneration unit or heat pump is not worth a lot.

2.4 TECHNOLOGY EVALUATION

After the previous paragraphs described the way that the technology evaluation is going to take place, the following will provide the actual analysis.

Cogeneration-, electricity- and heat- production technologies will be evaluated based on their current and future profitability, their emissions and resource consumption.

From these technologies, today only medium-size reciprocating engines are macroeconomically profitable, but all others except photovoltaics and solar thermal collectors are likely to become so. The prospects of heat pumps and SOFC ultra clearly dominate all other technologies and should become the focus of government policy.

2.4.1 Cost

2.4.1.1 Cogeneration today

Among the 2/1-cogeneration technologies that are readily available on the market today, medium sized reciprocating engines are the only ones that are clearly economically viable. Micro reciprocating engines are clearly not profitable for the national economy and microturbines and mini reciprocating engines basically break even (see Figure 7). Even raising annual runtime to 8760 hrs would not significantly change that. Table 12 gives the absolute profit figures.

Table 13 shows the parameters necessary for calculating current economic viability from a macroeconomic point of view[96]. Runtimes are smaller for residential applications than for commercial ones. Due to the peaky heat demand of households, the annual runtime could not be higher than some 1300 hrs/a if the full residential heat demand had to be provided by the cogeneration unit. This would never be economically viable. Therefore, those units are dimensioned to cover base load only. The additional heat demand has to be generated by an additional boiler; the electricity demand can be completed from the grid. In this case, an annual runtime of 3000 hrs has been chosen. This value can normally only be achieved for multi-dwelling units.

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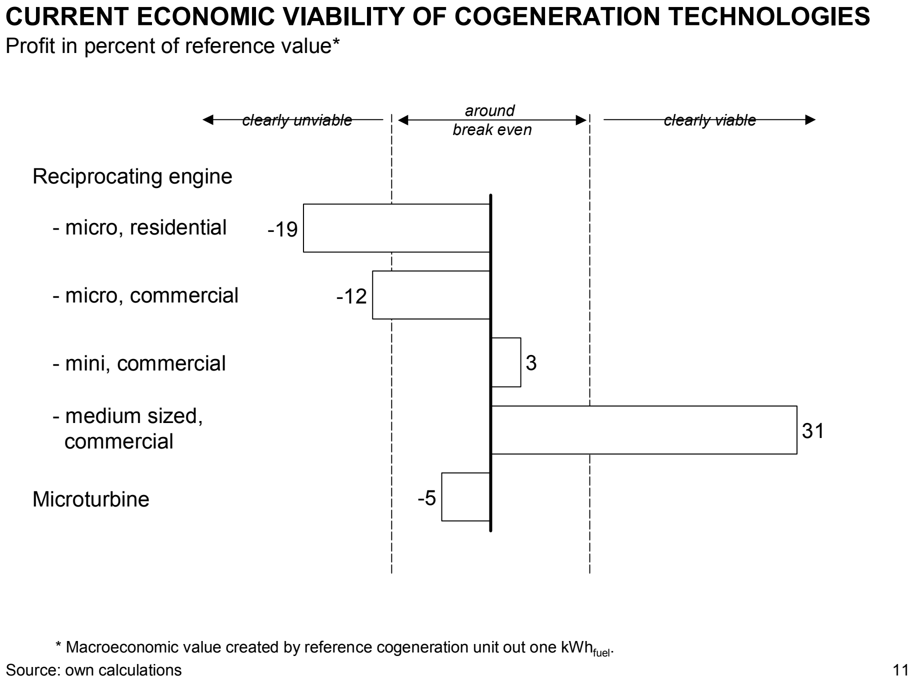
[96] Parameters are based on data from [FFM-1], [ASU-1] and own estimates.



CURRENT ECONOMIC VIABILITY OF COGENERATION TECHNOLOGIES
Profit in percent of reference value*

* Macroeconomic value created by reference cogeneration unit out one kWh_{fuel}.
Source: own calculations

Figure 7: Current economic viability of cogeneration technologies

Technology	**Macro-economic profit (ct/kWhfuel)**
Reciprocating engines - Micro, residential	-0,35
- Micro, commercial	-0,22
- Mini, commercial	0,06
- Medium sized, commercial	0,5
Microturbine	-0,14

Table 12: Financial viability of current cogeneration technologies

	Efficiency		**Invest** (€/kW_e)	**O&M** (€/kW_e a)	**Lifetime** (hrs)	**Runtime** (hrs/a)
	Electric	**Thermal**				
Reciprocating engine - Micro, residential	27%	61%	1700	1,4	80.000	3000
- Micro, commercial						4000
- Mini, commercial	34%	50%	960	1,4		
- Medium sized, commercial	38%	50%	540	1,0		
Microturbine	26%	54%	1500	0,7		

Table 13: Parameters for current cogeneration technologies[97]

The fact, that cogeneration units only cover base load, means also, that both cost and emission calculations have to consider the mix of the cogeneration and the peak supply units. The latter are often more expensive and dirtier than regular decoupled capacity and therefore deteriorate the performance of cogeneration units. It also limits the application of cogeneration technologies to a fraction of the total energy demand.[98] This is a significant weak point that is normally not discussed.[99]

Commercial applications can have much higher runtimes, up to 8760 hrs/year in case of high heat and little electricity demand, for instance in case of a swimming pool or a greenhouse. For this study, the regular runtime for cogeneration units is set to 4000 hrs/a.

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[97] Parameters have been taken from existing products, a medium-sized - (800kW$_e$, Höfler/Caterpillar), a mini - (65 kW$_e$, Höfler), a micro reciprocating engine (5 kW$_e$, Senertech) and a microturbine (60 kW$_e$, Capstone).

[98] Own simulations suggest a potential of 30%-60% of total electricity demand that theoretically could be supplied with cogeneration. See also [MCK-2].

[99] It is neither accounted for in this analysis. As cogeneration technologies do not look very favorable in this results anyway, not measuring those issues makes the statement even more secure.

Looking into the future, three new technologies will appear: PEMFC, SOFC ultra and Stirling engines. Furthermore, manufacturing costs will go down according to learning curve theory.

2.4.1.2 Cogeneration in the future

Table 14 gives an overview on the parameters of those new cogeneration technologies.

Stirling engines have been introduced on the US market for off-grid and backup power already, competing against microturbines. The first cogeneration Stirling engine is currently developed for the German market. Entry prices are estimated at €2700/kW$_e$[100] and expected to reach €1500/kW$_e$ once mass production has started [KÜB-1].

PEMFC cogeneration units are currently under field test. [ABB-1] estimates current cost at around €3100/kWe. For the following calculations, an earlier, but more comprehensive data point has been taken: the first installation of a Ballard 250kW$_e$ PEMFC in Berlin for roughly €15.000/kWe [SAN-1]. O&M costs are estimated on the basis of [NIT-1]. Lifetime is estimated at the manufacturer's target [VAI-1][101].

SOFC ultra's electric efficiency is estimated at 63%, the leading manufacturer's target. The current value is 58% only, but the potential goes up to 80%[102]. It is not a cogeneration technology in the narrow sense of 1/2-cogeneration, but more of an electricity generation or 2/1-cogeneration technology. That is way literature currently does not mention values on the potential additional thermal efficiency. The value has therefore been estimated. Indeed, the additional value of the heat bonus is little, but nevertheless both modes are feasible. The values for O&M and lifetime are taken from PEMFC. The runtime of SOFC ultras should be a little higher though, as they have a higher electricity-to-heat ratio and therefore have more generation hours for the same heat requirement. The cost sensitivity to that is negligible, though.

As Table 15 shows, none of these emerging technologies is currently financially viable. Especially fuel cells are too expensive.

The next step is to estimate whether those technologies will become economically viable with cost reduction thanks to learning effects or not.

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[100] [SEI-3] and interview with solo Stirling engines

[101] MCFC only achieve 40.000h, but work on a very difficult electrolyte. PAFC have a longer lifetime, but have sinking electric efficiency from 40.000h on. Vaillant's target of 80.000h seems ambitious, but is not contradicted by other sources.

[102] [AGF-2], page 257ff

	Efficiency		**Invest** (€/kW$_e$)	**O&M** (€/kW$_e$ a)	**Lifetime** (hrs)	**Runtime** (hrs/a)
	Electric	**Thermal**				
Stirling engine[103]	23%	67%	2.700	1,0	60.000	3.000
PEMFC[104]	35%	50%	15.000	0,7	80.000	3.000
SOFC ultra[105]	63%	23%	5.000	0,5	80.000	5.000

Table 14: Parameters for emerging cogeneration technologies

With every doubling of cumulative output, total cost are expected to drop by a certain percentage. Therefore reference point and growth volumes are needed in order to calculate the cost reduction. The reference point consists of the cumulative output at a certain time and the respective cost. Cumulative output and growth volume are measured in units. Here, the unit number will be translated into generation capacity.

	Profit (ct/kWh$_{fuel}$)	**Profit (% of reference value)** [106]	**Evaluation**
Stirling engine	-1,0	-52%	Very unprofitable
PEMFC	-11,0	-583%	Very unprofitable
SOFC ultra	-4,0	-215%	Very unprofitable

Table 15: Current profitability of new cogen technologies

Learning effects are not calculated for the reference technologies. In principle, also they profit from learning, but they have been produced in such high numbers, that

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[103] The Stirling Company -"Stirling 161", Interview Solo, [KÜB-1], [SEI-3]

[104] Vaillant, [ASU-1], [SAN-1], [NIT-1], own estimates

[105] [JOB-1], [AGF-2] p.257ff, own estimates

[106] For a better judgment on the relative profitability, the absolute profit is referred to the value generated from one kWh$_{fuel}$ by a generic cogeneration unit with an electric efficiency of 30% and an absolute efficiency of 80% which is 1.9 ct/kWh$_{fuel}$.

the expected cost reduction of a few thousand MW or € billions invested can be neglected.[107]

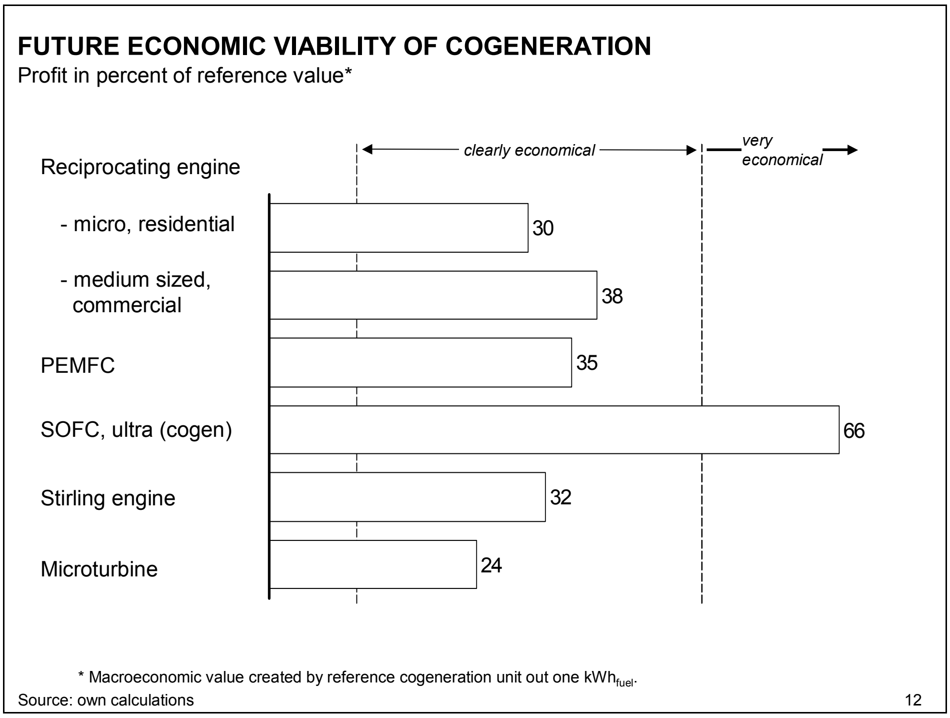

Figure 8: Future economic viability of cogeneration technologies

Table 16 and Figure 8 show the cost reduction effects of an investment worth € 5 billions under different assumptions for progress rates (PR). The amount of € 5 billions has been chosen randomly and represents a significant, but not unreasonable sum. It is equal to the government subsidies paid to German coal mining in 2001.[108]

At a progress ratio of 80% all emerging technologies would become clearly profitable, SOFC ultra even very profitable.

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[107] [AGF-2], p. 272, estimates cumulated CCGT capacity in 1997 being close to 150 GW and the progress ratio at 90%. Even reaching the expected future potential of €300/kWe would reduce reference electricity cost by 5% only.

[108] [HBL-1]

	Reciprocating engine		**PEMFC**	**SOFC ultra**	**Stirling engine**[109]	**Micro-turbine**
	Micro	**Medium**				
Capacity cost (€/kW$_e$) - Current[110]	1.700	540	15.000	5.000	2.750	1.500
- Future[111]	255	270	590	480	210	390
Profit - (ct/kWh$_{fuel}$)	0,6	0,7	0,7	1,2	0,6	0,5
- (% of ref. value)[112]	30%	38%	35%	66%	32%	24%
Viability	Clearly profit.	Clearly profit.	Clearly profit.	Very profit.	Clearly profit.	Clearly profit.
Min. PR[113]	97%	>100%	85%	89%	93%	>100%
Estim. PR[114]	75%	75%	75%	-	-	-

Table 16: Economic viability of cogeneration technologies after learning effects

The real progress ratio might be different though. Therefore, it also has to be analyzed, what minimum progress ratio is needed in order to reach break even. The financial viability of reciprocating engines and microturbines seems to be guaranteed, fuel cells and Stirling engines have the highest learning needs. Especially PEMFC are sensitive to the progress ratio. The results for Stirling engines are based on vague input data and have to be regarded with care. SOFC ultra have the highest upside potential. As fixed costs become less important with lower capacity costs, their high operating margin gives them a competitive edge compared to the others.

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[109] Figures based on vague input data. Learning effects would lead to the lowest capacity costs of all technologies regarded, 50% under those of micro reciprocating engines.

[110] Senertech; [SAN-1]; rough estimates based on [KÜB-1], [SEI-1] and interviews; [ASU-1]; [EID-12]

[111] Underlying progress ratio of 80%

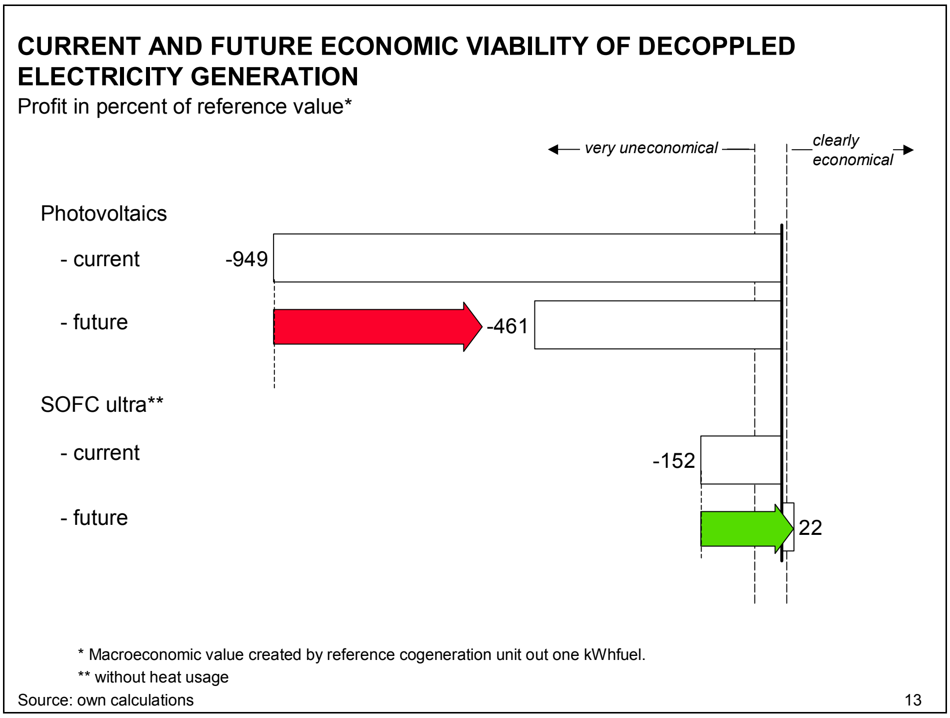
[112] For a better judgment on the relative profitability, the absolute profit is referred to the value generated from one kWh$_{fuel}$ by a generic cogeneration unit with an electric efficiency of 30% and an absolute efficiency of 80% which is 1.9 ct/kWh$_{fuel}$.

[113] Minimum progress ratio to achieve economic viability over learning curve on € 5 billion worth of investment

[114] Actual progress ration estimate for each technology, based on literature ([AGF-2], [NIT-1], [SAN-1]) and own estimates.

2.4.1.3 Decoupled electricity generation

Both photovoltaics and SOFC ultra without heat usage are very unprofitable today. Learning curve effects after the same investment as above change that partly (see Figure 9).



* Macroeconomic value created by reference cogeneration unit out one kWhfuel.
** without heat usage
Source: own calculations

Figure 9: Current and future economic viability of decoupled electricity generation

SOFC ultra enjoys roughly the same, high profitability whether the waste heat is used or not. The results are hence rather similar to those in the previous chapter. SOFC ultra today is very unprofitable, but can become clearly viable. The progress ratio needed for break even seems feasible.

Photovoltaics on the other hand would still remain to be very unprofitable. At the progress rate of 78%[115], PV would require investments of € 90 billions in order to come close to break even. This amount of money has been spend to subsidize coal mining in Germany in the last decades and in contrast to that, they would not be consumptive, but investive. Nevertheless, it is a lot of money compared to the funds needed for the financial viability of other technologies discussed so far.

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[115] suggested by [AGF-2], page 282

So, the PV technology that will be financially viable in Germany is probably not yet on the market.[116] Even exploding prices for natural gas would not change that. For this reason, [WEL-1] argues that subsidies should not be supporting market entry, as this is the case in Germany, but invested into further R&D.[117]

Table 17 summarizes the results.

	Profit (ct/kWh$_e$)	**Profit (% of electricity reference value)[118]**
Photovoltaics - Current	-42,0	-949%
- Future[119]	-20,4	-461%
SOFC ultra[120] - Current	-4,2	-152%
- Future[121]	1,0	+22%

Table 17: Economic viability of decoupled electricity generation technologies after learning effects

2.4.1.4 Decoupled heat generation

In contrast to electricity generation, there are no major cost savings to be expected for heat generation.

None of the three emerging technologies - high efficiency boilers, solar thermal collectors or heat pumps - is economically viable as add-on technology working in parallel to a regular boiler. Neither learning effects, nor high increases in natural gas prices are likely to change that (see Table 18).

---

[116] Nevertheless, the current renewable energy legislation (EEG) subsidizes photovoltaics with 50ct/kWh [GAI-3], while fuel cells get subsidies of only 5ct/kWh [FAZ-1].

[117] Another often mentioned aspect of photovoltaics is, that supply is rather unstable and still would require backup capacity. That is true, though once a higher share of electricity is derived from wind and solar energy, the "base load quality" of it will get better, as the likelihood is high that somewhere in Germany there is sun or wind.

[118] For a better judgment on the relative profitability, the absolute profit is referred to the value of one kWh$_e$, in this case 4,4 ct/ kWh$_e$.

[119] progress ratio 78%, investment € 5 billions. The installed base is estimated at 170 MWe peak in Germany for 2001 [KAL-1], [FTD-4].

[120] No usage of waste heat

[121] Progress ratio 80%, investment volume € 5 billions. Break even requires a progress ratio of at least 88%.

	Profit (ct/kWh_{therm})		**Profit (% of heat reference cost)**	
	Current	**Future**	**Current**	**Future**
High efficiency boiler	-0.7	-0.5	-82%	-54%
Solar thermal collector	-4.4	-2.8	-485%	-315%
Heat pump	-6.1	-2.2	-671%	-239%

Table 18: Economic viability of heat generation technologies in supplementary mode

The case is different when they entirely replace the boiler and hence have lower opportunity costs. High efficiency boilers could do so for all applications, heat pumps due to the limited local supply of solar energy only for small applications. Solar thermal collectors cannot replace a boiler entirely for two reasons: first, especially during winter peak demand needs to be supplied. While daytime is getting shorter, heat demand is getting up. The second reason is security of supply. Heat needs to be supplied even after a few days with only little sun.

When analyzing the financial viability of high efficiency boilers, a new reference value for heat costs has to be taken. The new boilers would replace the regular ones completely, but still need a gas grid connection. Opportunity costs hence have to comprise boiler cost, but not grid cost. The resulting reference cost for heat is ct 2.6/$kWh_{thermal}$.

For heat pumps, the regular heat reference cost for micro applications, substituting both boiler and gas grid connection, will be taken[122].

Under these assumptions, high-efficiency boilers would be profitable already today[123], heat pumps not. The learning effects of a € 5 billions investment would be sufficient for heat pumps to reach viability as well (see Table 19).

---

[122] 3.3 ct/$kWh_{thermal}$

[123] [GAS-2] still sees high-efficiency boilers a little, but not clearly more expensive than regular boilers.

	Profit (ct/kWh$_{therm}$)		**Profit (% of heat reference cost)**	
	Current	**Future**	**Current**	**Future**
High efficiency boiler	1.0	1.3	38%	-54%
Heat pump	-3.7	0.2	47%	7%

Table 19: Current and future economic viability of heat generation technologies as replacement

The parameters for both decoupled heating and electricity generation technologies are displayed in Table 20.

	Efficiency		**Invest (€/kW$_e$) (€/kW$_{therm}$)**	**O&M (€/kW$_e$ a) (€/kW$_{therm}$ a)**	**Lifetime (hrs)**	**Runtime (hrs/a)**
	Electric	**Thermal**				
Photovoltaics[124]	-		6.750	0,1	30.000	900
SOFC ultra (w/o heat usage)[125]	63%		5.000	0,5	80.000	5.000
High efficiency boiler[126]		103%	120	0,2	21.000	2.100
Solar thermal collector[127]		-	600	0,3	25.000	750
Heat pump[128]		370%	850	0,3	25.000	1.300

Table 20: Parameters for emerging decoupled technologies

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[124] see [GRE-1], interview with Shell Solar

[125] [JOB-1], [AGF-2]

[126] see [GAS-2], for 30kW$_{thermal}$,. For smaller applications, 11 kW $_{thermal}$,, regular boilers would still be slightly, but not clearly cheaper (8%).

[127] [EAE-1], [FAZ-2], [AGF-2], [HES-1], own estimates. As supplement, storage volume can be shared, reducing cost by another 15% [HES-1]. Some offers go down to €350/kW$_{thermal}$, without installation cost, though.

[128] [EAE-1] contains some calculations for earth based heat pumps with vertical connection. Values for O&M and lifetime are own estimates. The runtime corresponds to a house isolated according to new standards. Heat pumps can be applied in houses with floor heating only, anyway, which are mostly new houses. Furthermore, they often are not able to supply bigger heat demands, so that they could only supplement an existing boiler. Here, the favorable example is taken only. Bigger applications will not be viable anyway in most cases.

Summarizing, the only technology for electricity generation that is currently financially viable from a macroeconomic point of view is medium-sized reciprocating engines in cogeneration mode. Microturbines are close to break even.

In the future, especially ultra efficient systems consisting out of high temperature fuels cells and microturbines[129] could become very profitable. Financially, they could outperform all other technologies regardless whether the waste heat is used or not.

Learning effects[130] could make most other emerging technologies viable as well, to a smaller degree though. The case of Stirling engines needs further investigation, but could be financially promising as well.

Out of the two self-sufficient heating technologies, high efficiency boilers are profitable already[131] today and heat pumps can reach break even.

The two "direct-solar" technologies, photovoltaics and solar thermal collectors, are very unprofitable today and will remain so, regardless of medium-term learning effects and energy price changes. The technology exploiting renewable energy that looks economically promising is hence heat pumps.

2.4.2 Resources

As discussed before, the fuel consumption of the technologies compared is proportional to their CO_2 emissions and will be examined in detail in the next chapter.

Nevertheless, this is a good point to put the general Sanctus on cogeneration into perspective. Even the well-staffed environmental council[132] generally views cogeneration as "indispensable instrument for a national climate protection policy".[133]

This general statement holds only, though, if making the illegitimate reference to old technologies. As shown in Figure 10 on the left table, in that case the fuel and CO_2 savings are huge, basically regardless the parameters of the cogeneration unit. Choosing a fair reference with current gas-based technologies changes that

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[129] SOFC ultra

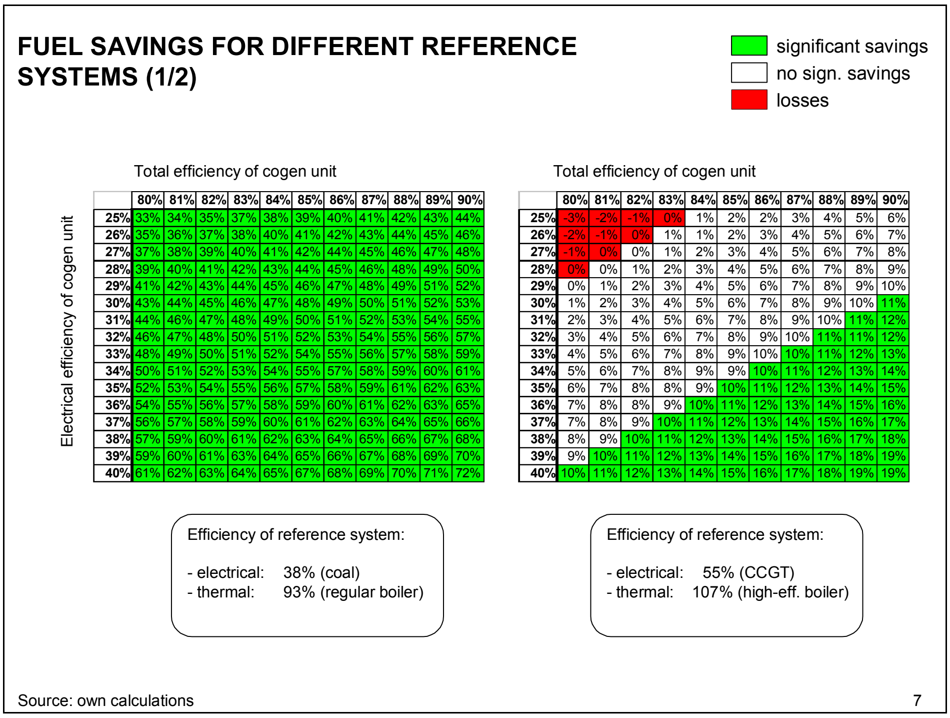
[130] a total investment worth € 5 billion

[131] for $30kW_{thermal}$ applications. For small, single household applications of $11kW_{thermal}$ they roughly break even.

[132] "Umweltrat", comprising seven professors and counseling the Federal Minister of Environment

[133] see [EID-8]

drastically. Only the more efficient machines still achieve significant savings[134]. Most machines would be roughly equal, some even with the tendency to consume more fuel than the reference system. And that at a much higher cost!



FUEL SAVINGS FOR DIFFERENT REFERENCE SYSTEMS (1/2)

🟩 significant savings
☐ no sign. savings
🟥 losses

Total efficiency of cogen unit

Electrical efficiency of cogen unit

	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%
25%	33%	34%	35%	37%	38%	39%	40%	41%	42%	43%	44%
26%	35%	36%	37%	38%	40%	41%	42%	43%	44%	45%	46%
27%	37%	38%	39%	40%	41%	42%	44%	45%	46%	47%	48%
28%	39%	40%	41%	42%	43%	44%	45%	46%	48%	49%	50%
29%	41%	42%	43%	44%	45%	46%	47%	48%	49%	51%	52%
30%	43%	44%	45%	46%	47%	48%	49%	50%	51%	52%	53%
31%	44%	46%	47%	48%	49%	50%	51%	52%	53%	54%	55%
32%	46%	47%	48%	50%	51%	52%	53%	54%	55%	56%	57%
33%	48%	49%	50%	51%	52%	54%	55%	56%	57%	58%	59%
34%	50%	51%	52%	53%	54%	55%	57%	58%	59%	60%	61%
35%	52%	53%	54%	55%	56%	57%	58%	59%	61%	62%	63%
36%	54%	55%	56%	57%	58%	59%	60%	61%	62%	63%	65%
37%	56%	57%	58%	59%	60%	61%	62%	63%	64%	65%	66%
38%	57%	59%	60%	61%	62%	63%	64%	65%	66%	67%	68%
39%	59%	60%	61%	63%	64%	65%	66%	67%	68%	69%	70%
40%	61%	62%	63%	64%	65%	67%	68%	69%	70%	71%	72%

Efficiency of reference system:

- electrical: 38% (coal)
- thermal: 93% (regular boiler)

Total efficiency of cogen unit

	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%
25%	-3%	-2%	-1%	0%	1%	2%	2%	3%	4%	5%	6%
26%	-2%	-1%	0%	1%	1%	2%	3%	4%	5%	6%	7%
27%	-1%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%
28%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%
29%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
30%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%
31%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%
32%	3%	4%	5%	6%	7%	8%	9%	10%	11%	11%	12%
33%	4%	5%	6%	7%	8%	9%	10%	10%	11%	12%	13%
34%	5%	6%	7%	8%	9%	9%	10%	11%	12%	13%	14%
35%	6%	7%	8%	8%	9%	10%	11%	12%	13%	14%	15%
36%	7%	8%	8%	9%	10%	11%	12%	13%	14%	15%	16%
37%	7%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%
38%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%
39%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%
40%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%	19%

Efficiency of reference system:

- electrical: 55% (CCGT)
- thermal: 107% (high-eff. boiler)

Source: own calculations

7

Figure 10: Fuel savings for different reference systems (1/2)

Figure 11 shows, that under current conditions, only PEM fuel cells and big reciprocating engines would have significant savings. The first do not yet exist for household applications, for the latter those savings are only valid for sizable applications. In small district heating nets, the huge distribution losses for heat would change that result. Small reciprocating engines and Stirling engines would just break even, microturbines even with a tendency to waste fuel.

Looking ahead, the arrival of SOFC ultra on the market[135] will put the initial statement completely upside down (see Figure 12). None of the 1/2-cogeneration technologies[136] will still achieve significant savings, if any at all. Microturbines would even significantly waste fuel and emit significantly more CO_2.

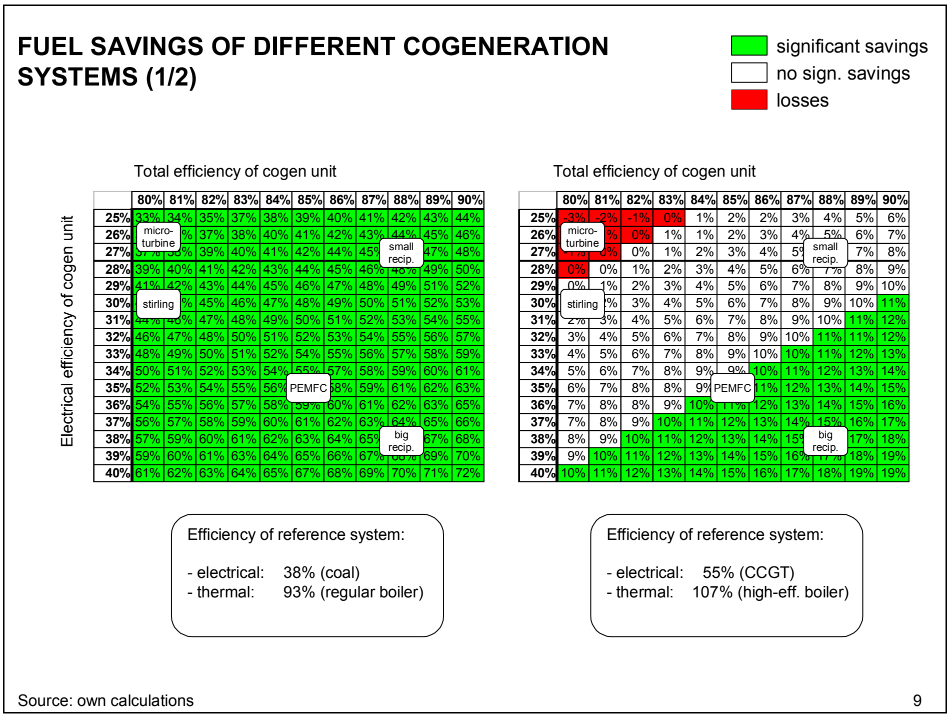
---

[134] larger than 10%

[135] Also the thermal efficiency of the high-efficiency boiler has been chosen a little higher. This value is nevertheless already achieved today, see for instance MAN Micromat EC at http://www.klint.de/heizung.htm.

[136] Technologies where the thermal efficiency is twice as high as the electric one, as Stirling or reciprocating engines, as opposed to 2/1-cogeneration technologies like CCGT or SOFC ultra, where the electric efficiency is twice as

Summarizing, cogeneration is neither the solution to our energy nor to our climate problems. Already today, not all cogeneration systems do achieve any savings at all and none to the extent that could really address the problem.[137] In the future, those technologies will even look worse.



FUEL SAVINGS OF DIFFERENT COGENERATION SYSTEMS (1/2)

🟩 significant savings
☐ no sign. savings
🟥 losses

Total efficiency of cogen unit (columns); Electrical efficiency of cogen unit (rows)

	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%
25%	33%	34%	35%	37%	38%	39%	40%	41%	42%	43%	44%
26%	[illegible]	[illegible]	37%	38%	40%	41%	42%	43%	44%	45%	46%
27%	37%	38%	39%	40%	41%	42%	44%	45%	[illegible]	47%	48%
28%	39%	40%	41%	42%	43%	44%	45%	46%	48%	49%	50%
29%	41%	42%	43%	44%	45%	46%	47%	48%	49%	51%	52%
30%	[illegible]	[illegible]	45%	46%	47%	48%	49%	50%	51%	52%	53%
31%	44%	46%	47%	48%	49%	50%	51%	52%	53%	54%	55%
32%	46%	47%	48%	50%	51%	52%	53%	54%	55%	56%	57%
33%	48%	49%	50%	51%	52%	54%	55%	56%	57%	58%	59%
34%	50%	51%	52%	53%	54%	55%	57%	58%	59%	60%	61%
35%	52%	53%	54%	55%	56%	[illegible]	58%	59%	61%	62%	63%
36%	54%	55%	56%	57%	58%	59%	60%	61%	62%	63%	65%
37%	56%	57%	58%	59%	60%	61%	62%	63%	64%	65%	66%
38%	57%	59%	60%	61%	62%	63%	64%	65%	[illegible]	67%	68%
39%	59%	60%	61%	63%	64%	65%	66%	67%	68%	69%	70%
40%	61%	62%	63%	64%	65%	67%	68%	69%	70%	71%	72%

Efficiency of reference system:

- electrical: 38% (coal)
- thermal: 93% (regular boiler)

	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%
25%	-3%	-2%	-1%	0%	1%	2%	2%	3%	4%	5%	6%
26%	[illegible]	[illegible]	0%	1%	1%	2%	3%	4%	5%	6%	7%
27%	-1%	0%	0%	1%	2%	3%	4%	5%	[illegible]	7%	8%
28%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%
29%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
30%	[illegible]	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%
31%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%
32%	3%	4%	5%	6%	7%	8%	9%	10%	11%	11%	12%
33%	4%	5%	6%	7%	8%	9%	10%	10%	11%	12%	13%
34%	5%	6%	7%	8%	9%	9%	10%	11%	12%	13%	14%
35%	6%	7%	8%	8%	9%	[illegible]	11%	12%	13%	14%	15%
36%	7%	8%	8%	9%	10%	11%	12%	13%	14%	15%	16%
37%	7%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%
38%	8%	9%	10%	11%	12%	13%	14%	15%	[illegible]	17%	18%
39%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%
40%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%	19%

Efficiency of reference system:

- electrical: 55% (CCGT)
- thermal: 107% (high-eff. boiler)

Source: own calculations

Figure 11: Fuel savings of different cogeneration systems (1/2)

The statement, that cogeneration was an indispensable tool for our climate protection policy is wrong. It is a thermodynamic principal and its application does not generally absolve technologies from having low electrical efficiencies. Efficient technologies like CCGTs or SOFC ultras can of course be operated in cogeneration. This will further, but only to a small extent, improve their performance.

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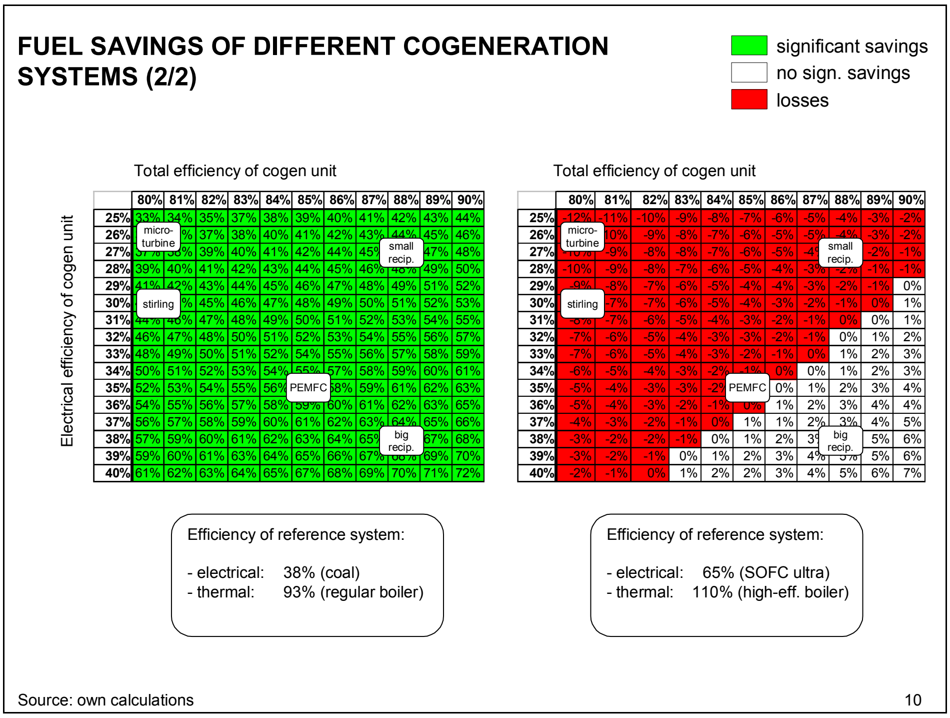
high as the thermal one. In fact, the latter could also be just called electricity generation technologies and they are viable as well, when they do not use the heat.

[137] Additionally it has to be seen, that cogeneration can technically only supply a part of the total electricity demand, as it requires a heat consumer with a good fit close by. This share is much less than 60%, see [MCK-2]. District heating systems also operate with high losses in the distribution systems that are not accounted for here.

The current investments into outdated 1/2-cogeneration technologies are a waste of subsidies, tax exemptions and people's mind share.



FUEL SAVINGS OF DIFFERENT COGENERATION SYSTEMS (2/2)

🟩 significant savings
☐ no sign. savings
🟥 losses

Total efficiency of cogen unit

Electrical efficiency of cogen unit

	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%
25%	33%	34%	35%	37%	38%	39%	40%	41%	42%	43%	44%
26%	[illegible]	[illegible]	37%	38%	40%	41%	42%	43%	44%	45%	46%
27%	37%	38%	39%	40%	41%	42%	44%	45%	[illegible]	47%	48%
28%	39%	40%	41%	42%	43%	44%	45%	46%	48%	49%	50%
29%	41%	42%	43%	44%	45%	46%	47%	48%	49%	51%	52%
30%	[illegible]	[illegible]	45%	46%	47%	48%	49%	50%	51%	52%	53%
31%	44%	46%	47%	48%	49%	50%	51%	52%	53%	54%	55%
32%	46%	47%	48%	50%	51%	52%	53%	54%	55%	56%	57%
33%	48%	49%	50%	51%	52%	54%	55%	56%	57%	58%	59%
34%	50%	51%	52%	53%	54%	55%	57%	58%	59%	60%	61%
35%	52%	53%	54%	55%	56%	[illegible]	58%	59%	61%	62%	63%
36%	54%	55%	56%	57%	58%	59%	60%	61%	62%	63%	65%
37%	56%	57%	58%	59%	60%	61%	62%	63%	64%	65%	66%
38%	57%	59%	60%	61%	62%	63%	64%	65%	[illegible]	67%	68%
39%	59%	60%	61%	63%	64%	65%	66%	67%	68%	69%	70%
40%	61%	62%	63%	64%	65%	67%	68%	69%	70%	71%	72%

Efficiency of reference system:

- electrical: 38% (coal)
- thermal: 93% (regular boiler)

Total efficiency of cogen unit

	80%	81%	82%	83%	84%	85%	86%	87%	88%	89%	90%
25%	-12%	-11%	-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%
26%	[illegible]	10%	-9%	-8%	-7%	-6%	-5%	-5%	-4%	-3%	-2%
27%	-10%	-9%	-8%	-8%	-7%	-6%	-5%	-4%	[illegible]	-2%	-1%
28%	-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	-1%
29%	-9%	-8%	-7%	-6%	-5%	-4%	-4%	-3%	-2%	-1%	0%
30%	[illegible]	-7%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%
31%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	0%	1%
32%	-7%	-6%	-5%	-4%	-3%	-3%	-2%	-1%	0%	1%	2%
33%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%
34%	-6%	-5%	-4%	-3%	-2%	-1%	0%	0%	1%	2%	3%
35%	-5%	-4%	-3%	-3%	-2%	[illegible]	0%	1%	2%	3%	4%
36%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	4%
37%	-4%	-3%	-2%	-1%	0%	1%	1%	2%	3%	4%	5%
38%	-3%	-2%	-2%	-1%	0%	1%	2%	3%	[illegible]	5%	6%
39%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%	5%	6%
40%	-2%	-1%	0%	1%	2%	2%	3%	4%	5%	6%	7%

Efficiency of reference system:

- electrical: 65% (SOFC ultra)
- thermal: 110% (high-eff. boiler)

Source: own calculations

10

Figure 12: Fuel savings of different cogeneration systems (2/2)

2.4.3 Emissions

Emissions are another important factor when deciding on future energy technologies. The calculation of emissions has quite a few different aspects.

1. First, technologies have different electrical and thermal efficiencies and therefore need more or less fuel.
2. Second, different fuels have different chemical compositions and therefore automatically cause different levels of, for instance, CO_2- and SO_2-emissions. Those two effects combined lead to a kind of minimum pollution based on the chemical and thermo dynamical fundamentals of fuels and technologies.
3. A third aspect is the cleanliness of the combustion, that determines whether additional emissions, like NO_x, are generated or not.
4. Last, emissions during the production process of fuels and machinery have to be considered as well for a comprehensive picture.

Two different approaches will be used for calculating emissions:

¶ A simple one, easy to understand, with results on three substances, comprising the steps 1-3 from above and looking at the combustion process only.

¶ A sophisticated one, using GEMIS in order to calculate emission equivalents and conducting analysis along the entire value chain. It is less transparent and has some principal disadvantages, but it is useful to verify and extent the results of the first approach.

2.4.3.1 Basic emission analysis

This model will look at the effects that different electrical and thermal efficiencies, different types of fuel and different cleanliness of the technologies have and results in a kind of minimum pollution caused by each of them. Fully renewable technologies will not be regarded, as their emissions are caused in the manufacturing process only, which is omitted here.

2.4.3.1.1 Fuel savings

Fuel savings, to start with, are calculated by burning the same amount of fuel in each technology to be evaluated. Then, the technology gets a fuel bonus for both the heat and electricity that it generated and that now do not have to be produced with the reference technologies. There are three different reference scenarios: coal plants and regular boilers, CCGTs and regular boilers and, third, SOFC ultra and high-efficiency boilers. The efficiencies of the emerging technologies are displayed in Table 21, those of the reference technologies in Table 22.

Technology	Electric efficiency	Thermal efficiency
Heat pump		368%
Microturbine	26%	54%
PEMFC	35%	50%
Reciprocating engine, big	38%	50%
Reciprocating engine, small	27%	61%
SOFC ultra	65%	0%
SOFC ultra, cogen	65%	20%
Stirling engine	30%	50%

Table 21: Efficiency parameters of emerging technologies

Technology	Electric efficiency	Thermal efficiency
CCGT	55%	
Coal plant[138]	34%	
High efficiency boiler		107%
Regular boiler		94%
SOFC ultra	65%	

Table 22: Efficiency parameters of reference technologies

Table 23 shows the results for all three different scenarios. A negative value means that fuel is saved compared to the reference scenario.

Emerging technology	Scenario 1	Scenario 2	Scenario 3
Heat pump	-33%	-115%	-124%
Microturbine	-35%	-5%	9%
PEMFC	-56%	-17%	-1%
Reciprocating engine, big	-65%	-22%	-5%
Reciprocating engine, small	-44%	-14%	1%
SOFC ultra	-91%	-18%	0%
SOFC ultra, cogen	-112%	-39%	-19%
Stirling engine	-41%	-8%	7%

Table 23: Fuel savings of emerging technologies

In scenario 1, with coal plants and regular boilers as reference technologies, SOFC ultra save by far the most fuel, regardless whether used in cogeneration or not. Second are big reciprocating engines and PEMFC with half of that savings, more closely following by the other cogeneration technologies and heat pumps.

The result looks rather different for scenario 2, where CCGTs and regular boilers are reference technologies (see Figure 13). Here, heat pumps are suddenly not the

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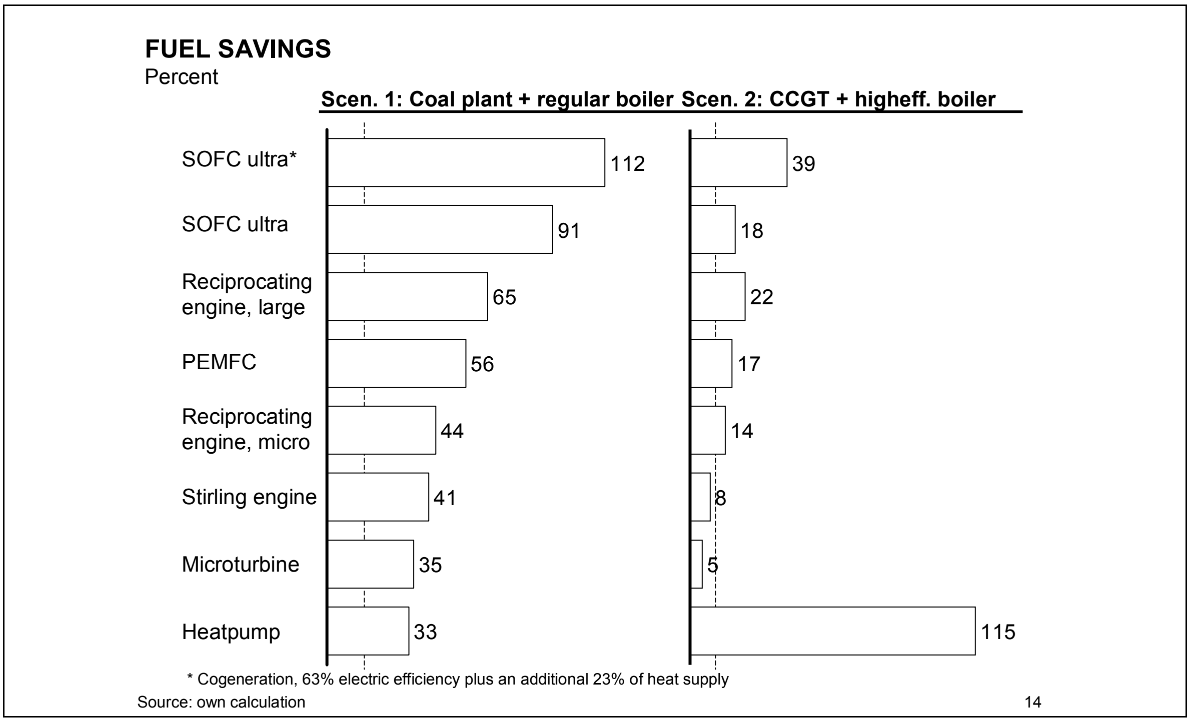
[138] at technological level of current generation park

least, but by far the most fuel economic technology. Second are SOFC ultra in cogeneration mode, with only a third of that reduction. Third, with another 50% below that, are big reciprocating engines, SOFC ultra without cogen and PEMFC. Still most technologies lead to significant reductions, only Stirling engines and microturbines just more or less break even.



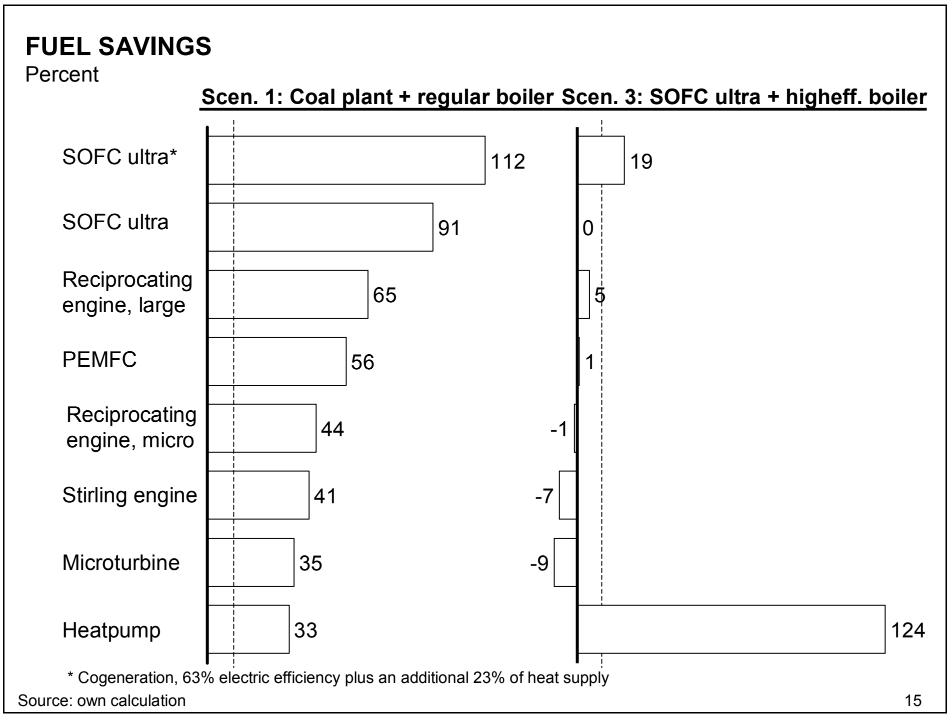
* Cogeneration, 63% electric efficiency plus an additional 23% of heat supply

Source: own calculation

Figure 13: Fuel savings in scenario 1 and 2

This reversal is even a little stronger in the third scenario, with SOFC ultra and high-efficiency boilers as reference (see Figure 13). Heat pumps have an even bigger fuel saving advantage than any other technology. Second are SOFC ultra in cogeneration, with 1/6 of the savings. Big reciprocating engines and PEMFC still save fuel, to a rather modest extent though. The other technologies, small reciprocating engines, Stirling engines and microturbines more or less break even, with tendencies to even consume more energy than the reference case (see Figure 14).

Looking at fuel consumption alone leads to two conclusions: First, choosing the reference case is crucial and influences results by 180°: heat pumps are either best or worst, some cogeneration technologies either save fuel or waste it. Second, looking at relevant reference technologies of today and tomorrow, heat pumps are by far the most economic technology. SOFC ultra should be supported whether in cogeneration or not[139]. Last, big reciprocating engines and PEMFC are not harmful, but do not have significant effects on fuel consumption, especially when considering that they need concurrent demand of heat and electricity in a certain relation.



Source: own calculation

Figure 14: Fuel savings in scenario 1 and 3

2.4.3.1.2 Fuel-inherent pollution

The combustion of fuel frees energy because of the oxidation of C, H and S. Depending on the share of those elements in a certain type of fuel, its combustion leads automatically to different emission levels of CO_2 and SO_2. This is why different fuels should not be compared. Table 24 and Figure 15 will make this even more apparent. Lignite and coal principally cause twice as much CO_2 emissions and several thousand times more SO_2 emissions than natural gas. Even the most outdated technologies will therefore look brilliant, if they only replace coal with natural gas.

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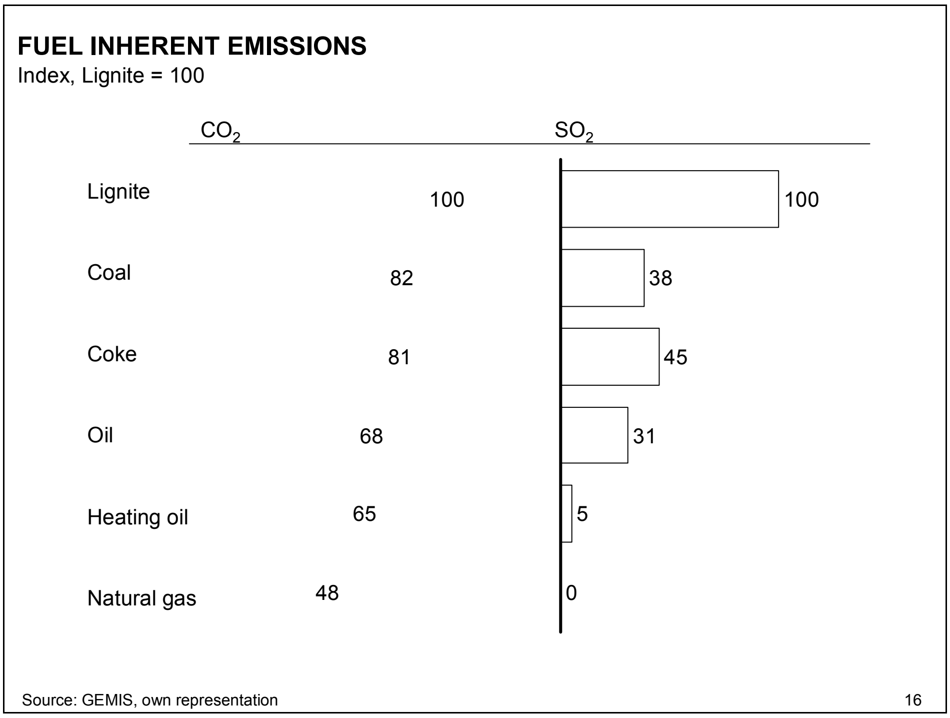
[139] SOFC ultra without cogeneration seem not to lead to any savings in the 3rd scenario, but this is by definition: they are taken as reference technology.



Source: GEMIS, own representation

Figure 15: Fuel inherent emissions

Fuel	CO2 Kg/GJ	SO2 Kg/TJ
Lignite	114,4	1616,9
Coal	93,3	611,6
Coke	92,5	719,8
Oil	78,3	499,5
Heating oil	74,4	77,4
Natural gas	55,2	0,4

Table 24[140]: Fuel-inherent emissions

2.4.3.1.3 Minimum pollution

Combining fuel efficiency with fuel inherent emissions of the required fuels leads to minimum emissions of technologies.

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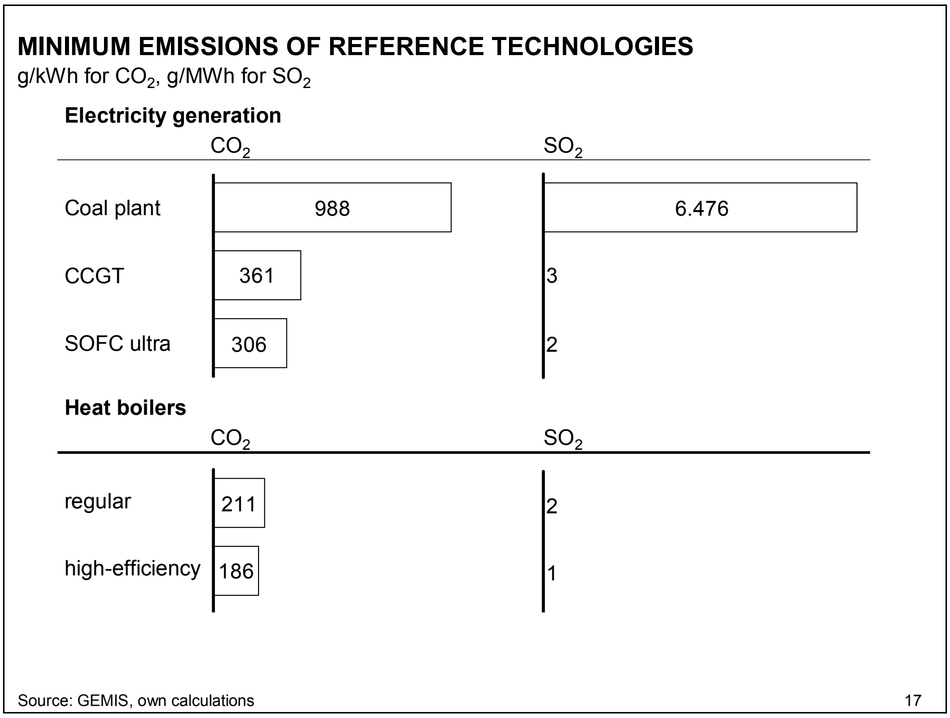
[140] GEMIS

Table 25 and Figure 16 and show the results for the reference technologies, Table 26 those of the emerging technologies.

Technology	**Electricity**		**Heat**	
	CO2 (g/kWh)	**SO2 (g/MWh)**	**CO2 (g/kWh)**	**SO2 (g/MWh)**
CCGT	361	3		
Coal plant	988	6.476		
High efficiency boiler			186	1
Regular boiler			211	2
SOFC ultra	306	2		

Table 25: Minimum emissions of reference technologies

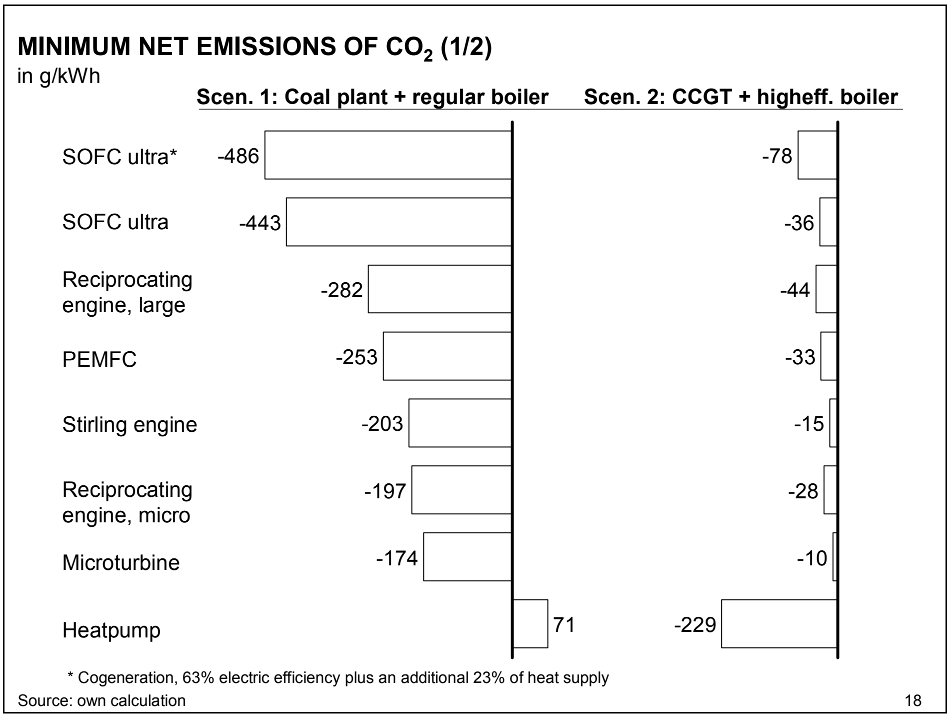


Source: GEMIS, own calculations

Figure 16: Minimum emissions of reference technologies

	Scenario 1		Scenario 2		Scenario 3	
Technology	**CO2 (g/kWh)**	**SO2 (g/MWh)**	**CO2 (g/kWh)**	**SO2 (g/kWh)**	**CO2 (g/kWh)**	**SO2 (g/kWh)**
Heat pump	71	2.200	-229	-1,66	-246	-1,78
Microturbine	-174	-1.689	-10	-0,08	18	0,13
PEMFC	-253	-2.266	-33	-0,24	-1	-0,01
Reciprocating engines, big	-282	-2.460	-44	-0,32	-10	-0,07
Reciprocating engines, small	-197	-1.748	-28	-0,20	3	0,02
SOFC ultra	-443	-4.208	-36	-0,26	0	0,00
SOFC ultra, cogen	-486	-4.208	-78	-0,57	-37	-0,27
Stirling engine	-203	-1.942	-15	-0,11	14	0,10

Table 26: Minimum emissions of decentral technologies



* Cogeneration, 63% electric efficiency plus an additional 23% of heat supply

Source: own calculation

Figure 17: Minimum net emissions of CO$_2$ in scenario 1 and 2

The results are principally like that of fuel savings. Heat pumps are by far least performing in the first scenario and by far best performing in the other ones. SOFC ultra is second, the only other technology with relevant savings at least on the CO_2 side are big reciprocating engines. Figure 17 shows the dramatic difference between coal and CCGT as references (scenario 1 and 2). Changing reference from CCGT to SOFC ultra leads to a little further improvement of heat pumps and to a small further loss of competitiveness for cogeneration technologies, see Figure 18.

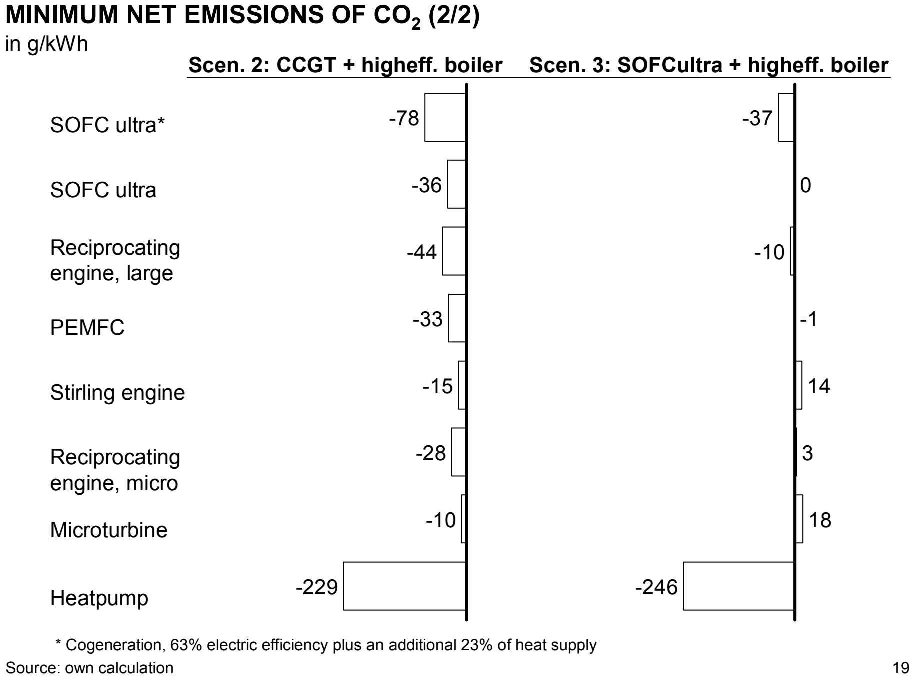


Figure 18: Minimum net emissions of CO_2 in scenario 2 and 3

2.4.3.1.4 Cleanliness of combustion

Due to different temperatures, pressures or even physical processes, the combustion of fuels leads to harmful substances that could principally be avoided. The most important one is NO_x that harms both biology and materials and therefore influences SO_2- and TOPP- equivalents. Table 27 shows the NO_x values of emerging technologies, Table 28 that of reference technologies. The values are based on an index related to mg/Nm^3 of the exhausts.

Technology	**NOx (Index)**
Heat pump	
Microturbine	20
PEMFC	4
Reciprocating engine, big	250
Reciprocating engine, small	400
SOFC ultra	10
SOFC ultra, cogen	10
Stirling engine	20

Table 27: Cleanliness of pollution - emerging technologies

	Electricity	**Heat**
	NOx (Index)	**NOx (Index)**
Scenario 1	2.941	85
Scenario 2	455	85
Scenario 3	15	75

Table 28: Cleanliness of reference technologies

The parameters show, that there are huge differences in the cleanliness of the different technologies. Coal plants, in scenario 1, are again by far the dirtiest ones. Reciprocating engines are clearly second, this time. All other technologies are much cleaner. Microturbines and Stirling engines have very constant and rather low-temperature combustion[141]. Fuel cells do not work on combustion in its narrow sense, but with a catalytic process and are even cleaner.

As a result, heat pumps are again dirtiest and SOFC ultra cleanest in scenario 1. Taking CCGTs as reference in scenario 2 drastically reduces differences between the technologies (Figure 19). And the only one, that clearly is less competitive than the reference, is micro reciprocating engines. Taking SOFC ultra as reference in the third scenario (see Figure 20), this time makes a big difference as well. Heat

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[141] current Stirling prototypes in Germany apply the so-called FLOX technology, operating at rather low temperatures and therefore achieving very little levels of NO_x.

pumps become they only technology that significantly saves NO_x emissions and reciprocating engines the only ones that significantly pollute more. All other ones more or less break even.[142]

	Scenario 1	Scenario 2	Scenario 3
Technology	**NOx (Index)**	**NOx (Index)**	**NOx (Index)**
Heat pump	894	78	-169
Microturbine	-794	-145	-25
PEMFC	-1.068	-198	-39
Reciprocating engine, big	-910	35	207
Reciprocating engine, small	-446	225	350
SOFC ultra	-1.902	-285	0
SOFC ultra, cogen	-1.919	-302	-15
Stirling engine	-905	-159	-22

Table 29: Net cleanliness of emerging technologies

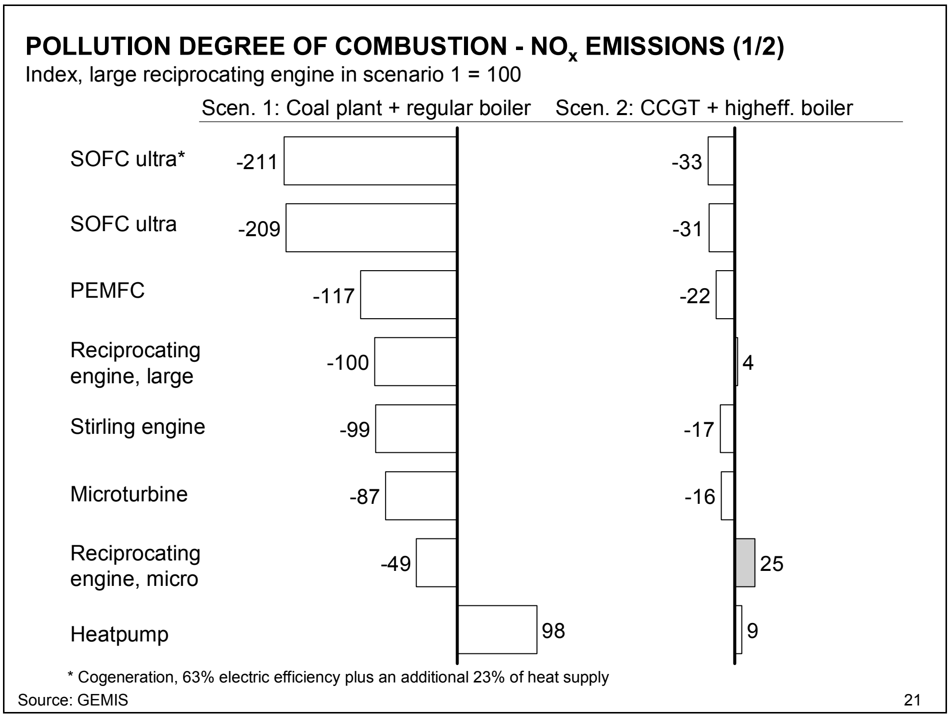

Figure 19: Pollution degree of combustions (1/2)

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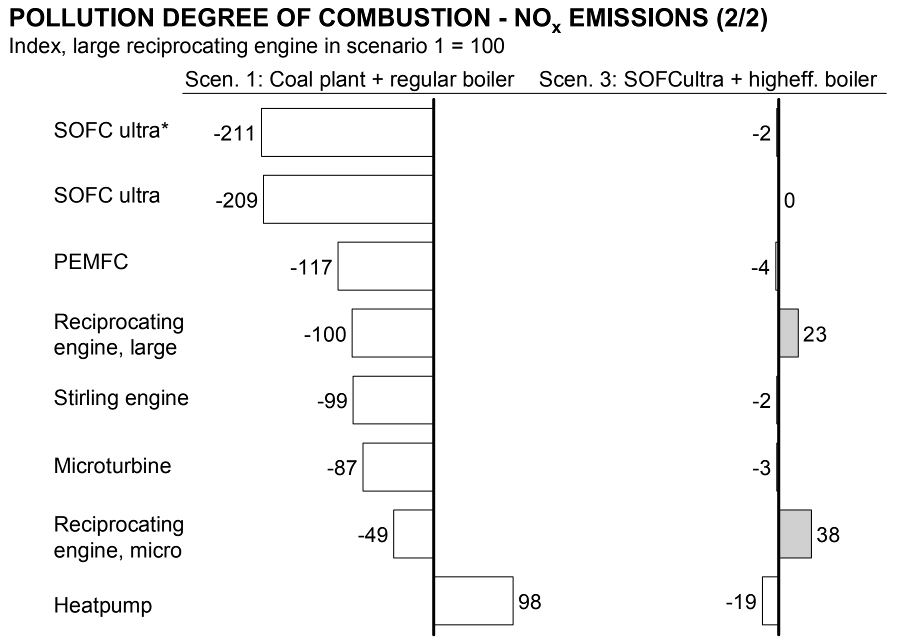
[142] For fuel cells, Stirling engines and microturbines, input parameters are even not that accurate, so that the small differences that exist amongst them are not significant.



* Cogeneration, 63% electric efficiency plus an additional 23% of heat supply

Source: own calculation

Figure 20: Pollution degree of combustions (2/2)

Summarizing, the basic analysis leads to three conclusions:

¶ SOFC ultra, with or without cogeneration, is undoubtedly the key technology to cleaner energy generation.

¶ Heat pumps lead to the greatest emission savings under a relevant comparison. The only exceptions are NO_x values in case of CCGT generated electricity. These are still better than those of reciprocating engines, though.

¶ The currently favored cogeneration technologies[143] lead, if at all, to minor emission savings only.

2.4.3.2 Emission calculation based on GEMIS

In the following, emissions will be calculated using GEMIS in order to answer the following questions:

1. Does GEMIS come to the same results?

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[143] In the narrow sense of 1/2-cogeneration technologies like reciprocating engines, microturbines and Stirling engines

2. Are CO_2, SO_2 and NO_x good indicators for CO_2-, SO_2- and TOPP-equivalents and therefore for external effects caused?
3. Do results change when the entire value chain is regarded? How well do pure renewables compare to the technologies discussed above?

Regarding the first question, GEMIS results are not entirely different, but nevertheless not comparably to the results from the above calculation. The most important reason is, that it supports emission calculation per kWh_e or $kWh_{thermal}$ and therefore causes the distortion effects discussed in chapter 2.1.1.5. Furthermore, effects from the early value chain seem to always integrate to some extent. Nevertheless, comparing results from different GEMIS scenarios leads to conclusions that are valid in general as well.

Looking at the second question, the three substances - CO_2, SO_2 and NO_x - are indeed good indicators for CO_2-, SO_2- and TOPP-equivalents. The relation between CO_2 and its equivalent is rather direct, as shown in Figure 21.

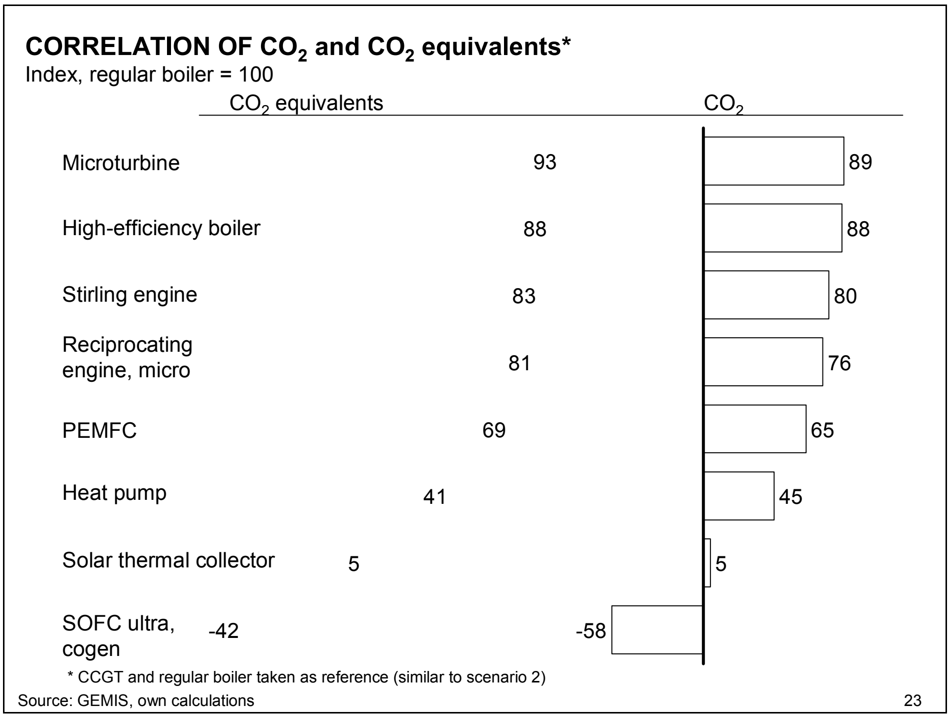
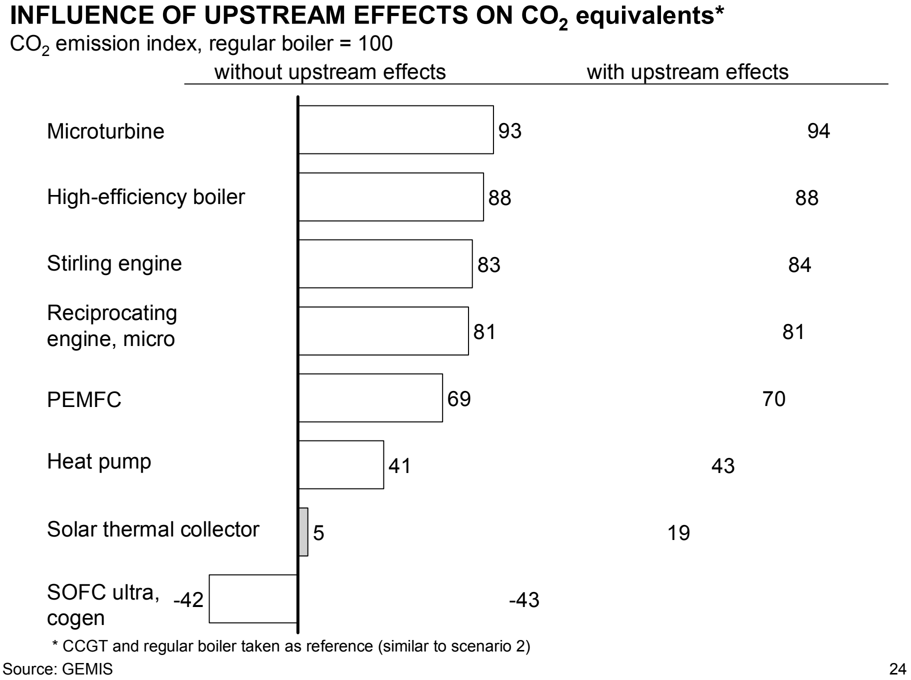


Figure 21: Correlation of CO_2 and CO_2-equivalents

In contrast to that, SO_2 equivalents cannot be explained by SO_2 only, but from a combination of SO_2 and NO_x. NO_x explains rather exhaustively the GEMIS results for TOPP equivalents.

Last, looking at the entire value chain instead of the generation process only does not significantly change results. Pure renewables, though, suddenly appear as more pollutant than supposed, but still remain cleaner than other technologies, see Figure 22.[144]



* CCGT and regular boiler taken as reference (similar to scenario 2)

Source: GEMIS

Figure 22: Influence of upstream effects on CO_2 equivalents

Summarizing, GEMIS results should not be compared with the analysis of this study as it is looking at different aspects. Nevertheless, it can be concluded that the results of the emission analysis conducted in this study are valid on a larger scale, including the impact of emissions and upstream value chain impact.

2.5 WHAT ARE THE DOMINANT TECHNOLOGIES?

The energy technologies selected in this study have been compared along four quantitative parameters: cost and emissions of CO_2-, SO_2- and TOPP equivalents. Coming up with a clear ranking in most cases would require weighting the different factors and come up with a single, composed performance indicator.

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[144] For the upstream ecologic impact of photovoltaics see [MAR-1]

As explained in chapter 2.1.2.3, this does not make sense. How many asthma patients equal 1000 ill trees or one big flood? Any attempt of weighting the effects on a scientific base is principally doomed.

Hence, the quest is for technologies that are better than current or other future ones in all four aspects. Those technologies would then have to be compared to benchmark technologies for each single parameter. In case of large performance differences, science can search for ways of reducing those and politics has to make trade-offs.

The first choice that impacts emissions most is that of fuel. In most cases an inefficient unit burning natural gas will still be less pollutant than an efficient one burning lignite. This choice is dominated by strategic hedging and politics (see chapter 2.1.2.2). Hence, this paper will investigate the best ways to burn natural gas only.

Other authors have taken a different approach[145]. They consider exergy losses, not emissions. Indeed, this way of thinking will lead to the most efficient use of the whole variety of fossil fuels. It is contra productive though under the assumption, that we do not want to burn all reserves of fossil fuels and then look for something else, but already today start moving towards renewable energy generation and need fossil fuels only during a phase of transition. In that case, we would of course take the cleanest fuels to bridge the way.

The choice of technology comes only second. The technologies that are clearly preferred from this analysis are SOFC ultra and heat pumps.

SOFC ultra lead to drastic emission reductions over all three sorts. They are clearly second only to heat pumps and to photovoltaic energy, when neglecting manufacturing caused emissions. Compared to any other reliable electricity generating technology the reductions are at least similar to the benchmark technology, but significantly higher on a different parameter.

Even under cost consideration SOFC ultra are likely to become not only competitive to current technologies, but also cheaper than other future technologies.

Heat pumps in combination with SOFC ultra lead to the by far biggest reductions. Instead of burning gas in order to heat water, it is used to generate electricity in a SOFC ultra that drives an electric heat pump, which exploits solar energy stored in the ground. The use of heat pumps is restricted though to small low temperature applications like warm water, low temperature process heat and floor heating. In

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[145] see for instance [AGF-2], [SCHA-2] or [ZOE-1]

most cases those will be new residential buildings. All the same, those make up for roughly 200.000 units per year in Germany.[146]

Next are emerging technologies like microturbines, Stirling engines and PEMFC. They employ extremely clean transformation processes, but have a lower electric efficiency than SOFC ultra and do not exploit renewable energy, like heat pumps. Cost wise they can get to break even.

Pure renewables are clean, though less clean than often thought when also considering manufacturing emissions. Their cost position looks rather hopeless though. Probably, neither PV nor solar collectors that will be financially viable in Germany have yet been developed. So, we either have to develop new types, look for entirely different ways like Sun Belt based solar thermal applications or cope with higher specific energy prices.

Small reciprocating engines do not have any advantages; they even significantly under perform in some parameters.

This leads to the third conclusion. The question whether energy is generated with cogeneration or not is only third after fuel and technology considerations. This view is much more refined and accurate than a large part of current publications[147]. Their authors raised the principle of cogeneration to a dogma, regardless how old, inefficient or dirty the actual technology is.

SOFC ultra will be better than small reciprocating engines in all aspects, no matter whether used in cogeneration or not, nor whether heat comes from heat pumps or high efficiency burners. It is important to clarify the superiority of technology over the principle of cogeneration; otherwise money and public interest will be misallocated. This can already be seen in the recent cogeneration subsidy legislation.

2.6 RECONCILIATION OF RESULTS WITH PREVIOUS STUDIES

The ecological and economical performance of different generation technologies is often discussed in literature. Few of them analyzed the performance from a national economic point of view and in a correct way, though. The questions are what systematic defects occur in current literature and what are the implications of it.

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[146] Rough estimate based on [EIC-1], who estimates 3000 - 3500 heat pumps installed per year cover 1-2% of new buildings. In Switzerland, 40% of all new residential buildings are equipped with heat pumps [INN-2]

[147] see for instance GRE-1, GAI-5, SEI-3 or EID-8

Out of a sample of articles and books[148], all kinds of opinions can be found. Furthermore, it appears that people tend to write mainly about technologies that they find ecologically beneficial, rarely they write in order to criticize a technology. The choice of the reference system differs between studies and does explain the contradicting results. Economical analysis is done less frequent and often from a private owner perspective.

Looking at each of the defects individually, none of the studies actually calculated the decision-relevant economic cost. They all accounted for electricity distribution grid fees as well, despite the fact that they would be paid anyway, regardless of any distributed generation option. The impact of that defect is limited though for two reasons. Concerning heat pumps, studies often refer to special heat pump tariffs that are close to electricity costs without distribution grid fee. Concerning decentral cogeneration units, those are unprofitable even with the electricity bonus being too high. A proper analysis would therefore not inverse the result, but deteriorate it.

Concerning the calculation of economic cost instead of private prices, quite a few studies incorporated taxes and subsidies. This leads to some decentral units being profitable already today, whereas this is rarely the case from a macroeconomic point of view. The private perspective is important, of course, but results cannot be projected to the interest of the economy in total. If done so, decentral cogeneration units and pure renewables would look better than they actually are, because they profit strongly from subsidies. Heat pumps, on the other hand, would look less attractive than they actually are, because they currently are even punished by higher taxes.

The choice of the reference system seems to indicate the preferred technology of an author. While supporters of micro-cogeneration choose the average mix, sometimes even without renewables and nuclear, supporters of heat pumps choose CCGTs. Interestingly, in both parties some people manage to proof that their proposed technology is superior even under the other reference system. In general though, literature suggests that all gas driven generation, including gas driven cogeneration units of whatever electric efficiency, are superior to coal-based central generation, and heat pumps are the most ecological option in case of CCGT generated electricity. As discussed before, the true electric reference system has to be either CCGT or SOFC ultra, because a new investment into heat and electricity generation capacity has to be compared with new investments into heat and electricity generation capacity and nothing else.[149] None of the studies so far analyzed the effects of SOFC ultra coming to market, which will further promote heat pumps and reduce competitiveness of micro cogeneration.

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148 [AGF-2], [BEH-1], [EID-8], [FDD-1], [FIS-2], [GAI-5], [GER-1], [GRE-1], [HEI-1], [HEI-2], [HEI-3], [SCHA-1], [SEI-3], [ZOE-1]. [MAT-1] compared several different studies and did some own calculations as well.

[149] For example, investing in a reciprocating engine that generates heat and electricity has to be compared with investing into a heat pump and some CCGT capacity.

Some of the studies use distorting business ratios. In most cases, this even distends the seemingly positive image of cogeneration units with low electric efficiency.[150] Looking at valid ratios, cogeneration units with a low electric efficiency appear unattractive as opposed to attractive in the distorted view.[151]

Lastly, only [AGF-2] gives a comprehensive and thorough overview on learning curve effects. Reciprocating engines profit most from this defect today. Emerging technologies like Stirling engines and fuel cells look much better when learning effects are considered.

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[150] If subsidized enough to become profitable or if oil is taken as heating reference and at the same time, economic or ecologic performance is referred to kWh_e.

[151] The same is true for comparison referred to $kWh_{thermal}$ and cogeneration units with little thermal efficiency

3 Interests of market players

3.1 GAMES THE ENERGY MARKET PLAYS

With its "S-C-P Model"152, McKinsey argues that market performance like profitability, degree of innovation or price level is not a random result of individual player's behavior, but depends to a large degree on the structure of the market, like the number of players, entry and exit barriers. [NAL-1] as well states that in the world of business, the highest rewards do not come from playing the game better, but from changing it.

The state has significant power to change games. And he frequently does by granting subsidies, raising taxes or allowing big mergers, but he does by far not use the entire scope of possibilities to do so. Neither does he sufficiently consider the interest of players not directly concerned, nor the possible reactions of those who are.

This chapter will deal with the following questions: What is the large strategic context of the energy industry in Germany and what are the parameters that define the "game"?

The next chapter will then generate detailed options for the state to change the game in order to macroeconomically optimize the German energy system. Those will be the building blocks of an integrated policy recommendation.

3.1.1 Game elements

[NAL-1] argues, that there are exactly five elements of economic "games" that together make up for the acronym PARTS: players, added-value, rules, tactics and space. Each of them determines what profits a market player can hope for.

3.1.1.1 Players

In the eyes of any company there are principally four different kinds of players: suppliers, customers, competitors and complementors. The number of players in each role strongly determines everybody's added value and hence their profits.

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[152] Structure - Conduct - Performance

Entry or exit of a player can significantly change added values and hence the entire game.

A player who is already in the market should hence think how to attract others to enter as customers, suppliers or complementors and how to defer companies from entering as competitors.

A player that considers entering a certain market should think "cui bono"[153] and make himself paid for entering - or staying outside.

The state as well can invite players to enter, to some extent defer them from doing so or even enter himself.

3.1.1.2 Added-value

The added value of a player is the difference of the value created in the game while he is part of it and the value when he is out. Added value is the main source of power in a market. Regularly, a player cannot extract more value from the game than he brings to it.[154]

Upstream electricity players, for instance, are currently exposed to competition and overcapacity[155]. If a player operating with the marginal technology drops out, another one will still be able to supply. The value created does not change. The added value of such a player is hence zero. And, indeed, at current wholesale prices, electricity players claim to operate without profit at marginal cost.

While added values change when players enter or exit, there are more direct ways of changing added values as well.

Monopolists can reduce offer, create scarcity and thereby destroy the added value of their customers. Others can look for opportunities to create high customer value at low cost. Thirdly, customer relationships can be a source of added value, when it leads to better insight into the customer or high switching costs.

In Germany, the state already plays a role in controlling monopolies and monopolistic behavior. It also has principally the power to reduce the value of incumbent long-term customer relationships in the course of deregulation by making information available to new entrants and by ensuring low switching cost.

3.1.1.3 Rules

Rules are perhaps the most obvious way to change the game and policy makers largely use them today already. In his cover story on distributed generation, "The

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[153] [NAL-1], page 83

[154] [NAL-1], pages 123 and 174

[155] [VDI-1] estimates generation overcapacity in the EU at 40%.

Economist" sees three obstacles to "the electric revolution": taxation[156], lack of technical standards and a "regulatory mess"[157]. All three of them hence concern rules.

[NAL-1] refers to rules as an art. There is no comprehensive framework that would comprise them all, but he gives a couple of examples:

¶ Clauses that guarantee customers only to pay the lowest price paid by anybody else

¶ Clauses that guarantee suppliers to get the contract if they offer to draw equal to the best alternative offer

¶ All sorts of discounts or voluntary encumbering of strategic handicaps.

Already today there is a large set of rules on local, state, federal, European and international level and they comprise:

¶ Concessions: generation capacity installation, plant security, right of way for grids

¶ Market supervision: market behavior of incumbent retailers, fusion control, grid regulation concerning both price and access, information ownership, take-or-pay contracts

¶ Emissions: Kyoto, clean air act, house isolation standards

3.1.1.4 Tactics

This concerns the perception of reality by different players. For instance, how does the public perceive cogeneration? Or nuclear energy? What effects would changing that picture have?

The state can alter perceptions by clarifying complex matters and enhancing transparency or by doing the opposite.

3.1.1.5 Space

There is always a larger and a smaller game. For instance, the electricity sector could be linked to telecom, as another utility, or separated from gas.

Telecoms know the least sticky customers in telecom deregulation. Would they be the least sticky in energy deregulation as well? Should those two markets somehow be linked in order to make this knowledge available to energy players?

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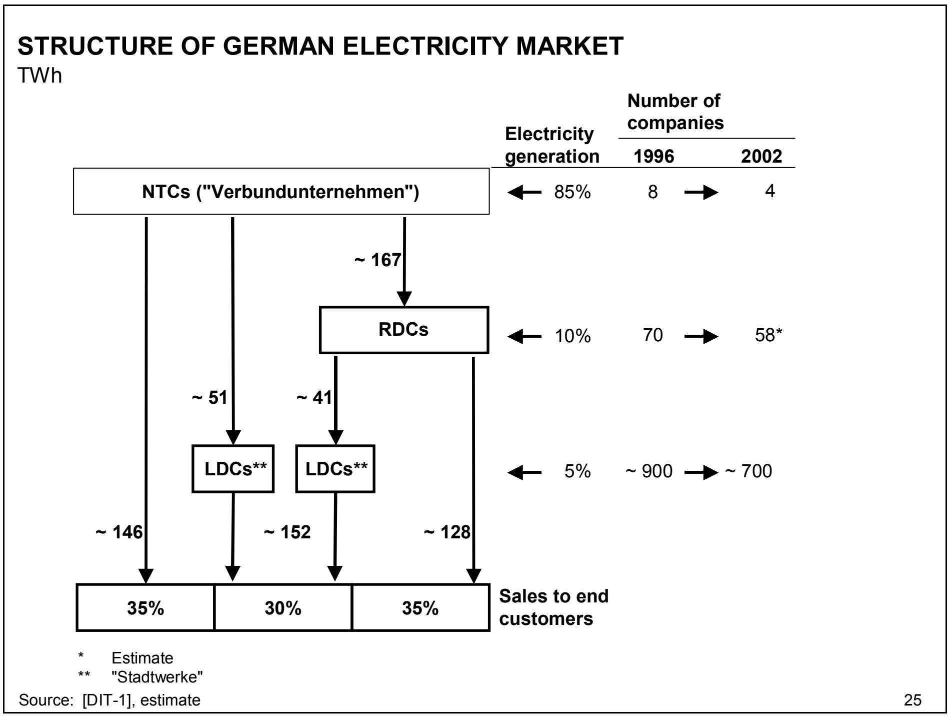
[156] that favours coal

[157] [ECO-1]

The state can separate markets by force or allow players, and hence markets, to merge. He also can influence the behavior of municipal utilities, which are regularly state-controlled, and bundle/unbundle his own demand.

3.1.2 Market structure

The relevant market comprises electricity, natural gas and related investment goods. It amounts to a total of more than € 100 billions per year.[158]



Source: [DIT-1], estimate

Figure 23: The structure of the German electricity market

Before the deregulation in 1998, the electricity market was extremely dispersed with more than 900 players[159], split into three groups: eight national transmission companies ("Verbundgesellschaften", NTC), 70 regional distribution companies (RDCs) and roughly 900 local distribution companies (LDCs or "Stadtwerke"). While NTCs generated most electricity (75%)[160], RDCs and LDCs only had little

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[158] [BUN-2] estimates the total turnover for energy and water in 1998 at € 125 billions. This comprises district heating and water supply as well, though. Investments in the German electricity sector are estimated by [MAR-3] to amount for another € 22 billions between 1995 and 2003, or € 2-3 billions per year, in the German gas sector to € 3 billions, [GAS-1] for 1999.

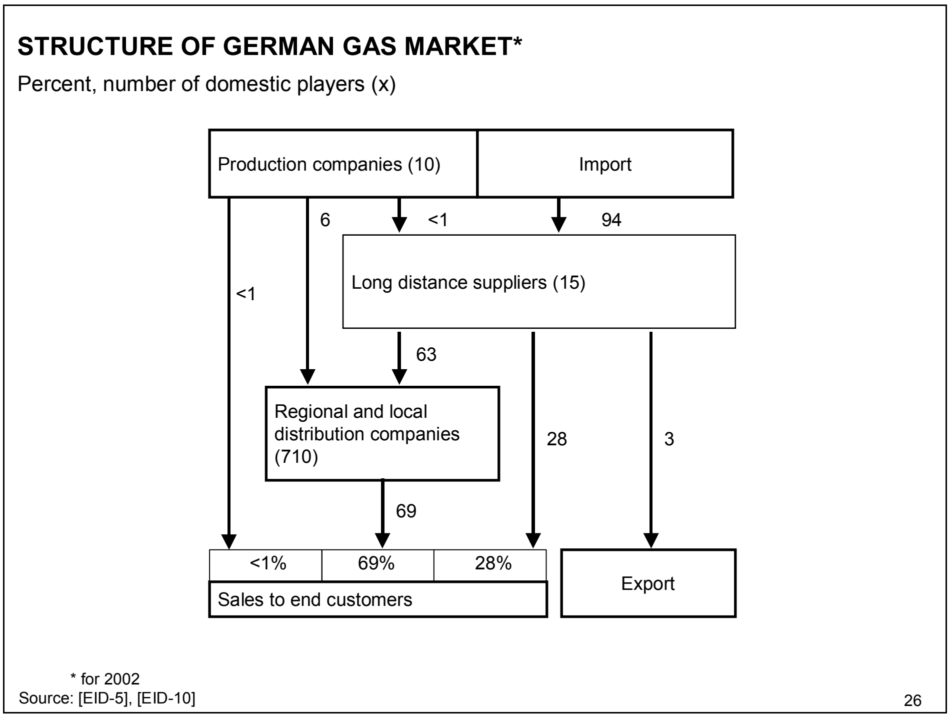
[159] [DIT-1], page 371

[160] see [SCHU-3], page 6, and also [SCHL-1]

generation capacity, in most cases cogeneration units. Each group had roughly 30% of the end customer market, with residential customers normally being supplied by LDCs (see Figure 23).[161]

The deregulation did not lead to the expected mass bankruptcy of LDCs, but the concentration of the market has grown significantly. Four NTCs have swallowed the other NTCs and most RDCs and dominate the market. They also often have minority stakes in LDCs that secure their sales position.[162]

The situation on the gas market looks different. With more than 700 players, the market is rather dispersed as well[163]. Ten production companies and 15 long-distance suppliers (LDS) control production, import and transmission of natural gas. The LDS also own 28% of end customer supply. The majority of end customers, 69% of the total volume, are supplied by 60 RDCs and 650 LDCs[164]. One company, Ruhrgas, dominates the entire gas market though. Owning more than 50% of the upstream market it also integrated into the downstream business by acquiring RDC and LDC stakes.[165]



STRUCTURE OF GERMAN GAS MARKET*

Percent, number of domestic players (x)

* for 2002

Source: [EID-5], [EID-10]

Figure 24: The structure of the German gas market

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[161] [DIT-1], page 371ff

[162] [SCHU-3], page 10ff, [PRE-1]

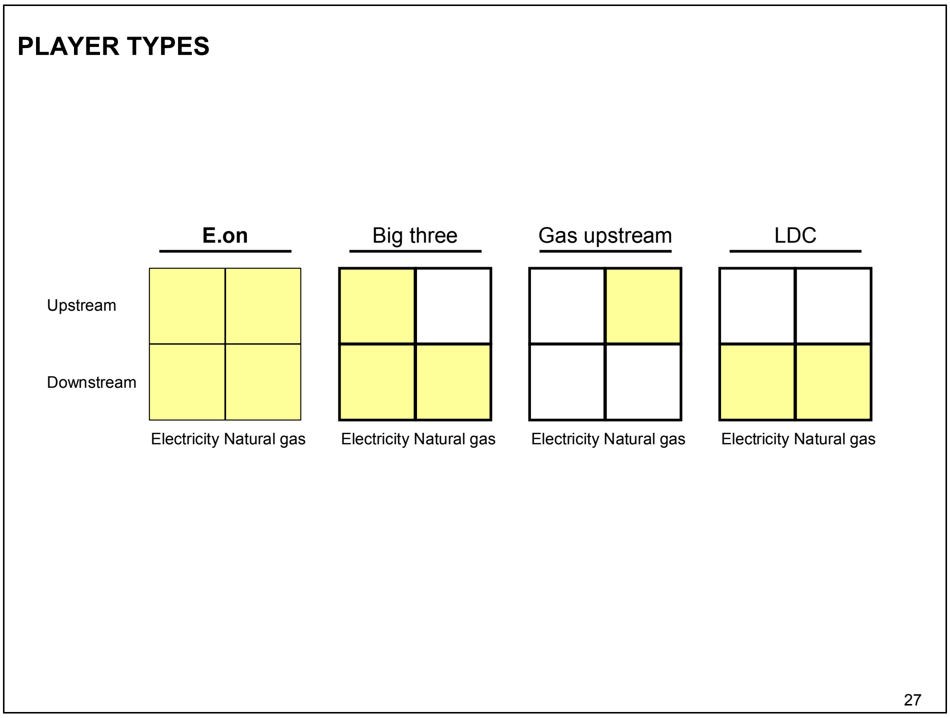
[163] [EID-10], [EID-5]

[164] [EID-10]

[165] [SCHU-3]

RDCs and LDCs frequently are multi-utilities and supply both gas and electricity, sometimes water and heat as well. Roughly 350 utilities follow that concept. Around the same number of utilities supplies only electricity and not gas. 150 utilities supply natural gas only, not electricity.

Most RDCs and LDCs have sold at least minority shares to the big players directly or through intermediaries like Thügas. Only among small LDCs, a significant amount[166] of small LDCs is still independent from the four big NTCs.[167]



PLAYER TYPES

Figure 25: Player types

As a conclusion, and under the assumption of the E.ON / Ruhrgas merger taking place, four different types of players have to be analyzed (see Figure 25):

- E.ON, as the only fully integrated and dominant energy company
- The other three of the big four NTCs, with significant electricity generation, downstream integration on both gas and electricity, but currently left dependent to Ruhrgas/E.ON in the upstream business

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[166] ca. 50%

[167] expert interview

- Upstream gas players, rather small compared to Ruhrgas
- Small LDCs, still independent from the other groups and belonging to the municipal utilities. There are three different types: those supplying both gas and electricity, those with a gas- but not an electricity business and those, that supply electricity, but not gas.

3.1.3 Discontinuities

The broad strategic context of those four types of players is dominated by major discontinuities in regulation, technology and demand.

The regulatory environment changed significantly in the 1990ies. The full liberalization of the German electricity market caused household falling by 40%, wholesale prices by 60%[168]. While distributors profited from grid monopoly rents and the fact, that wholesale price went down faster than residential electricity tariffs, generators could sometimes barely make up for their variable cost. New entrants entered the German market, both from abroad and from inside Germany, like EnBW's retail body "Yello". Another consequence of liberalization was growing concentration in the strongly dispersed electricity market. Competition was less severe in transportation & distribution and in the not yet fully liberalized gas market. Nevertheless, upstream players are integrating downstream as well.[169]

Furthermore, with the Kyoto protocol and the Green Party in the German government, renewable energy sources and cogeneration received additional subsidies and a long-term scenario for quitting nuclear energy has been passed.

Concerning technology, there were also some significant changes: new generation technologies like fuel cells, microturbines or Stirling engines have been introduced to the market or at least announced and wind generators become profitable.

Last, demand underwent some changes. Green energy has been established as a distinct product, though only for a niche. The power crisis in California made the public more sensitive to power quality and premium power might emerge as a sizable market in the future.

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[168] see [BER-4] and [BIR-3], [HOE-1] mentions values that are a little smaller (30%, 50%).

[169] See [HAN-1], who judges the downward integration as strategic imperative for upstream gas players.

3.2 SLIVER STRATEGIES

After getting an overview on game elements and the general strategic context, the next chapter will analyze value-chain-specific interests concerning SOFC ultra and heat pumps and the options for government intervention.

3.2.1 Manufacturers

3.2.1.1 Strategic context

The market for distributed generation promises huge growths rates, both in Europe and the world. The share of cogeneration is planned to double from currently 6% to 12% in 2010. In the world, 750 million households are not connected to the electricity grid.[170] There, distributed generation is much more competitive already today, because grid capacity alone costs \$1000-\$1500/kW in the Third World[171]. In the US, venture capital flowing into distributed generation doubled in 1998 and 1999 and reached \$800 millions[172] in 2000.[173]

The market context for manufacturers of heat pumps and SOFC ultra is rather different. While heat pumps are a mature product with more than a dozen significant producers in Germany alone, SOFC ultra are still in the phase of development and with a single player in a dominant position: SIEMENS Westinghouse.

3.2.1.2 Game-theoretic options

3.2.1.2.1 Complementors

The most obvious complementing product for both technologies is fuel: electricity for heat pumps and natural gas for SOFC ultra. Other complements for both are maintenance services, grids and risk hedging. Complements for heat pumps are isolation for houses, floor heating, engineering of heating system or drilling for earth connection.

3.2.1.2.1.1 Players

The financial viability of a heat pump is based on investment cost and the spread between heat price and electricity cost. A customer's decision to install a heat pump would be much easier, if he could calculate with a fixed electricity/heat

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[170] For these figures and the overall strategic importance, ABB assigns to alternative energy solutions see [ABB-1].

[171] [ECO-2]

[172] [WEL-1]

[173] In total nearly \$2 billions of venture capital have been invested into micro power in the US [ECO-2].

spread and hence fixed operating margins. He would be left with the volume risk only, that means with the forecast of his own demand.

Someone could offer a derivate on the electricity/heat spread and therefore free the customer from it in order to boost heat pumps sales. As the competing heat generation technology are gas boilers, a derivative on the spread between electricity and gas, instead of heat, would have the same effect and be easier to establish.

The state could invite players to offer those derivatives or do it himself.

A similar problem exists for customers that want to run SOFC ultra. They have to see that the spread between natural gas cost and electricity price is large enough over the unit's lifetime in order to cover for the investment cost.

Here, again, someone should offer a derivate on the spread between natural gas and electricity as well. Actually, the risk of the SOFC ultra owner is inverse to that of the heat pump owner. By issuing the same amount of derivates to both heat pump and SOFC ultra operators and covering the risks of both, the resulting risk position for the derivate trader would be zero.[174]

The state can either invite or pay others to play or enter himself. In a market economy, the market solution should be preferred. Trading of those derivatives could happen either over-the-counter (OTC) or via an exchange market. For the latter one, two functions have to be provided:

¶ A transaction platform: Any stock exchange should be ready to do so, if governmental involvement promises a liquid market and hence a flourishing business. Dozens of energy exchanges have opened since the 1990ies in Europe alone.[175] Therefore, government should be able to find a supplier for that service easily.

¶ A market maker: The market maker function is risky at the beginning when markets are not yet very liquid. Government could offer to cover positions to both sides up to a certain amount in the beginning. Later, a private body can take that position.

Derivates on the gas/electricity spread can become a key tool of supporting SOFC ultra and heat pumps. They will be discussed more in detail later.

Another way to hedge risks between CCGTs and heat pumps is to index electricity prices for heat pumps on natural gas. The index could be a national one, better would even be the consumer gas price of each municipality. This would guarantee the consumer that he would never pay more than he would have done with a

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[174] The exact mathematics will be dealt with later. In fact, there is a small residential risk on the general price level of natural gas.

[175] [GUE-1]

boiler, though he might pay more than the average in Germany. The indexation can be enforced by law, by the state using his political influence on municipal utilities, by the state using his buying power and sourcing his electricity on that index only or by only granting subsidies to units that work on gas-indexed electricity.

Reliable maintenance field forces are an important complementary product as well. The state should assure quality vocational training of sufficient people by creating necessary professions and curricula, advertising them to pupils and offer competitive schools for teaching. In parallel, improving higher education on energy engineering with a special focus on heat pumps and SOFC ultra is another, long-term way of supporting those technologies. Germany has rather established educational players that are mostly paid by the state. He either could exert his influence to make the necessary changes happen. A bold move would be to open the educational system to private players, at least in the areas discussed above. If both public and private institutions would receive the same money per student from the state, a lot new educational players would probably enter the game.

One complementary product that only concerns heat pumps is drillings. Heat pumps need to be connected to the ground. Those drillings make up for more than 50% of the entire investment cost[176]. Two types of players are involved: the drilling companies and the regulatory agencies[177]. Competition and capacity building by drilling companies seem uncritical, but could be supported by access to government-vouched credits. Announcing a credible heat pump strategy, calling public attention to the high prices in that field and setting up a price information platform should initiate competition and innovation in that field. The regulatory agencies can further streamline and standardize processes - like online authorization and access to geologic information or concentrating all activities in a single agency.

Heat pumps also have limit supply capacity, so houses have to be well isolated in order to be sufficiently supplied in wintertime as well. Improving the isolation of existing buildings is a profitable business in itself, depending on the isolation standard of the building. The state can invite companies to enter the market for savings contracting, improving the isolation of a building and getting paid from the cost savings. A good way to do so is becoming a customer himself, as the state owns a vast number of buildings: government, administration, universities, schools, hospitals, swimming pools, libraries, museums, theatres, multifunction halls, army facilities and public housing programs.[178]

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[176] [EAE-1], page 227

[177] "Untere Wasserbehörde" and "Oberbergamt"

[178] The German association of energy consumers, "Bund der Energieverbraucher", demands that already, independently of generation technologies [ENE-1a].

3.2.1.2.1.2 Added-value

Protection against changing spreads is not enough, though. The higher the natural gas price level, the easier for energy efficient technologies to break even. The state can raise that level with taxes. Higher taxes on natural gas increase the added value of heat pumps and SOFC ultra.

There are a few more ways to increase the added value of heat pumps.

First, due to the low feed-in temperature, heat pumps require floor heating systems, which as well are easily installed when constructing a new house, but difficult to revamp. The same is true for the earth connection. Both could be promoted for new residential buildings. This measure would raise the cost of housing by €10.000 per house or 2%. This is acceptable and cost will go down with higher sales volumes as well. The state could either force house builders by law or incite them with subsidies. Probably a combination of both is the best solution: subsidies high enough to ensure a proper capacity build-up on the supplier side followed by mandatory regulation. Taking one Bundesland at a time will smoothen capacity build-up, prevent over demand and keep market prices low.

Additionally, heat pumps can easily used to cool in the summer as well. Cooling ceilings are equivalent concepts should be installed from the beginning on as well. On the other hand, the state might not want to incite additional energy usage for cooling.

Last, the regulatory agency should by law collect geologic information from any heat pump drilling and make it freely available to everybody. This will prohibit local de facto monopolies due to increasing returns based on superior geologic knowledge of an area.

3.2.1.2.1.3 Rules

Heat pumps have a limited supply capacity, as they work on solar energy. Residential buildings need therefore to be well isolated. Raising isolations standards saves resources and emissions. It has even been proved cost effective as well, in case of WschVO 1995 or lower.[179] That isolation standard normally proves sufficient for heat pumps, so no further laws for new buildings are required. Even a faster revamp of old buildings will not largely improve the chances of heat pumps, because of rarely existing floor heating and earth connection.

What can be done, on the other hand is to force architects to propose heat pumps as option to their customers. Creating a new movement of heat pumps has to draw on "push" and "pull" activities. That one would be a "push".

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[179] [OSC-1]

The new isolation legislation, "EnEV", is a good step towards more severe standards, but taking primary energy demand, as reference is not smart. The statutory electric efficiency of 33% does not correspond to the reality of CCGTs or SOFC ultra and sabotages heat pumps. The same is true for simplifying administrative processes for 1/2-cogeneration units, but not for heat pumps. This has to be changed. Tactics

The state can enhance price transparency for complementary products, like floor heating, drilling or isolation by publishing market reports similar to [FFM-1] or Stiftung Warentest.

3.2.1.2.1.4 Space

The state could enlarge the business for manufacturing by lifetime fuel supply. In principle, already today manufacturers could offer their equipment together with lifetime fuel contracts. One reason for not doing so is that they suddenly would become competitors to their customers, which instantly could threaten them to by from the competition if they do not stop from doing so. If the state on the other hand binds subsidies for heat pumps to the fact that they are sold with a lifetime supply of clean electricity generated from CCGT or SOFC ultra, manufacturers would start selling fuel without having to worry about retaliation - this is one of the cases where inflexibility turns out to have a game theoretic advantage.

Companies like SIEMENS that manufacture both CCGT/SOFC and heat pumps probably would prefer to sell the electricity contracts for the heat pumps to the customers of their CCGT/SOFC units. This is a way to strengthen their customer relationship and make an additional profit.

Smaller heat pump manufacturers are more open to other, smaller and non-generating partners, like small municipal utilities or focused retail players. Anyway, this measure would strengthen the position on manufacturers and the interest in CCGT, SOFC and heat pumps.

Linking contracting deals for public facilities to the supply of SOFC ultra electricity also enlarges the space of the game and will attract additional interest.

3.2.1.2.2 Customers

3.2.1.2.2.1 Players

The state could either pay new customers to enter or enter himself.

Paying new customers is often accomplished by granting subsidies, tax exemptions or low interest credits. Those tools are often used in an inefficient way. The new cogeneration bill[180] for instance grants a per kWh subsidy for electricity generated in certain cogeneration units. The amount of the subsidy is regardless of the unit's profitability gap[181]. A much smarter way of granting subsidies would be auctioning them to potential customers. In this way, the units would be sold to those that are willing to buy with the least amount of subsidies. This approach can also be combined with the sale of derivates of the gas/electricity spread. The government would sell those derivates with different prices for call and put - the subsidy making up for that difference. The amount of the subsidy can be changed any minute. This gives way to a much higher degree of fine-tuning than setting a fixed subsidy for several years.

The state himself could enter in two ways: either buy and operate the machinery himself or outsource that and become the customer of a contractor. In both cases, governments should become aware of their immense buying power: government, administration, universities, schools, hospitals, swimming pools, libraries, museums, theatres, multifunction halls, army facilities and public housing programs. This buying power can be used to pay others to enter the game.

The above is also relevant for isolation and the installation of floor heating systems. The state should set a good example and thereby prepare the market.

3.2.1.2.2.2 Added-value

Current legislation's support for cogeneration is regardless of emissions or actual efficiency and damages heat pumps and SOFC. There is no ecologic or economic justification for that.

3.2.1.2.2.3 Rules

There are also regulatory possibilities to improve heat pump sales. The federal government could pass a law that binds Bundesländer and municipal utilities to grant at least the same benefits to SOFC ultra and heat pumps as to any other decentral energy generation technology. The effect of such a most-favored-customer-clause would be twofold. On the one hand, Länder and municipal utilities would give fewer benefits, because they get more expensive when to be paid for other technologies at the same time. This has positive implications on budget discipline and the abundance of sometimes even contradictive subsidy policies. Secondly, customers can decide more easily for heat pumps or SOFC ultra when selecting an energy generation technology, as they will at least have the same government subsidies as with any other one.

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[180] "KWK-Gesetz"

[181] This can both mean that subsidies are too high and bridge more than actually necessary to incite an investment, or too low, so that people still not use those technologies. [FAZ-1] states, for instance, that the subsidies for fuel cells in the current cogeneration law are too small to incite capacity investment and only lead to windfall gains on research projects, that are rather price insensitive anyways.

Furthermore, current discrimination of heat pumps compared to micro cogeneration should be stopped: Cogeneration receives subsidies from the current cogeneration act, while heat pumps driven by electricity generated from natural gas do not. Those subsidies should be stopped, as they do not make macroeconomic sense. And, architects are freed from conducting an expensive heat dissipation and demand analysis if a cogeneration unit is installed in the building[182]. This privilege is again counterproductive and should be abandoned.

Here, certificates that proof the origin of the electricity might be useful again: the new standard suddenly refers to primary energy demand and not end energy demand.[183] Electricity generation efficiency has been defined by the state to 33%. Certificates from CCGTs or SOFC ultras can prove that the actual electric efficiency is greater than 50%. This should end the discrimination of heat pumps against 1/2-cogeneration.[184]

Additionally, exempting night storage heaters from electricity tax[185] is not only ecologically absurd, but also directly reduces market potential of both heat pumps and SOFC ultra. This tax exemption has to disappear.

Last, government should design subsidies in a way, that profitability will never be higher than today. Otherwise, potential buyers might wait buying and keep waiting for a better deal, as it happened with solar thermal collectors in Germany[186]. One way of doing so is a most-favored-subsidy clause that would grant additional payments to earlier buyers in case new ones get a getter deal. Like the most-favored-customer-clause above, the effect would be twofold: the state would be less incited to give out better deals, as they get more expensive. Second, customers have no incentive anymore to wait.

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[182] and covers at least 70% of heat demand [LAM-4].

[183] The logic defects of that shall not be discussed here in detail. Here again, the average generation park has been taken as reference for electricity, which is not correct.

[184] The current legislation does not give this opportunity. The government should change that. Otherwise, even courts might open that possibility, once a case would end there.

[185] see [GAI-1]

[186] See [ENE-1b] for a discussion on subsidies for solar thermal collectors.

3.2.1.2.2.4 Tactics

Governments can both clear and distort the view of players in order to support the technologies they want.

Lots of consumers are definitely not aware of the ecologic superiority of heat pumps vs. 1/2-cogeneration and the much higher cost efficiency compared to solar thermal collectors. There are two ways of clearing their perception.

First, it has be made clear, that future capacity investment will be into natural gas, not coal, that more heat pumps mean more CCGTs, not more coal plants and that heat pumps are fueled by natural gas-, not coal-based electricity. This can either be achieved with certificates, like those used for green energy in Europe or the United States or with the derivates on the gas/electricity spread that were already mentioned.

Second, communication is very important. Architects could be obliged to compare both emissions and cost of any other heating system solution to heat pumps and held liable for money lost to their customers due to insufficient information on heat pumps.

In any case, success stories should be communicated well. Those should be publicized in the media and with new forms of "viral marketing": Individuals and environmental organizations will be happy to engage themselves in a good cause and promote heat pumps once they are convinced themselves. Applying them in governmental programs and thanking them with public recognition will be a low cost and effective way, because it addresses consumers via friends and people they trust - the equivalent of "Tupperware-parties" for electric heat pumps.

On the other hand, the state can add intransparency to the game and grant benefits for heat pumps or SOFC whose value is difficult to assess and that look ultimately more valuable than they actually are. This could for instance be a tax exemption for a minor tax and a limited time or low interest credits. It might also be an idea to copy the success of air miles and start to distribute ecology points that later lead to tax reductions, honorary admission to public services like theater or invitations to government events. The administration costs of all the above ideas should not be underestimated though. Concerning ecology points, best is to find a private supplier for running the program and to launch a small pilot project.

3.2.1.2.2.5 Space

Last, the state could broaden the game and include other services and utilities. For instance, he could outsource the entire management of facilities like offices or public swimming pools to a contractor that agrees to supply the necessary energy using SOFC ultra including thermal usage of waste heat (2/1-cogeneration).

Under this point falls also the idea to stop regarding SOFC ultra respectively CCGT and heat pumps as separate entities, but to see them as one distributed system and to grant subsidies accordingly.

3.2.1.2.3 Competitors

3.2.1.2.3.1 Players

While becoming a competitor himself in a lot of cases is probably not a viable option, the state can pay others to compete with manufacturers of heat pumps or SOFC ultra on the German market. Due to the different structure and degree of maturity of those two markets the approaches have to be different.

Heat pumps are mature products manufactured by more than a dozen producers in Germany alone. The market structure and the size of the companies suggests, that economies of scale on supplied parts and R&D and learning effects are not captured to their full extent.

The state could start a design contest for a "Volks heat pump", setting clear evaluation criteria and inviting German and foreign manufacturers to take part.

Manufacturers would be incited to take part, because

¶ The winner is guaranteed a certain sales volume, either used for government buildings or sold on the open market, subsidized by the state to the necessary extent.

¶ All concepts complying with the evaluation criteria would get a certain label as quality indicator that would be advertised by the government[187]. Selling machines without that label might become much more difficult.

¶ The state could limit subsidies to units that comply with the standard.

In order to both foster industry-wide learning and market transparency for the customer, the state could buy the winning design and license it to other manufacturers. Or, he could agree upfront with the participants that the winner is going to do so. In that case, the conditions and number of licenses have to be agreed on in order to avoid a monopoly.[188]

The state could also hire specialists in order to design state-of-the-art supply chain and manufacturing processes. Those business processes could also be licensed out, this time by the state. Limiting licenses to those companies that took part in the

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[187] The advantage of that label would have been bigger before the manufacturers teamed up to create the "Wärmepumpensiegel" themselves

[188] That is a learning from famous cases of Nintendo or Intel, that both managed to set a standard, license it and then steadily reduce licenses and take advantage from their growing power. [NAL-1]

competition would make further pressure on manufacturers to join the competition.

At the end, a large number of manufacturers would produce the same machine, significantly reducing insecurity amongst consumers. The high guaranteed volume and the option to become a licensee would attract most German producers and even make foreign new entrants join. Business processes would be improved, learning could be spread more easily .The state could also help the basically mid-sized producers to market this "Volks heat pump" abroad.

3.2.1.2.3.2 Rules

Giving out licenses to heat pump manufacturers has the advantage of turning otherwise fix, even sunk, costs into variable ones. This not only reduces risk, but also keeps prices up. Manufacturers generally do not sell below marginal cost. In case of a license, the fee is part of it. In case of regular R&D, those costs are sunk and not part of marginal cost anymore. So, the manufacturers themselves have a high interest in licensing the technology, as it will make competition on price less violating.

Concerning SOFC, government should support the standardization of solutions in order to reduce cost. For reciprocating engines, first standardized plants enter the market: turn key, fixed price, optional contracting[189]. They have a general license for residential areas. SOFC ultra needs general approval as well, in order to be deployed quickly and at low cost.

3.2.1.2.3.3 Tactics

Announcing and conducting the design contest, allocating a serious budget on communication or harmonizing the German market with that of leading heat pump countries like Switzerland or Austria should be enough to convince manufacturers that Germany is to become an attractive heat pump market.

The same is true for SOFC ultra. There, binding tenders for installations in the public sector will interest US players to enter the German market and raise the level of competition. Those tenders should be subject to certain price, time and quality levels in order to put additional time pressure on manufacturers. While managements undoubtedly already have an interest to bring SOFC ultra to market as fast as possible, a real external pressure could help them mobilize their employees. One way to achieve that is to incur a strategic handicap by guaranteeing SOFC ultra manufacturers, that no construction of a new nuclear plant will be allowed until for instance 2012 and from then on only, if SOFC ultra plants are not available on a price less than x% above nuclear power. Otherwise, the government agrees to pay penalties. For a green government this would have a

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[189] see [HYR-1]

second advantage: it would be very expensive for a subsequent government to turn around nuclear policies. This instrument is known in business as "poison pill", where absurd lump-sum settlements of board members prevent raiders to take over a company.

3.2.1.2.3.4 Space

Label and government support for the winners of the heat pump contest could be extended to other heat pump countries like Switzerland or Austria or the EU. The same is true for SOFC and their installation in the public sector conditional to certain price, time and quality targets.

3.2.1.2.4 Suppliers

3.2.1.2.4.1 Players

Higher sales figures thanks to a "Volks heat pump" would raise supply parts volumes accordingly. Ideas like the non-variable parts concept[190] in the automotive industry would reduce the overall number of supply parts in the industry and lead to economies of scale and better capturing of learning. Supply portals and state-of-the-art electronic supply chain management would raise transparency and pressure on suppliers and attract large-scale foreign players to join the market. This will lead to falling supply costs, both due to higher efficiencies and shrinking margins.

At least for heat pumps, there are no parts with a supply monopoly that draw away a large part of the added value. This is currently the case for solar collectors that need a special high quality glass that is only available from a few suppliers in Japan. Prices for that glass are accordingly. The German government should therefore consider supporting R&D to build a German supplier of that glass. Sales quotas have to be agreed on with panel manufacturers before starting R&D, though. Otherwise, they will still buy from the current manufacturer, but use the new competitor to lower prices.[191]

There is no such situation for heat pumps. For SOFC ultra it is still too early to say, but Capstone seems to arrive in a monopoly-like position for microturbines, that make part of the system.

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[190] "Gleichteilekonzept"

[191] This is a learning from "Nutrasweet", a classic case study to explain the game theoretic concept of added value and getting paid for entering the game. The Holland Sweetener Company (HSC) entered the market for Aspartame, after a monopoly of Nutrasweet expired. They invested large sums into production facilities, but did not fix sales contracts in advance. Large customers like Pepsi and Coca-Cola threatened Nutrasweet to switch suppliers, but kept on buying from them after they significantly reduced prices. HSC never really gained ground [NAL-1].

3.2.1.2.4.2 Added-value

E-supply-chain solutions and non-variable parts philosophies would also reduce switching cost for manufacturers and therefore reduce the added value of long-term relationships that can be exploited by suppliers. Spot markets can reduce warehousing costs.

3.2.1.2.4.3 Rules

In the field of procurement, the Internet boom lead to innovative formats with very elaborated rule sets. The success of online trading, e-procurement or reverse auctions still has to be seen, but opportunities look impressive.[192]

3.2.1.2.4.4 Tactics

A reduced number of parts in the industry and electronic supply platforms enhance the transparency of the market, ease the entry of new players and principally reduce prices.

3.2.1.2.4.5 Space

The supply platform as well can be extended to countries, where heat pumps play an important role already today, like Austria and Switzerland, to neighboring in Eastern Europe or to the EU.

3.2.2 Retailing

3.2.2.1 Strategic context

Retailing is dominated by municipal utilities. Some of them are focused gas- or electricity players, others offer integrated packages that often include heat and water as well.

After deregulation, mainly the big integrated utilities tried to establish brands and invade the end customer bases of municipal utilities. A few new focused players tried the same, like Yello[193], Greenpeace and Deutsche Post.[194] Success was rather limited in all cases. Not even 4% of all households changed their supplier since the

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[192] see [HOE-1] for a short overview on different auction schemes

[193] Yello engaged in a few joint ventures with retailers from other sectors for that, for instance Otto (mail order), Mediamarkt (consumer electronics) or Globus (food) [FTD-3].

[194] Energy giant Shell entered the electricity retail business in Norway [EID-16]. The strategic intention of that move is unclear, but shows that the energy retail business might still hold some surprises for the future.

beginning of deregulation in 1998.[195] Looking at a country like Sweden, where regulation started earlier, suggests that switching rates might significantly go up over time with consumers learning.[196] Furthermore, competition has so far been played mostly on price, but only 20% of all households are really price sensitive.[197] Both heat pumps and SOFC ultra could therefore expand competition on the field of quality and features. But also commercial customers could be fond not only of the technical and financial aspects, but also of the attributes and values.[198]

Approaches to leverage customer contact for cross-selling of energy-related or non-related products and services have not been very successful so far, Centrica in the UK perhaps being an exception.[199] Nevertheless, they are extremely important. How can the huge acquisition costs for new customers be justified otherwise? [200]

More popular than growing their own retail activities, upstream players integrated downstream by buying minority shares in municipal utilities. It is a way to secure sales volume and to reduce the bargaining power of downstream players, that themselves become less fragmented.[201]

Retail players are hence preoccupied with two questions: Can heat pumps or SOFC ultra become a weapon for incumbents to cement their customer base or for new entrants to increase switching rates?[202] And, do those technologies open the way to successful cross-selling opportunities?

Electricity retailers are in favor of both electric heat pumps, which significantly grow demand, and SOFC ultra, which put additional competition to their suppliers.

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[195] [ZFK-2] speaks of 1.4 million or 3.7% of all 39 million German households. For instance, E.ON only managed to win 75.000 new customers [DEL-2] despite a €50 million campaign [WIL-1].

[196] By looking at countries like Norway and Great Britain, that have been liberalized earlier, [DRA-1] expects switching rates mid-term to reach 25%.

[197] see [DRA-1]. "NaturEnergie" even manages to receive a 20% premium on green power [SCHLU-1].

[198] The municipal utility of Hannover managed to increase commercial customers by 50%. Their brand "enercity" is not positioned on technical features, but more on values like "warmth" and "partnership" [HAG-1]. On the other side, [REM-2] estimates the share of commercial customers that are willing to pay a premium for green energy to 5% only. And, [DRE-1] states that currently only 0,25% of all customers is choosing green electricity. [NAT-1] also addresses the dissense of 12% of customers expressing the will to buy green electricity, but only 0,5% doing so.

[199] Yello definitely is the most innovative player in this respect on the German market. They try to sell not only electricity, but also repair services, white ware leasing, telecom and financial services [SDZ-1]. The success has not been proven yet, though [BER-1].

[200] The E.ON-Powergen deal valued each customer at €1500, RWE's acquisition of Innogen at €1200 [DEL-2]. A rough-cut estimate dividing E.ON new customers on the German market by their advertisement spending suggest €670 per customer [DEL-2], [WIL-1].

[201] for the gas side see [EID-5] and [HAN-1], who describes downward integration as strategic imperative for upstream gas players

[202] [MEN-1] gives an overview on new ways of keeping customers. Compared to those, both heat pumps and SOFC ultra seem to have much more convincing possibilities.

Gas retailers would be less enthusiastic: where applied, electric heat pumps destroy their residential business of supplying gas boilers. SOFC ultra significantly grow volume, but due to the size of their gas demand, they would probably be served by wholesalers and not by gas retailers.

Another strategic issue is trading: more and more retailers start their own trading activities and big customers ask others to structure and buy their electricity need. [KRE-2] argues that classic full supply contracts will be in the minority in the future.[203]

3.2.2.2 Game-theoretic options

3.2.2.2.1 Complementors

Complementing products for retailers are all kinds of items that use electricity or gas, service providers for those and producers of products that prove to be cross-salable. Especially retailers could partner with contractors of heat pumps or SOFC.

3.2.2.2.1.1 Players

Ways to incite contractors to join the game have already been discussed. Retailers, of course, could become contractors themselves. The market is rather attractive[204] and still emerging. [205] Such contracting agreements can also be the first step for offering other products and services. [206]

Apart from selling electricity, gas and perhaps contracting services, retailers can offer insurances for decentral generation units or even the entire household. Teaming up with traditional insurances helps to bring in the necessary knowledge.

3.2.2.2.1.2 Added-value

Electricity is the most important complementary product for heat pumps. The issue with electricity prices is that they largely depend on grid fees. Monopolists that are often at the same time retail competitors dictate those. The state should therefore foster cheap grid fees and guaranteed, easy access. On the other hand, cheap electricity prices also lead to higher spending, something that governments

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[203] For current developments in electricity trading refer to [CUR-1]. [ELL-1] estimates minimum size for own trading floor to 1TWh/a.

[204] [ROO-1] estimates the savings potential in facility management at 10-30%.

[205] Only 3% of German industry, hospitals, district heating plants, housing societies and commercial customers use contracting services [KAI-1]. [TÖG-1] speaks of 50.000 contracts in a rather dispersed market of 500 contracting partners. [KOH-1] sees the demand for energy services as mayor driver for distributed generation.

[206] [EAW-1] describes an example of a school that engaged in a cost reduction-contracting model: a contracting partner installed a couple of facilities in order to reduce annual electricity costs from €62.500 to €35.000. Those savings are shared and lead to 10% interest for the contractor over a 15-year period. [SEI-1] addresses sale-and-lease-back deals contractors could engage in, once they entered the customer relationship. [FRE-1] discovered a new field of decentralization: water cleaning, with especially industrial and commercial applications. [WUP-1] gives an overview on contracting services for households and a brief assessment to some of them.

normally do not wish for. This calls for a split tariff system with one tariff for regular household demand and another for heat pump electricity. A system with a low tariff for heat pump electricity would be fair, as well: grid costs are fix and basically do not increase with additional load. The cost for the base load is already covered for by regular household demand. Heat pump electricity therefore does not have to cover for additional cost. The same logic applies to SOFC and transmission grids.

3.2.2.2.1.3 Rules

A problem of today's vendors of distributed generation units is that just before they close a deal, the incumbent comes up with a slightly cheaper bid for conventional electricity [207]. This behavior has been judged offensive towards the law of a free market economy, especially by the unit vendors concerned. Of course, the state could force incumbents to publish prices of deals that were competitive to installation of distributed technologies. Or, even stronger, he could decide that incumbents have to give all customers with a similar demand structure the lowest price given to any of them[208]. Incumbents therefore would think twice before kicking out a competitor with dumping prices.

A much simpler and market conform measure lies in the hand of unit vendors, and therefore retailers, themselves. Before making an offer, they agree with their potential customer to receive half of the savings that are thanks to a cheaper conventional contract their customer engages in instead of buying a distributed generation unit.

3.2.2.2.1.4 Space

Filling stations employ training technical personnel, at least in case they have garages. They have a huge network and therefore could enter the household technical service business, for instance by maintaining heat pumps.

Another partner, that does not seem to be related at first sight, but might become so, are German telecom attackers. Their customer base consists of people that are mentally more flexible and open to switching then the average. They also trusted their new telecom supplier once and apparently have not been deceived. Chances are, that they would follow their telecom's advice and switch their energy supplier as well. Telecoms therefore could become interesting retail partners for energy retailers.

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[207] [VDI-1]

[208] Most-favored-customer-clause

3.2.2.2.2 Customers

3.2.2.2.2.1 Players

The state could pay early customers to enter with subsidies on a limited number of units or with eco tax exemptions for heat pump electricity. Or, he could become a customer to retailers that move into heat pump contracting himself.

3.2.2.2.2.2 Added-value

Subsidies for heat pumps and SOFC ultra have to be given out in smaller numbers than actual demand in order to create scarcity. Customers will content themselves with less consumer rent and esteem the technologies higher than in case of oversupply.

3.2.2.2.2.3 Rules

High quality power can become an interesting market segment.[209] SOFC and Ultra DIPPs[210] are easy-to-grasp opportunities to supply business in a certain area with premium power. Government should establish clear standards for power with different quality and thereby open a new segment: electricity from an SOFC ultra, that is within a certain reach of the consumer and therefore more secure and cleaner than regular electricity that has to travel long ways. Given the high cost of black and gray outs[211], this segment could become very interesting.

Furthermore, there are legal problems, when the owners of multi-dwelling units want to outsource heat generation or make a profit on improving the current system. This also includes installing SOFC ultra or heat pumps. The house owner currently cannot pass old contracts over to a new service provider, nor can he charge more than his cost for heat.[212] Government should adjust legislation accordingly.

3.2.2.2.2.4 Tactics

The state could fight the unfamiliarity that leads to reluctance towards heat pumps, and the perception of customers, that heat pumps are dirty. The best way to do that, again, is to become a customer himself and to create and communicate

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[209] [GER-1] talks of two different segments of grid and power quality: a norm quality, that is a little below today's standard and an individual supply, that is customized to a company's need and includes "local tuning" by filters, batteries, etc.

[210] "Ultra-efficient DIstrict Power Plant", see chapter 4.2

[211] [BIR-3] estimates the value of lost load to 2600 GBP/MWh, [SEI-2] refers to spot market prices of \$7000/kWh$_e$ in the US.

[212] see [BER-3]

success cases. The design contest that was discussed above could be an important tool for branding as well.

Limiting an attractive offer to a certain region and creating scarcity within will create the sense of "sales", the possibility of a bargain. Ultra-DIPPs[213] are a credible way to do so.

3.2.2.2.2.5 Space

"There is always a bigger game"[214], the state could hence not only source contracting services from his energy retailer, but also fuels, peak energy and more distant products, like insurances, for instances. Thereby, he might initiate higher cross-selling willingness among others as well.

3.2.2.2.3 Competitors

SOFC ultras are rather small compared to CCGTs, the current benchmark for electricity generation. They are not larger than the electricity need for a small city district[215]. They could hence be installed "semi-decentrally" in every district. If placed close to a reasonably large heat consumer (20-200kWh thermal), they even could be run in cogeneration, which is not necessary neither for their economic nor their ecologic performance, but would even further enhance their efficiency. From a governmental point of view, this concept of "ultra efficiency district plants" (Ultra DIPPs) is very charming: environmentally second to none, very robust against aggression from terror, catastrophes and war, they can become financially viable and could be a tool to enhance competition amongst generators and retailers.

3.2.2.2.3.1 Players

For electricity retailers SOFC ultra would both be threat and opportunity. Once installed, such a system has extremely low operating costs: no fees for electricity transmission, low fees if any for electricity distribution, the highest electric efficiency of all technologies and perhaps even revenues from waste heat sales. Variable cost would hence be around 2ct/kWh and therefore lower than any other technology at the retail level. Big customers can hence be protected very efficiently; no one would dare to attack, as chances are so little. That means that retailers can secure their existing customer relations and attack in other markets by installing SOFC ultra in cogeneration where customers have important electricity

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[213] "Ultra-efficient DIstrict Power Plant", see chapter 4.2

[214] [NAL-1]

[215] Sizes will start at 100kW$_e$ and regularly go up to 1MW$_e$. This is enough to supply 50 to 1000 residential customers during peak load.

and heat need. Long-term contracts have to make sure that sunk costs are recovered.[216]

New entrants would also enter the Ultra DIPP market quickly if they see as opportunity to enter this current stronghold of incumbents. Two features would make this even more attractive: first, it must be a way to escape discrimination by grid operators, for instance due to a nationwide lean process with a low fee.[217] Second, Ultra DIPPs are the possibility to create a feeling of scarcity and a movement in public opinion.

Retail players should become equally interested in selling heat pumps along with life long electricity supply. And heat pumps might suddenly need professional owners: They get considerably more attractive when combined with derivatives, that hedge risks, include subsidies and assure ecological impact. Derivatives need a professional owner, willing and able to deposit money at the issuing body along with value fluctuations. And most retailers will have to build up some trading capacity anyway.[218]

A final way of getting players to join the game is to address municipal utilities. In most cases, they are under governmental influence. So, the state should be able to convince a reasonable number of them to join the game of heat pump contracting and Ultra DIPPs - especially as it makes sense for them from a business perspective.

3.2.2.2.3.2 Added-value

In order to support Ultra DIPPs, the state has to ensure low prices for the electricity distribution grid. As stated above, grid operators normally are retailers themselves and therefore not inclined to offer competitive prices for the grid and efficient processes to access them. The story of grid regulation in the last years has not been a success case. Government should cut Ultra DIPPs out of the regular market and establish an easy and low-cost grid access for them. One solution might be a Germany-wide tariff, oriented at the lowest city grid cost that is open to Ultra DIPPs[219] and all consumers within 1km of reach from there.

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[216] The implications of this are huge. [BIR-3] states, that 2/3 of European electricity supply have been "invincible" so far: They are either "must-run" capacity, like cogeneration units that are needed for heat supply, or capacity with extremely high start-up cost, like nuclear energy. The next step in the supply curve is generation based on take-or-pay contracts and then comes "regular" generation. But, considering grid fees as well, SOFC ultra could suddenly even compete with "must-run" and nuclear energy, because it would have to cover for grid fee to a smaller degree only. In case of heat pump electricity and onsite generation variable grid fees should be close to zero.

[217] For a newcomer's statement on daily hassle with Germany's incumbent net operators see [GOD-1]. Also refer to [LAM-2].

[218] see [KRE-2]

[219] Ultra efficient DIstrict electricity Plants: SOFC ultra, run at a reasonably large heat consumer to whom it is supplying waste heat. It supplies a small district with electricity, improving power quality and reducing grid capacity need.

There are a couple of other ways to reduce cost for Ultra DIPPs, like granting tax exemptions on eco tax or low interest credits.

3.2.2.2.3.3 Rules

A well functioning competition on the level of gas retailers is in the interest of the state, because retailers are more incited to drive new business models and technologies like SOFC ultra.

Retailers have two strategic options to deal with the competitive threat of upstream players integrating downstream.[220] One is backward integration that is risky, capital intensive and requires very different skills. The other one are strategic alliances with upstream players. While the first one would enhance competition, the second one reduces it. Government should at least make sure that minority shares of upstream in downstream players do not entirely block competition. Which big player would make interesting deals or still acquire shares of a player his competitor owns partly? A clause for a "Texan auction" would diminish the problem. The downstream player states a certain price for the company and the upstream shareholder has to either buy the entire company for that value or sell his parts at that price. The downstream player then can engage with a competing upstream company.

Furthermore, competition on the retail level can be enhanced by legally securing direct sales possibilities.[221]

3.2.2.2.3.4 Tactics

Ultra DIPPs would not only be a way to improve competition at the retail level, but at the same time change consumers "tactics" or perception. Like in "summer sales", they could make a bargain for an easily understandable reason: a plant in their near neighborhood, that can be seen and touched. If contracts are marketed well on a first-come-first-serve basis, switching rates should go up significantly.

Additionally, the state has to set regulations, that reduce the general fear of consumers when doing something unknown, of being ripped off or of being without electricity. This can be done with clauses that allow consumers to switch back at no cost during the first months and general state support for consumers in dealing with retailers.

This clause should be kept for a few years, until general population accepts both the fact of changing a utility provider and the technologies concerned.

The state also has to take care about gas retailers worries. For them, electric heat pumps are a competitive threat. There are no independent gas retailers today, but

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[220] see [EID-5]

[221] BP currently has a legal process pending with the German antitrust agency [EID-5].

municipal utilities are integrated gas distributors and retailers. Their business would considerably change in a world of heat pumps and SOFC ultra. Transformation time is long though, as heat pumps are restricted to new buildings and to small applications. This time should be sufficient to cash out existing assets and to adapt size and products to new circumstances. Anyway, heat pumps will never serve the entire heat market. The state could provide strategic advice to those players in order to reduce their reluctance. SOFC could become an opportunity for them to serve considerably large customers with an adapted business model.

3.2.2.2.4 Suppliers

The suppliers of retailers are basically generators, grid operators and manufacturers. They will be dealt with in different paragraphs.

3.2.3 Transmission and Distribution

3.2.3.1 Strategic context

A few players own most of transmission grids: the four big integrated players for electricity transmission and the importers and transmitters for gas transmission. Distribution grids on the other hand are mostly in the hands of a large number of municipal utilities. Transmission and distribution is the only sliver that is still largely profitable after deregulation. It does not seem likely that this will change in the near future, because the municipal utilities have strong lobbying power and energy consumers don't seem to be very sensitive about grid fees. Current legislation underlines this opinion: a regulator is not insight and grid operator friendly accounting standards have been declared "good practice" by law[222].

On the transmission side, especially E.ON and RWE have an information oligopoly: they know about imports and exports, about the utilization of grids and when most plants get on/off grid. This gives them a significant advantage as traders.

A lot of money is at stake, so technologies will be hard to push through against the will of grid operators.

The advantage of decentral generation in general is, that grid operators can use them in order to open up bottlenecks, temporary and long-lasting ones. Apart from that, electric heat pumps are a great opportunity for electricity grid operators and a significant threat to gas grid operators as they replace gas distribution with electricity distribution. Except for grid losses, grid costs can be regarded fix and

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[222] see [WET-2]

most of it even sunk. This means that any additional volume on a grid translates nearly one by one into additional margin. Competition could become fierce.

The battle is probably less intense for SOFC ultra as only a small length of gas grid would be used more intensely and only little length of electricity grid would be used less.

Apart from that, grid operators try to cut cost[223]. Regulation will one day cut their fees anyway, until then they can earn higher margins and cover for losses in other areas. In this spirit, grid investments have been sharply reduced since deregulation.[224] SOFC can prove to be a cheap way to avoid grid upgrades, especially temporary ones. Some authors[225] suggest that grid operators should also open different quality segments for electricity and offer separated products for them. SOFC can be used in that way to assure premium power for a small group of customers. Given the high cost of grid failures, this could prove a very interesting product.[226]

3.2.3.2 Game-theoretic options

3.2.3.2.1 Complementors

Electricity and gas grids are to some extent competing, to some extent complementing. Optimizing both from an integrated perspective can lead to important synergies.[227] In order to keep competition in the race for deploying heat pumps and SOFC ultra, those mergers should only be allowed if fair grid access is guaranteed, best by separating ownership and operation.

3.2.3.2.2 Customers

Customers are currently electricity and gas retailers and wholesalers, including the retailing bodies of today's municipal utilities that comprise grid ownership, - management and retailing. They have been dealt with before.

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[223] [STA-3] underlines that fact and suggests changing net architecture in order to reduce cost. [KRE-1] discusses the whole bandwidth of cost reduction measures. [NEH-1] describes a specific case of bundling net operating centers.

[224] Investments into the gas infrastructure have been reduced by 10% in 1999, but are now back to old levels [GAS-1]. [SEE-1] on the other side projects further reductions in grid investments.

[225] See for instance [GER-1], [REI-1], [SCHM-1] or [MAR-2]

[226] [BIR-3] estimates the value of lost load to 2600 GBP/MWh, [SEI-2] refers to spot market prices of \$7000/kWh_e in the US. [LAM-2] demands quality standards as well.

[227] In the UK, the merger of the national electricity transmission player "National Grid" and the "Lattice Group", that owns gas transmission player "Transco" is expected to save some GBP 100 mio annually [EID-8]. [MAR-2] talks about the benefit of independent geographic information systems.

3.2.3.2.2.1 Rules

Different official quality standards for electricity help creating a new energy product: premium power, from the grid, but generated in the neighborhood on SOFC.[228]

3.2.3.2.2.2 Space

Apart from that, separating distribution and retailing could credibly open a new business field for distributors: energy saving. Distributors would be left with grid operation and incentivised accordingly: grid fees would always cover for fixed cost and good performance in improving energy efficiency would be rewarded financially by the state. Reducing energy consumption would therefore not mean less revenue for them. They credibly could support consumers in their area by raising energy efficiency. The retailers would lose business, not them.

3.2.3.2.3 Competitors

3.2.3.2.3.1 Players

The state has an interest in promoting heat pumps. Electricity is the most important input factor and should be kept cheap. Grid tariffs make up for a big chunk of that and by far for the largest margin.

The first step in inviting players to enter is to establish the possibility to do so, for instance by separating grid ownership and operation[229]. The first would remain with the municipal utilities; the second would be tendered to the most competitive offer every three years.

Then, government has to assure that there are competing offers. For a company, writing a competing offer is costly[230]. Players are only likely to participate in the bidding process if they see reasonable chances of winning it or if they get paid for bidding. The bidding process therefore has to be transparent and at least the top one or two losing offers paid for.

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[228] Such applications might become very interesting in Eastern Europe where grid quality is much lower than in Germany. And those markets are very interesting: they make up for 20% of current EU demand and are growing. German players are already engaged over there [EWT-1].

[229] One of Germany's biggest net players, RWE, already separated those two functions and calls them "asset management" and "asset operation" [GER-1]

[230] Cost for work, increasing market transparency and competition and therefore a loss of competitor's good will and the risk of retaliation measures from their side.

3.2.3.2.3.2 Added-value

Here again, the separation of grid ownership and operation proves beneficiary. The added value of grid operators would be reduced significantly in case they could be threatened to lose their contract if they sabotage deregulation.

The state also should reduce added value of incumbents deriving from their better insight into the specific grid. Due to this better insight, they should always be able to make the best bid. Worse, competitors would know that if they will get the contract, their bid was probably too high (winner's curse). They will hence bid more conservatively, and therefore have little chances ever to win.

In order to solve this problem, information has to be made available to both parts. One approach would be that instead of tendering the grid operation as such, the incumbent player would have to make a detailed list of projects and tasks to be performed. This list would be agreed with the grid owner. Both players would set their prices for each of those items. Any changes to that plan[231] would later be agreed on with the grid owner. Engineering & construction companies work with this approach when building huge industrial plants.

Different quality segments would also open the possibility for reducing cost not only by improving efficiency, but also by lowering grid quality.[232] SOFC ultras could then be used to improve quality in certain micro grids when necessary and paid for.[233]

3.2.3.2.3.3 Rules

Rules play a very important role in a natural monopoly. Two aspects are important: access and price. Principle problems occur in case of grid bottlenecks, where grid players under all auction schemes are able to extract most of the value-added.[234] In all other cases, fair access is principally feasible[235]. Prices are alleged to be too high in various cases.[236] Lowering grid prices causes two problems, though: first, they still have to generate enough cash flow in order to recover investments. Second, lower electricity prices might boost consumption, which is not necessarily in line with government policy.

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[231] In the E&C sector, this procedure is called "change orders" which lead to claims in case accepted.

[232] [REI-1] analyses the grid fault tolerance of different customer groups and compares German to European grid quality.

[233] According to [WEC-1] more than 90% of all grid failures originate in distribution grids, [SCHM-1] states similar figures. [WAR-2] demands to stop seeing electricity as a pure commodity, but to create tailor-made products for different quality demands.

[234] For a brief discussion of regulation mechanisms, different auctions schemes and their current application in Germany and the UK, refer to [HOE-1].

[235] [BIR-1] gives a detailed discussion on legal reasons to deny grid access.

[236] see [FAZ-9] for current law suits pending, or [KÄS-1]

The best way out of this problem is to have two tariffs: general electricity supply at a high tariff, which covers for grid investments and keeps energy saving incentives, and heat pump electricity, that only covers for a small grid fee enough to grid losses.

Concerning SOFC and the "Ultra DIPPs", both gas supply for the SOFC and electricity distribution to the end customers have to be assured at low prizes and easy processes. Friction by gas players is less likely, but electricity grid operators might be less inclined to support them.

Furthermore, a look at telecom deregulation is insightful. There, a powerful regulator with the power for fast response has proved successful. Self-regulation in the energy sector has been rather cumbersome. Germany is the only EU country that has not installed such an institution.[237] But, Germany has as well the most dispersed market. A regulator would not have to deal with one incumbent, but with more than 800 of them.[238] Proving to every single one that he has done something wrong and then make sure that he does not come up with other sneaky ideas is virtually impossible. The rules of dealing with the regulating body have to be changed therefore. First, punishments have to become more severe and immediate[239], like loss of operation contract, sanctions on management or high fines. Second, the regulator should announce the scheme to choose which cases to deal with first. Right now, grid operators that play against the rules can be rather sure that it will take a long time until they get focused on. If the selection algorithm for dealing with cases was known and punishments are high, all players in the higher ranks would align quickly. Game-theoretically, even all would do so.

3.2.3.2.3.4 Tactics

Increasing heat pump sales will principally hurt gas distribution grid operators, but the impact is rather limited, for three reasons

- First, heat pump deployment is more or less limited to newly constructed residential buildings, which means only roughly 200.000 houses per year.
- Second, it often affects areas where gas grid investments have not yet been made.
- Better isolation standards strongly reduce demand and therefore put grid-based distribution at stake anyway.

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[237] see [BIR-2]

[238] [KÄS-1] argues, that the current telecom regulation office has 2600 employees and an annual budget of € 140 Mio, dealing with a handful of players.

[239] [FAZ-9] cites the president of "Bundeskartellamt" that suggests "Sofortvollzug", immediate execution, of the regulatory body's decisions.

This has to be clearly communicated to gas distribution grid operators.

3.2.3.2.3.5 Space

Integrating gas and electricity grid operators would on the one hand reduce incentives for electricity grid operators to support heat pumps. On the other hand, it would enable an integrated optimization of both gas and electricity grids and reduce resistance from the gas side.

3.2.3.2.4 Suppliers

Suppliers of T&D players are especially the manufacturers of grid infrastructure hardware like cabling, switches or measurement and control systems. Also construction and maintenance services play an important role. There are no big issues in the field. In general, outsourcing as much of those services as possible will make it easier for municipal utilities to adapt as they are in an especially difficult position to lay off workforce.

Other suppliers are generators of regulation and reserve power[240]. The demand for it is growing with the generator landscape getting more dispersed and unpredictable sources like wind and solar becoming more important. SOFC and heat pumps could reduce that demand, if they were to be regulated partly by grid operators. The state could provide a communication protocol for that. Before, he has to assure a fair bidding process for regulation and reserve power, though. Today, it seems to be an important source of revenue for incumbents that so far managed to avoid a market environment in this field. [241] [HÖF-1] argues, that the state has to set up a market place run by an independent institution. Most liberalized countries have so.

3.2.4 Trading & wholesaling

3.2.4.1 Strategic context

On the electricity side, the four integrated electricity players dominate trading and wholesaling for two reasons. First, still over 80% of trade is OTC[242] where they have a historically strong incumbent position. Second, they have a quasi information monopoly, as they own 80% of generation capacity and 100% of all

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[240] "Regelenergie"

[241] see [EID-11], [FAZ-9] and [ZFK-1]

[242] Over-the-counter

transmissions lines, including the international ones.[243] This information lead gives them a structural advantage in the zero-sum part of the game.[244]

A few new entrants entered the market, especially the European Electricity eXchange (EEX) in Frankfurt that provides a market place [245] for traders and wholesalers. The transactions volume accounts for 7% of the total market only, though.[246] In the US, most electricity is sold on the spot market.[247]

The trading business promises high returns, as prices are very volatile and regularly reach differences of factor 10. This leads to spreads of 40 base points, compared with 5 base points for $/€ options, for instance.[248]

The wholesale business gets more and more taken over by the four big integrated electricity companies.

The gas market is not yet liberalized. There is no exchange market yet, neither, so all trade happens OTC. And, one player, Ruhrgas, controls more than 50%[249] of import and wholesale.[250]

3.2.4.2 Game-theoretic options

3.2.4.2.1 Complementors

Traders can play an important role in decentralizing generation. They have to support derivatives to the necessary extent, but especially could be an important source of finance for players that want to invest into decentral generation. Generation capacity has two aspects: asset ownership and asset management. Traders are ideal asset owners, as they are in the best position to assess their value, hedge risks and structure finance. They turn physical assets into financial ones and trade them independently from their origin.

State support for that is not needed.

3.2.4.2.2 Customers

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[243] [ZFK-1] discusses those and other forms of discrimination of the big electricity upstream players. [LAU-1] states that competition only really started in Sweden, after import fees on electricity were forbidden. They still exist in Germany.

[244] This is why [CAE-1] argues in favor of an independent market clearing house, like in the USA. [LAU-1] demands the separation of IT Systems and production.

[245] spot market and futures

[246] see [FAZ-6]

[247] The energy industry in general is much more focused. Dedicated players generate electricity and the grids are controlled by a national regulator [RIE-1].

[248] [EEX-1], web and own calculations

[249] see [SCHU-3]

[250] [DEL-1] suspects E.ON to reach a market share of 58% in gas transmission, [DEL-3] the control of 90% of distribution after the merger with Ruhrgas.

Customers are retailers and direct customers. Both have been dealt with previously already.

An additional rule to support SOFC ultra deals with the volume risk of electricity sales. Electricity from those units can be granted priority for dispatch at EEX. This is already done so for green electricity in Scandinavia.

3.2.4.2.3 Competitors

3.2.4.2.3.1 Players

The electricity exchange could support the markets for heat pumps and SOFC ultra by providing a platform and making the market for electricity/gas spread options or by trading certificates that proof that heat pumps are run on clean electricity. The state would not even have to pay for that. It is the exchanges business, only some support with market making at the beginning could probably be helpful. The state might incur open positions to some extent in order to get liquidity on the market.

Another advantage for the EEX would be, that the information lead of the big players is reduced when generation is decentralized and owned by a wider group of companies. Both number of players and transaction volume will grow.

Wholesalers on the other hand will be concerned about SOFC, because they target their electricity customers. They therefore should consider entering the contracting business for SOFC ultra as well.

3.2.4.2.3.2 Added-value

On the gas side, deregulation is currently taking place and no gas spot market exists yet. Deregulating this market might lead to lower gas prices and therefore be disadvantageous for SOFC ultra and heat pumps. The state has to be prepared to raise taxes on natural gas quickly.

3.2.4.2.4 Suppliers

The most important suppliers of traders and wholesalers are electricity generators and gas importers. IT system suppliers are not relevant in this respect.

3.2.4.2.4.1 Players

Decentralizing electricity generation will increase the number of potential suppliers and thereby strengthen the position of wholesalers. This effect will be more important later, when the current overcapacities will be reduced. And, this effect is probably outweighed by the potential loss of electricity wholesale customers that will be served by decentral SOFC in the future. Government engagement is similar to that in the retail segment.

3.2.5 Electricity Generation

3.2.5.1 Strategic context

The generator's strategic agenda is shaped by overcapacity, state intervention in the choice of fuels, downward integration and a potential change in business models.

After deregulation, overcapacities of around 10GW[251] or 10% of total capacity on the generation side have put generators under severe cost pressure[252]. They conducted cost reduction programs in order to recover operating cost and survive the capacity adaptation process.

This overcapacity might stay at the same level until 2010. On the one hand, 7GW of lignite and coal and 3GW of nuclear are bound to be closed until then, but on the other hand, political intervention will lead to some 7GW of new cogeneration capacity, another 1.2 GW of biomass and 4.3GW wind. The generators themselves have announced another 5.6GW of capacity[253].

Generators currently try to secure their sales volume and to reduce the overall level of competitiveness in the market by integrating downstream. Half of all municipal utilities have sold a part of their equity directly or indirectly to one of the big. Amongst the larger ones, none of them is left independent[254].

The period from 2010-2020 might become that of German-wide capacity renewal. Half of the entire generation capacity or 50 GW are bound to be replaced.[255] For the European Union, this figures amounts for even 400GW.[256] This period will be crucial for generators in order to position themselves in the market and for the government in order to shape our energy infrastructure for the next 20-30 years. Nuclear capacity are planned to vanish until 2022, with three mayor waves of closures in 2008, 2016 and 2020 (see Figure 26).[257] Will manufacturers be ready for 2008?

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[251] [HEI-1]. For Europe, [VAH-1] and [HEI-1] estimate roughly 50 GW or again close to 10%, while [VDI-1] even claims overcapacities to amount to 40%.

[252] In Europe, overcapacity will not vanish before 2010 [VAH-1]

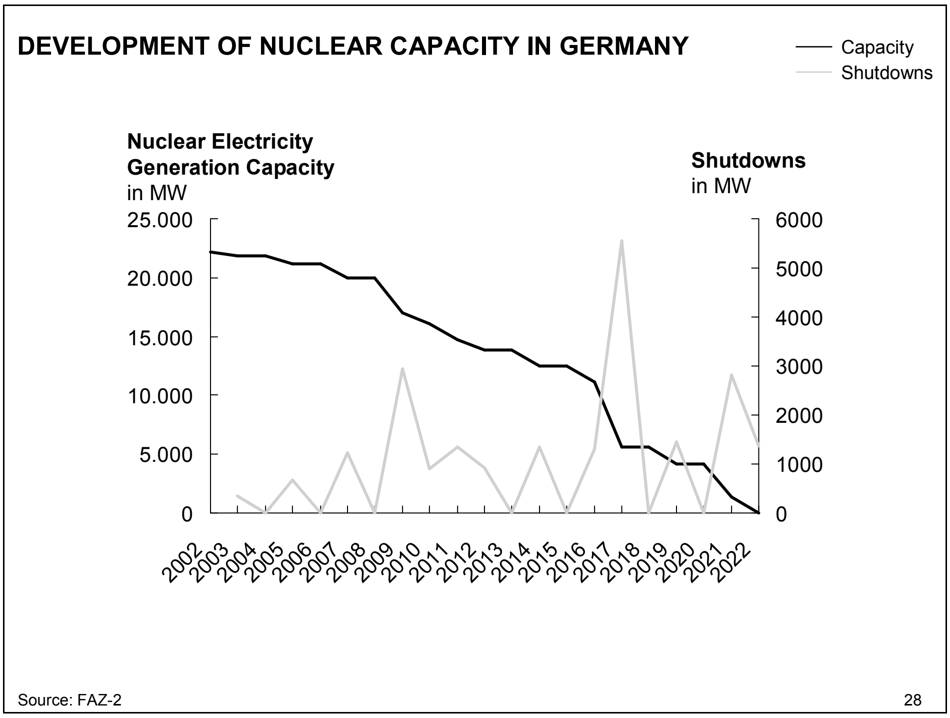
[253] [HEI-1]. For a discussion of the development of generation capacity see also [PFA-5]

[254] Eleven out of 13 have already sold equity, the last two have negotiations pending.

[255] see [PFA-5]

[256] see [KEM-1]

[257] see [FAZ-2]



Source: FAZ-2

Figure 26: Development of nuclear electricity generation capacity in Germany

In that period, the state will probably continue what he is doing today: shaping the choice of fuel. Today, he does so by granting subsidies for coal, cogeneration, wind and other renewables and by propagating the exit from nuclear energy.

Generators also entered a competition in cost cutting. Capacity adaptation more likely hits those that are less quick in reducing operating expenses.[258]

Last, generators might also split up into two different kinds of businesses: asset ownership and asset management. While someone with superior market insight, trading skills and capital market connections could buy up generation capacity, others could focus on transferring best practice between plants and on developing and managing local suppliers and service providers. This concept has been proven successful already in the hotel industry and is to some degree currently introduced in the energy industry as well.

What is the effect of decentral generation on central generators?

Micro power reduces the added value of current generators, that is based on skills in asset ownership and management: Capital sourcing, regulator management, negotiations with engineering & construction companies, operating and

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[258] see [BIR-3]

maintaining huge plants, esp. nuclear ones. Those skills are difficult for small players to acquire and therefore pose a significant entry barrier. Once capacity units get smaller, those entry barriers are gone.

Furthermore, generators currently have huge sunk costs in capacity and hence a vested interest to slow down a fast success of decentral electricity generation. Solar thermal collectors and heat pumps do not pose a threat to electricity generators. On the contrary, they are competitors for micro cogeneration applications and occupy niches where otherwise cogen units might have been installed.

Anyway, the near-term threat of micro cogeneration is limited[259]. Until 2010, neither renewables nor cogeneration is likely to gain a double-digit market share.

From then on, SOFC ultra systems could become very important though. Their optimal size does not allow for residential applications, but serving a single city district seems very feasible. They would be in a way "semi-decentral".

Their economics make them very powerful market share protectors. With high fixed- but low variable cost, they will be dispatched before other natural gas operated can-run capacity. Fixed cost are sunk and therefore not decision relevant and the by far highest efficiency puts them first, especially if run in cogeneration mode. So, a generator that has occupied a number of sites with sufficient heat demand will be hard to attack on the electricity supply in the neighborhood of those plants. They will in some cases even be competitive to "must-run" capacity and capacity with high start-up cost[260], like nuclear energy thanks to lower grid fees. Decision-relevant electricity distribution grid fees are close to zero when supplying heat pumps and in case of onsite generation.

Asset owners could just shift their investments from central to decentral technologies, if enough time is given, but they will encounter more competition.

Asset managers on the other hand will find their current skill set basically obsolete. While running central plants requires skills to negotiate fuel supply and manage inbound logistics, to operate and maintain big industrial machinery and plants and to manage outbound logistics, decentral capacity needs different skills: Building and operating virtual plants, operating and maintaining large number of distributed assets, remote maintenance assessment, accounting and payment of unit owners.

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[259] see [MCK-2]

[260] For an overview on the European electricity supply curve, refer to [BIR-3]

3.2.5.2 Game-theoretic options

3.2.5.2.1 Complementors

Electricity grid operators are complementors. They are sufficiently discussed elsewhere.

3.2.5.2.2 Customers

Wholesalers and retailers are customers. They have been discussed significantly already.

3.2.5.2.3 Competitors

3.2.5.2.3.1 Players

Of course, both heat pumps and SOFC have to be profitable from a company's perspective. Subsidizing capacity cost will be necessary for some time. Furthermore, gas taxes currently discriminate SOFC against coal plants.[261]

The state could invite foreign energy players to bid for Ultra DIPPs. Currently, foreigners are a bit reluctant to play in the German market, as so far they had a tough life entering it[262]. Due to streamlined regulation, Ultra DIPPs could be very interesting. They are a good way to bypass sabotage efforts and far-reaching integration of the incumbents. Giving out a tender for Ultra DIPPs in the area of a few GW would definitely call the interest of international players.

Government should be able to make derivatives a success. [KIS-1] mentions the positive effect that hedging cost- and price risks have on capital cost. Banks accept lower interest rates and higher credits on physical investments that are secured by derivatives. [LAP-1] also sees growing risk as the reason for declining market-to-book ratios and risk management as a possible solution. [MEI-1] talks about the new regulatory requirements for risk management.

There is also a new business model: the virtual utility, that buys access capacity of SOFC units, manages it and sells it to the market.[263] Additional state support is not required for that, right now.

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[261] [GOD-1] alleges that Tractebel would otherwise invest into CCGT capacity in Germany, today.

[262] see [GOD-1]

[263] see [STA-2]. See also [KEM-1] for the concept of virtual utilities

3.2.5.2.3.2 Added-value

At the same time, the information advantage of incumbents that is due to their long monopoly situation has to be reduced and historic information on demand and loads made available to everybody. The state can enforce that for all information during a certain intermediate period. Later, all information from monopoly assets should be open to everybody as well. This definitely concerns distribution grids and probably should comprise transmission grids as well.

3.2.5.2.3.3 Tactics

The state should be able to win the support of especially electricity generators for heat pumps and solar thermal collectors. Electricity generators oppose micro-cogeneration, because it increases supply and brings in new players. Both heat pumps and solar thermal collectors compete with micro cogeneration on the supply of low temperature heat base load. Hence, electricity generators should be actively promoting heat pumps. The state can support their campaigns by independently assuring the ecological and macroeconomic benefit of that technology. Government could also extent support on CCGT generated electricity until SOFC ultra really enter the market.

Electricity generators are not supportive towards SOFC ultra, though. Both owners and operators of current generation capacity need time for conversion and cashing out existing assets. In general, they favor working on large scale CCGT or other fuels like coal or nuclear.

The story of success cases is not only valid for consumers, but for CEOs as well. For them, being the first mover with a risky project like deploying Ultra DIPPs, can lead to serious trouble from shareholders. Not following a successful advantage as well. So, again, communication of success cases is crucial.

3.2.5.2.4 Suppliers

Main suppliers are CCGT manufacturers and gas suppliers. Both will be dealt with elsewhere.

3.2.6 Natural gas import

3.2.6.1 Strategic context

The gas import and generation market in Germany is still regulated and dominated by one big player, Ruhrgas, with 60% market share[264]. One player, Wingas,

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[264] Upstream, together with E.ON [DEL-1].

managed to enter in the recent years and to successfully apply "Sumo strategy"[265]. Apart from that, the market is rather stable.

In the future, the demand for natural gas is going to rise due to a stronger role in electricity generation. Concerning heating, it still wins market share against oil, but as isolation standards improve, there is no significant volume growth due to that. Fueling cars might be a new area for growth as well.[266]

The prices for gas might substantially rise from 2010, when a few natural gas and oil exporting countries become importers.

Upstream gas players are against heat pumps, as they reduce overall consumption and open the door for nuclear or coal to enter the residential heating market.

They favor SOFC ultra only if it is a means to win further market share from renewables or other fuels like nuclear, coal or lignite.

3.2.6.2 Game-theoretic options

3.2.6.2.1 Complementors

3.2.6.2.1.1 Space

Heat pumps principally threaten gas importers, as gas can suddenly be substituted with all different kinds of fuels for heating. Importers should hence be interested to create a link between heat pumps and natural gas. And, therefore, the state should be able to easily convince them to support communication and market making for derivatives.

Another way to gain support for Ultra DIPPs from gas importers could be to allow them to use Ultra DIPPs as fuel stations for natural gas driven cars. This would open a way to gas importers to boost natural gas as a car fuels even without the support of mineral oil companies and their filling station networks. In that case, government could pay importers for investing into Ultra DIPPs/gas filling station by converting the public transportation fleet to gas.

Or, the state could fix a certain percentage of gas driven cars in each car manufacturer's fleet as California did for low-emission cars. This would even be enough to incite filling stations and mineral oil players to stronger offer natural gas as well. Then, they might become locations for Ultra DIPPs as well.

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[265] Poaching in the incumbent's customer base without hurting him enough to cause retaliation measures.

[266] see [EWT-2] for current developments in gas fueled cars in Germany.

3.2.6.2.2 Customers

The customers of natural gas importers are wholesalers and retailers and have been discussed elsewhere already.

3.2.6.2.3 Competitors

3.2.6.2.3.1 Players

The merger of E.ON and Ruhrgas would reduce the number of players and give that company the possibility to hinder other players that would like to enter the field of Ultra DIPPs. It should hence only be allowed if national and low tariffs together with streamlined standard procedures assure easy set-up and supply of Ultra DIPPs.[267] Even then, the reduction of players will reduce competition and innovation.[268]

3.2.6.2.3.2 Added-value

Gas importers are threatened that they will lose volume on the heating business due to the general higher efficiency. Government should therefore clearly and credible point out, that fuel savings will go on the expense of coal or nuclear. They could even communicate a certain time scale for transferring capacity from nuclear or coal to natural gas.

3.2.6.2.4 Suppliers

3.2.6.2.4.1 Players

Looking at suppliers, important players like the UK will exit the game, when their reserves are bound to expire in 2010. Dependency on Russia will be rising and so will do prices probably.

On the one hand, rising gas prices improve the competitiveness of SOFC ultra and heat pumps, as they are more efficient than other gas fueled technologies, but it reduces its competitiveness compared to other fuels.

The state should make sure that new players enter the European markets via LNG in order to secure supply. The issue of keeping or growing fuel prices to a level that makes sense from a macroeconomic or political point of view can still be achieved via taxation.

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[267] [FAZ-7] thinks, that the merger is a decisive move of the two companies into a more decentralized generation paradigm.

[268] see [ENE-2] for additional comments

3.2.6.2.4.2 Rules

Take-or-pay contracts are a common way of commerce between gas producers and importers. They are justified by the huge sunk cost that producers have to spend. Their game theoretic effect is a reduced level of competition. Incumbents can cut prices to nearly zero, when attacked in their own field and are threatened not to be able to sell their agreed import volume. This normally deters invaders. In case it does not, competition can get ferocious. With such a concentrated upstream market as in Germany, that case is rather unlikely though.

The state does not have an interest in furious competition and dramatically falling prices on the gas market. The profitability of heat pumps and SOFC together correlates positively with the gas price.

On the other hand, the state does not have an interest in low competition and high profits of upstream players, neither. So, instead from easing competition among upstream gas players, he could raise gas import taxes.

[CZE-1] is in favor of both take-or-pay contracts and oil-price indication. His argument is that as we do not have suppliers that can exploit gas at cost lower than oil, we have to accept that price. Otherwise, exploiters will not be investing in the long run. For the same reason, we have to buy the volumes we committed to and which exploiters invested on. This is already partly true. Indeed, exploiters have to cover for their cost, otherwise they will not be investing anymore in the future and our gas supply is at risk. This means importers have to guarantee at least interest and amortization, better a fair profit as well. This is independent of any index. The question is who is going to cover for the risk of low competitiveness of gas compared to oil and who will benefit from the rent in case of high oil prices? The state could guarantee a "corridor":

- ¶ Keeping heating oil prices above a certain threshold by tax, assuring cost coverage for gas exploiters and importers,
- ¶ And keeping gas revenues for upstream players below a certain point as well, skimming rent by taxation on gas whenever there is a high oil price.

Anyway, neither take-or-pay contracts, nor oil-price indication[269] are principally barriers to the deployment of heat pumps or SOFC[270]. Changes would also take quite a long time due to the long-term character of current contracts.[271] Creating

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[269] First examples of non oil-price indexed contracts already appear in Germany [BIR-4]. [EID-19] estimates that oil price indexation will fall in 2005 as the role of natural gas in electricity generation is becoming more and more important, demand is growing and new supply can only be attracted at higher prices.

[270] [LAM-1] cites the EU Commission to be in favor of indexing gas more to electricity, not oil prices.

[271] see [IEA-1]

capacities for LNG[272] is important for reducing the power of the current four gas oligopoly suppliers to Germany.

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[272] Liquefied natural gas. According to [EID-1], ¼ of Europe's gas imports could come from LNG as soon as 2005.

3.3 STRATEGIES OF INTEGRATED PLAYERS

The last chapter analyzed the particular interests of each value chain sliver. In reality, there are very few players though, that focused on a single sliver. Most of them are integrated along several ones. The next chapter will hence synthesize those findings in order to assess the interest of integrated players and to draw conclusions for government involvement.

3.3.1 Electricity upstream

Electricity upstream players cover most of the generation and transmission of electricity. They secure their sales position by buying minority shares in local distribution companies and also serve customers directly.

Electricity upstream players are only to some extent inclined to support SOFC ultra. They possess 80% of the generation assets and still want to cash out on those mid-term. Even after that, they do prefer a central generation structure in order to keep their competitive advantage in planning, building and operating such huge plants. They also own the electricity transmission infrastructure, that otherwise would become less important.

Even the fact, that SOFC ultra is a good way to grow their retail business, does not change their attitude. They already secured their sales volume by acquiring minority stakes in RDCs and LDCs. Attacking the retail sector would therefore to some degree cannibalize existing strongholds. And, otherwise, it will cause retaliation measures by the other big players.

Electricity upstream players therefore have to build up SOFC ultra and Ultra DIPP capabilities important enough to become a credible threat to prevent the others to enter. They can invade the territories of small, still independent LDCs and might secure their own key customers.

The state therefore should raise competitive tension again, both amongst the big integrated electricity players themselves and between them and downstream players. In order to do so, the state should first prohibit further acquisition of municipal utility stakes by upstream players. Furthermore, it has to free municipal utilities again to some degree in order to light up the fight for retail market share. One way to do so is to prohibit OTC deals and make anonymous trade via the electricity exchange mandatory. The big players would then not have to fear retaliation when entering the space of their partners.

Another way of raising the big electricity upstream players' acceptance of Ultra DIPPs is a clear plan to exit nuclear energy and reduce the share of coal. Then, the choice of big players would not be to deploy Ultra DIPPs or coal plants, but to build gas capacity or let someone else do it. The companies closing down old capacity could be granted an option on Ultra DIPP concessions. This would give them the possibility to keep market share and therefore calm them down without significantly hurting anybody else.

The big electricity upstream players' position towards heat pumps is different. They are clearly in favor. Heat pumps grow electricity demand, reduce gas players' added value and gas prices and also might become a good way of entering the retail business. Customers might become less sticky, when a new product enters the market.

The problem gets more complicated in case E.ON acquires Ruhrgas. Then, one electricity upstream player would dominate the gas supply for the others. This player would be much less in favor of heat pumps, as they reduce the demand for natural gas and open up a significant part of the market to other fuels. For the same reason, the other three would be even more in favor of them.

The inverse would be true for SOFC and Ultra DIPPs. E.ON could make life difficult for its competitors. The state should therefore protect them against the risk of being patronized by E.ON. Unfair cost of gas could be avoided by introducing a compulsory market exchange for gas as well. Concerning transmission cost, a regulatory body could prove to be very successful, as the number of market players is rather close to that of the telecom sector. Last, a standardized, low cost access to gas for Ultra DIPPs is another means to secure competition.

Looking on a European level, big incumbents are in a race for supremacy and survival.[273] With distributed generation establishing long-term customer relationships and therefore reducing risk, companies could reduce their cost of capital and thereby significantly increase their market value.

3.3.2 Gas upstream

Gas upstream players have rather the inverse motivation than their electricity counterparts. They disfavor electric heat pumps for two reasons: first, the total gas consumption is reduced even if the respective electricity is produced on the basis of gas. Second, gas gets new competitors in the heating market, as heat pumps can be driven by electricity from coal, lignite and nuclear as well.

The same is true for SOFC ultra: if it replaces CCGT only, than the overall gas consumption will be reduced due to higher efficiency. If it replaces other fuels though, it would increase turnover.

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[273] [WIL-1] expresses the assumption, that only three international energy players will survive in Europe long-term.

The state can reduce gas upstream players' worries by assuring that all savings on natural gas in the economy will be used to reduce other fuels like coal or nuclear and not be on the expense of the natural gas market. In order to give credibility to his statement he could already issue licenses that are valid until gas import increases above a certain volume.

SOFC ultra may also become a possibility to enter into new markets and supply big customers not only with natural gas, but also offer them contracting schemes for SOFC ultra.

3.3.3 Integrated LDC

Integrated local distribution companies will focus on managing grid operations and retailing in the future.[274] Both heat pumps and SOFC ultra can become important retail products.[275] In fact, heat pumps do exploit renewable energy and therefore reduce fossil consumption, but margins for electricity are higher than for gas. This is due to the inverse profitability structure of the gas and electricity value chain: on the electricity side, most value is extracted downstream, while on the gas side most of it is kept upstream (see Figure 27).[276] An integrated LDC would therefore win much more on the additional sales of electricity to a heat pump than it loses on lost gas supply of a boiler[277] (see Figure 28).

Furthermore, the market share of LDCs is much higher in gas than it is in electricity.[278]

Second, contracting for electric heat pumps could become a new business field and bind customers in long-term contracts.[279]

It also might become a tool to reduce stickiness of non-heat-pump customers. That would be both a threat and a possibility to LDC and therefore be a significant motivation for them to engage themselves.

While in Switzerland 40% of all new houses install heat pumps[280], in Germany only 1-2% do so.[281] So, the problems are neither technical, nor economical, but

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[274] [LUE-1] gives a short overview on the strategic situation and current issues for municipal utilities over the entire value chain.

[275] MVV has innovative technologies, like fuel cells or cogeneration, as explicit block in their corporate strategy [HAR-1].

[276] own analysis, but see also [EID-17].

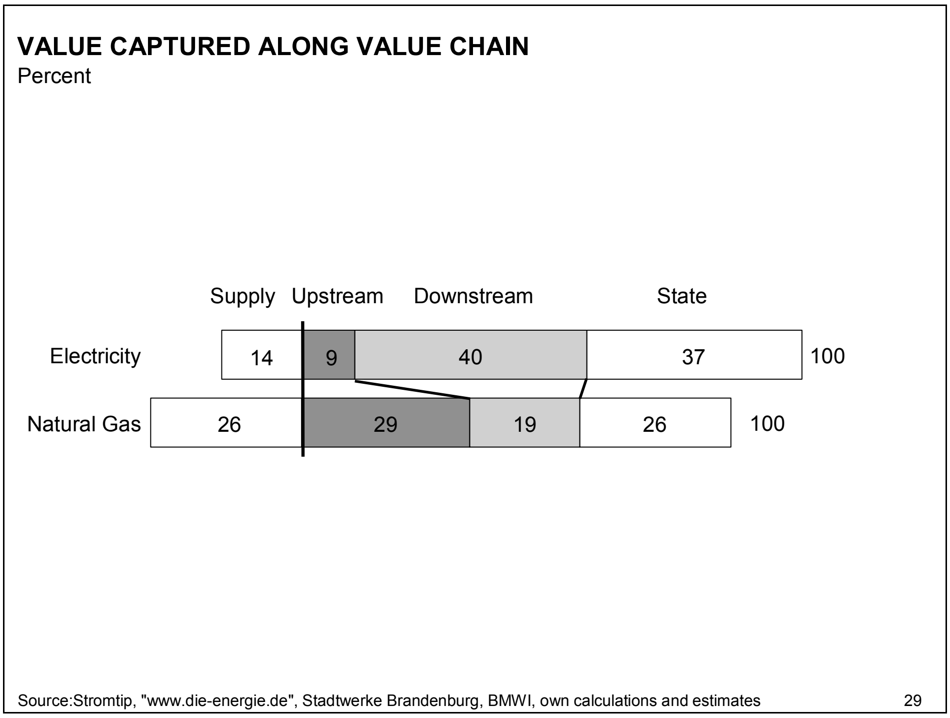
[277] The LDC would have to give a discount on the electricity supplied to the heat pump, though, because it would not be profitable for its owner otherwise. Interestingly, the state would also profit a lot more from a heat pump than from a boiler, regarding current taxes. He, as well, would have to give some of that margin to the consumers in order to make such an investment profitable.

[278] Municipal utilities supply only 37% of electricity demand in Germany, but 71% of gas [SDZ-2].

[279] [LAN-1] sees a big potential in contracting for municipal utilities, both for the financing and operating function.

[280] [INN-2]

more related to the motivation of consumers. Government should conduct a short, but intense campaign for heat pumps[282] and prevent misguiding information from lobbies. Once a critical mass of architects and house builders recognize heat pumps as system of choice, a movement running on its own will start.



VALUE CAPTURED ALONG VALUE CHAIN
Percent

Source:Stromtip, "www.die-energie.de", Stadtwerke Brandenburg, BMWI, own calculations and estimates 29

Figure 27: Value captured along value chain

SOFC ultra are a good way to lock-in big customers, Ultra DIPPs a tool to build strongholds and to invade the districts of other LDCs. In that way, they are both a threat and an opportunity. Government could smoothen resistance via a moderate license and support policy, making change not too fast and distribute effects geographically evenly.

LDCs can reduce upstream electricity players' added value and therefore keep electricity wholesale prices low, even long-term. On the other hand, especially the big integrated electricity players could use this tool for invasion of the retail market. Again, a license policy that sufficiently considers small incumbents will reduce resistance.

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[281] [EIC-1]

[282] Equivalent to the way Garry S. Becker suggests the enforcement of tempo limits. In his book "Homo Oeconomicus", Becker analyzes and optimizes issues of public life under a microeconomic perspective.

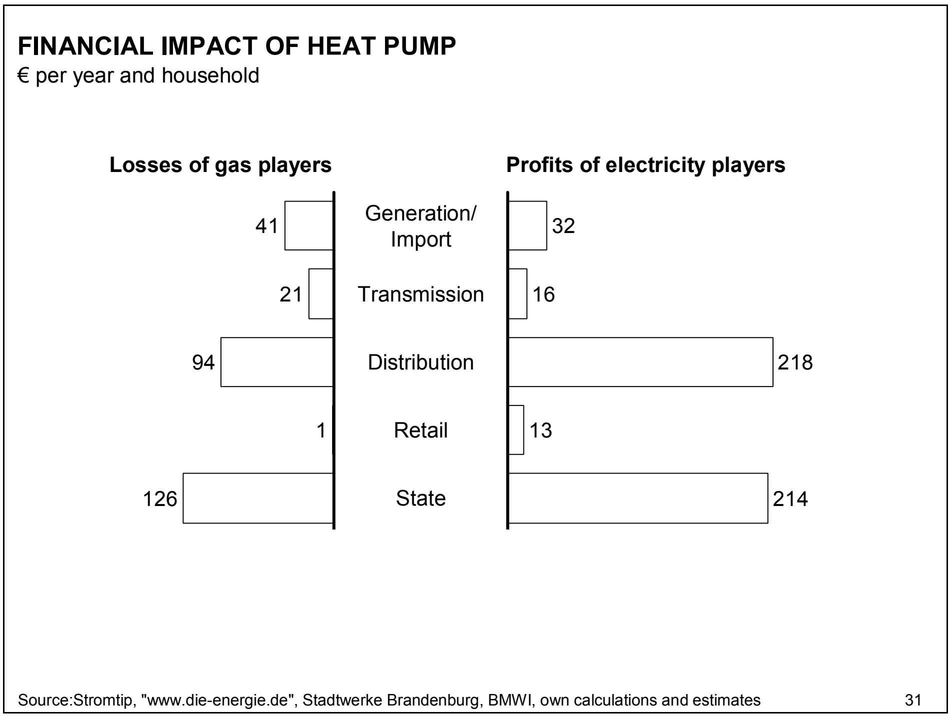

Figure 28: Financial impact of heat pump to different stakeholders

Currently, vertical competition is blocked to a large degree my minority shares taken by big upstream players in municipal utilities.[283] This is not helpful for the promotion of innovative products, like heat pumps and SOFC ultra. Those alliances should be stopped or at least contain Texan-auction clauses for breaking them up.[284] Most transactions have already taken place though. The only way out for government could be compulsory exchange market transactions.

Breaking up integrated electricity and gas LDCs into separate entities would be politically difficult, but increase competition especially in the field of heat pumps. Margins in distribution are huge, so the question whether houses are heated on gas or on electricity is a real issue. In the long run, the gas distribution grid should be significantly reduced. Due to the slow placement of heat pumps and the slow improvement of isolation standards, pressure on gas LDCs will be bearable. Furthermore, the state could reward non-renewal of gas grids with granting Ultra DIPP licenses and thereby help downstream gas players to enter the contracting business.

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[283] See [EID-15] for a statement of Wintershall CEO Zwitserloot, that they more or less never manage to enter municipal utilities where big upstream players have a share in, regardless its size. [BIN-1] supposes that the strategy of vertical integration aims at prohibiting foreign exploiters to directly enter the German market. [EWT-3] alleges that GdF follows as well the strategy of vertically integrated growth.

[284] [SEE-2] explains why LDCs should not engage in alliances with the big upstream players and rather stay independent.

4 Integrated government strategies

Governments principally have more strategic options than market players. They can become a market player with all options themselves by nationalizing existing players or creating new ones and they have much better possibilities to make rules. In a free market economy though, the state being a market player is in general politically not desired. Hence, in Germany, market players have more exclusive options on the "player" side, governments on the "rules" side.

The state should support SOFC ultra electricity generation and electric heat pumps instead of 1/2-cogeneration. Both technologies are supposed to generate not only ecologic, but even economic value, at least after a short period of ramp-up subsidies.

The success depends to a large degree on convincing the different players and consumers to adapt. It is also important to remove barriers and streamline processes for their implementation.

Three different programs are the key to success.

4.1 ELECTRICITY / GAS DERIVATIVES

Both heat pumps and SOFC ultra will become successful only if they are also profitable for private owners. Due to their long-term character, the profitability of those investments is threatened by the volatility of input and output energy prices. Furthermore, capital costs of both technologies are still too high to allow profitability. The state, though, can secure the financial viability without entering neither high risks nor costs by introducing a special kind of derivative. This will be of growing importance, as gas prices are supposed to become more volatile in the future.[285]

Equation 1 shows the mathematical condition for a heat pump to be profitable to its owner, including government payments. Each kWh_e saves a certain amount of gas, depending of the efficiencies of both the heat pump itself and that of an alternative technology, for instance a boiler. This gas volume has to be valued at its market price or opportunity cost. Other variable elements are the cost of fuel, electricity in this case, and the value of the state payment. The sum of these three

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[285] see [BIR-4]. [EID-9] even alleges spot market prices to six fold in case of cold winters. [SCHL-1] estimates a general price rise for natural gas by 38% until 2020, [LAM-3] of 20% until 2010.

factors is the operating margin that has to cover at least all fixed costs. Fix costs consist basically of investment and O&M.

A similar logic is valid for SOFC ultra and leads to Equation 2. The margin consists of the electricity revenue, the cost for fuel, in this case natural gas, and again the value of a state payment.

$$\frac{\eta_{heatpump}}{\eta_{boiler}} \times g - e + f_{Call} \geq FC_{heatpump}$$

Equation 1: Profitability condition for heat pump

$$e - \frac{g}{\eta_{SOFC}} + f_{Put} \geq FC_{SOFC}$$

Equation 2: Profitability condition for SOFC ultra

$$FC : Fix\cos t \left[\frac{ct}{kWh_e} \right]$$

$$\eta : efficiency$$

$$g : gas\ price \left[\frac{ct}{kWh_{gas}} \right]$$

$$e : electricity\ price \left[\frac{ct}{kWh_e} \right]$$

$$f : value\ of\ derivative \left[\frac{ct}{kWh_e} \right]$$

Table 30: Explanation of Equation Parameters

People will invest if the state payments are large enough to guarantee that margins will cover for fix costs. This is expressed mathematically in the above equations. If the state pays both parties sufficiently to break even, his net position is can be calculated according to Equation 3.

$$netposition = FC_{heatpump} + FC_{SOFC} - g\left(\frac{\eta_{heatpump}}{\eta_{boiler}} - \frac{1}{\eta_{SOFC}}\right)$$

Equation 3: Government net position

As one would expect the net position depends on the one hand on the fixed costs of both technologies and on the other hand on the general energy price level. The spread between gas and electricity is not important, as the effects are inverse on both technologies. The government can influence the price of natural gas by raising taxes on it, for instance. In principle, it could also secure its net position against fluctuations of the gas price with derivatives for gas. This market has to be created still, at least in Germany.

In real terms, this net position today would be worth 5ct/kWh$_e$[286], which is exactly the amount of subsidies allocated to fuel cells in the new German cogeneration law. Almost without additional cost, government could not only induce the installation of 1MW$_e$ of fuel cells, but at the same time of 3.7 MW$_{thermal}$ worth of heat pumps!

Cost could even be reduced further in case of special gas and electricity tariffs for SOFC and heat pumps.

$$\frac{\eta_{heatpump}}{\eta_{boiler}} \times g_{household} - e_{household} + f_{Call} \geq FC_{heatpump}$$

Equation 4: Profitability condition for heat pump, advanced

$$e_{district} - \frac{g_{district}}{\eta_{SOFC}} + f_{Put} \geq FC_{SOFC},$$

$$\text{with} \begin{array}{l} e_{household} = e_{district} + \Delta e \\ g_{household} = g_{district} + \Delta g \end{array}$$

Equation 5: Profitability condition for SOFC ultra, advanced

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[286] With fix cost equal to investment cost, not regarding differences on O&M or other costs

$$netposition_{new} = FC_{heatpump} + FC_{SOFC} - g_{district}\left(\frac{\eta_{heatpump}}{\eta_{boiler}} - \frac{1}{\eta_{SOFC}}\right) + \Delta e - \Delta g\frac{\eta_{heatpump}}{\eta_{boiler}}$$

$$= netposition_{old} + \Delta e - \Delta g\frac{\eta_{heatpump}}{\eta_{boiler}}$$

Equation 6: Government net position, advanced

Government's cost of subsidizing hence grows with the difference of the electricity price at the SOFC's feed-in point into the distribution grid and the household access point - in other words, the grid fee of the municipal utility.

For government, the magic policy should be a special, national low-cost grid tariff for SOFC-generated electricity that runs heat pumps. This would reduce Δe without reducing electricity cost in general. In other words, there would be two grid tariff segments:

- A basic one, which is expensive enough to cover municipal utilities' cost and prevent an irresponsible use of electricity and
- A second one, significantly cheaper and reserved for heat pumps.

This interference into price setting does not cause a problem of justification, as, firstly, grids are monopolies that do require interference in any case, and secondly, as heat pump electricity is on top of general household demand. The general household demand should cover for the basically fixed grid cost alone. Extra volume does not cause extra cost, so heat pump electricity does not have to generate high extra revenues.

The subsidy cost is also influenced by the gas grid tariff, this time positively. That means, the higher the gas distribution grid tariff, the cheaper the subsidy becomes for the government. It could hence place taxes on it or make regulation less efficient. The state has to assure though, that the gas grid tariffs for SOFC are low and easy to use, for instance again a national flat rate.

In other words, distribution tariff engineering can reduce the government's net position by half:

- A special low cost heat pump electricity tariff of 1 ct/kWh$_e$, instead of an average 4.2 ct/ kWh$_e$ [287] and
- A gas distribution fee of 0.8 ct/kWh. An increase of 1.5 ct/kWh would even reduce the government's net position to zero.

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[287] Average distribution fee according to a study of VIK in www.stromtip.de

Looking at the value of each derivate separately reveals that they can only be traded with professionals, not with private consumers. Why?

Figure 29 displays the value of each derivative for both SOFC- and heat pump owners. Keeping the electricity price fixed, a sinking gas price leads to a sinking value of the derivative for the SOFC owner. The value of the derivative can become even negative. In that case, the SOFC owner does not only not receive money, but also has to pay money to the state. The state will then forward the payment to the heat pump owner in order to make up for his losses. This is inherent to derivates of this type[288], but in practice requires a professional partner. In the case of futures, both sellers and buyers have to make deposits and adjust them with fluctuating prices. In the case of swaps, the rating of the business partner is important as well as the possibility to sew him at a justifiable cost/benefit ratio. Both futures and swaps are much too cumbersome for households and need professional partners that operate as contractors to the final consumers. This aspect opens up a new business opportunity especially for municipal utilities with their good end customer relations and should reduce their opposition.

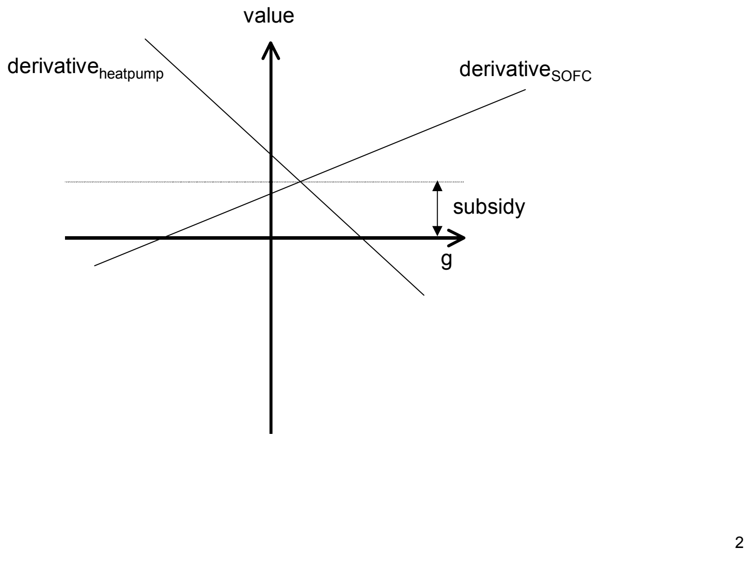

Figure 29: Value of derivate

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[288] swaps or futures

Generally, it is important to credibly make clear, that subsidies will always be set in a way that will keep unit profitability equal or sinking. This avoids that people do not invest, because they think a better deal is ahead.[289] One way of doing so is a most-favourite-consumer-clause to all recipients of the subsidies concerned.

4.1.1 Process

There are three different ways to deal with hedging cost and price risk between heat pumps and SOFC ultra.

4.1.1.1 Integrated municipal utility

The easiest case is that of an integrated municipal utility, that invests both in fuel cells and heat pumps[290]. Most price and cost risks would be hedged against complementary risks within the same company. The municipal utility would be left only with the risk of a falling gas price (see Equation 7).

$$risk \cong const - g\left(\frac{\eta_{heatpump}}{\eta_{boiler}} - \frac{1}{\eta_{SOFC}}\right)$$

Equation 7: Gas price dependency of risk to integrated player

For this risk, it should not be too difficult to find a hedging partner, though. Two players are natural owners for that risk: gas importers and the state. Both have a strong influence on the gas price not getting too low - gas importers due to the tight oligopoly, the state due to import taxes. They could sell options, not futures, to protect others against the risk of gas prices getting too low. This would leave an upside potential for the municipal utilities.

4.1.1.2 LDC and heat pump owners

The second case is that the owner of the heat pump is different from the LDC that runs the SOFC. It could either be another contractor or the consumer himself. Both parties could hedge their risks by indexing the electricity price for the heat pump to the local gas price. In that case, the owner of the heat pump does not have to be a professional. The LDC can manage the derivatives. The heat pump owner has a guaranteed margin thanks to an indexed gas price. It only has to be prohibited, that the heat pump owner buys electricity from someone else at a cheaper rate, in case

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[289] The opposite happened with solar thermal collectors [ENE-1b].

[290] And hence sell heat, not gas to its customers

the gas-based price is higher. Contracts have to be long-term then. One way to prevent contract offense from the part of the heat pump owner is, that the special heat pump grid fee is limited to gas-indexed electricity contracts and that subsidies are not paid entirely at the beginning, but over the entire lifetime by annual or output based payments. Government has to make sure to always be "cash positive"[291] and keep the incentive for the others to comply with agreements.

Also, third-party-access to both gas and electricity grid has to be assured. Government should establish a national standard procedure and a single fee, both assuring low-cost access. Grid operators that can measure actual output would pay out subsidies and be repaid by the state.

4.1.1.3 Anonymous markets

A special electricity tariff for heat pumps requires additional metering effort. Best are two electricity meters, one for general household electricity and a second one for heat pump electricity. Alternatively, a heat meter can be attached to the heat pump. This might not be feasible everywhere. Furthermore, a reasonable number of LDCs already have long-term contracts for their entire electricity supply and therefore are not in the position to source on gas-index prices. In that case, parties need the possibility to hedge their risks on purely financial markets, regardless where they buy electricity from or sell it to.

Exchange markets have a couple of other advantages: high transparency, low transaction cost, anonymity and absence of settlement risk.[292]

The SOFC operator has to buy gas futures in order to secure his supply and to sell electricity futures in order to secure sales. The heat pump operator or the above LDC[293] would do the opposite. A long-term market for both derivatives is necessary.

Today, only an electricity future market exists and that only for up to a year[294]. The state could play a role as market maker in the beginning providing liquidity. The electricity should explicitly be labeled "heat pump electricity" and open to suppliers that use 2/1-cogeneration, wind, water or other renewables as fuel. The subsidy for heat pumps should be granted only if they use that emission-low electricity. The grid operators would play major role in subsidy distribution and

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[291] The term "cash positive" is used in large engineering & construction projects, that last several years and can cost several hundred million EURO. There, the full payment is not made at the end, but partial payments are made along the course of the project. In case of disagreements, your position is much stronger, if you paid less than you received or did less than you have already been paid for.

[292] see [FUD-1]

[293] An LDC that has to supply someone electricity on a gas-price index basis, but sources on a wholesale price basis. The LDC would additionally sell the electricity from the future at the spot market, as it already has a supply contract for its entire volume.

[294] see [FUD-1]

billing & accounting, but transactions are standardized and low price. The state has to found a certificate-issuing agency.[295]

But risk coverage is not the only barrier to higher sales of heat pumps and SOFC ultra. Investment costs are still too high and have to be subsidized for some time. The state should not do that with a constant amount, though. He should either auction subsidized units or grant subsidies that have a gas price dependant component[296]. Equation 3 shows that the total operating risk of heat pumps and SOFC combined is getting smaller with higher gas prices. The state should therefore not pay more than necessary.

4.2 ULTRA EFFICIENT DISTRICT ELECTRICITY PRODUCTION FACILITIES (ULTRA DIPPS)

The heat pump market potential is not sufficient, though, to fully use the capacity of an SOFC ultra. A residential building uses such a device probably to around 1300 full time hours per year. Even when supplying a large number, the utilization would not go significantly higher than 2000h/a. With the high capital cost of SOFC, higher run times are needed in order to reach profitability. They hence have to sell electricity to the market. [297]

The current way of ensuring market access to politically supported technologies is to force utilities to buy all electricity at pre-fixed tariffs. The difference to market price is covered by the state or the energy sector in total. This is not a very fair approach, as it leaves incumbents with the problem of adjusting their capacities. On the other side, it deprives SOFC generators from customer contact and additional value from cross selling.

A way to leave SOFC with more entrepreneurial risk and chances are ultra efficient electricity production facilities (Ultra DIPPs).

Ultra DIPPs would neither be completely central nor decentral, but something like "semi-central", supplying a small district with electricity. With a capacity between $100kW_e$ and $1\ MW_e$, for instance $500kW_e$, and an electric efficiency of up to 75% they could still supply some 15% of low temperature heat[298]. That is enough to

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[295] [GRO-2] discusses a detailed process for green-energy certificates. He suggests a European-wide trading platform and national issuing agencies. He also suggests keeping the information of the origin and therefore opening a vast range of product possibilities, ranging from "Swedish water power" to "green energy from all over Europe".

[296] This is a way the state can make sure not to pay too much. [WIW-1] cites the "Bundesrechnungshof" to claim PV subsidies to even exceed total capital cost.

[297] This depends largely on the way electricity is accounted for, though. Current eco-labels do not consider the time green electricity is produced, just the volume [GRO-2]. An SOFC could therefore virtually supply more heat pumps than it could physically by producing eco-certificates in summer and selling them in winter.

[298] During the technology evaluation, a more conservative value of 65% has been taken. Potential heat supply would be bigger in that case.

supply a large office with heat, 3-5 of them would be sufficient for a secondary school, a hospital or a large hotel. Of course, the surplus of electricity would be significant.

But instead of guaranteeing feed-in and respective tariffs, those units could be granted special rights to access the electricity grid. Within an area of for instance 1km a special discount tariff would be established, together with a simple and standard business transaction, both universal all over Germany.

First, this would incite numerous players to join the game, being probably the first real chance to compete against incumbents.

Second, it would also incite consumers to join the game: a bargain, limited to a selected group of people and with offer being smaller than supply - probably few people could resist…[299] For this group, communication and making a few success cases at the beginning is crucial. Actually, the fight for bargains and the German soul's perception of justice could very quickly put high pressure on politicians and companies to bring everybody into the privilege of being served by an Ultra DIPP. This pull could also be used in order to support heat pumps: those areas with highest heat pump quota get served first, or better, those households that do have heat pump are considered to "virtually" be in this 1-km-zone regardless where they are physically located.

The companies involved could couple electricity with gas supply and perhaps other utilities, services or goods. Despite except Centrica, there are no really convincing examples of that, but Ultra DIPPs might be a new format that will prove successful. Marketing them as something like the district service center could create new opportunities.

A flat fee would also be justifiable. The actual grid used would principally be little and the entire electricity transmission & distribution system definitely be relieved. Neither the volume-, nor the price risk would be put on the LDC, or on anyone else.

Access to the gas grid in order to supply the Ultra DIPP would have to be standardized in both tariff and process as well. Otherwise, incumbents could use them to hinder their establishment. A slow start would be disastrous though. Again, early success cases are very important to gain momentum.

Standardization is also important for the engineering & construction process. Significant cost savings are possible, when standard solutions or at least standard modules are used instead of entirely tailor-made approaches[300]. Such solutions are

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[299] The reason for the bargain, as well as the ecological superiority and the high power quality are easily understood. All three also address the "end benefit" of the product and therefore can become mayor brand building elements [SCHI-1].

[300] see [BÄS-1]

currently entering the market for reciprocating engines[301]. Standardized plants with a general license for residential areas are sold turnkey at fixed price. They are manufactured and marketed by a joint venture of an E&C company and a municipal utility. Contracting models are offered as well. Ultra DIPPs are even in a better position for solutions using standard modules, because they can be much smaller. The above reciprocating engines have a total combined electric and thermal capacity of 11MW; SOFC ultra starts at 1% of that.

Another aspect of Ultra DIPPs is that they supply high quality power. They do so much cheaper than current alternatives and are very attractive looking at the sometimes enormous secondary costs of bad quality power[302]. So, suddenly residential and business customers in a certain area get the offer of high quality power.

4.3 HEAT PUMP DESIGN CONTEST

Heat pumps are today the cheapest established technology to use solar energy, much cheaper than both solar collectors and photovoltaics. Depending on the study, they are either even profitable for their owners or at least close to that. In the eighties, they already had tremendous growth rates, but unreliable machines and rising electricity prices have killed the movement.

Heat pumps today do not face those technical problems anymore, yet the old sales figures never came back. How can this momentum be gained again?

A national heat pump design contest might be the solution.[303] All national and international heat pump manufacturers are invited to present prototypes that compete under certain parameters chosen by the government, like reliability, price or efficiency in summer or winter time, for heating or warm water.

There are several ideas for dealing with the winning system. Either, all designs fulfilling the demand of the jury get labeled and the winning design would get a contract on an interesting number of units. Or, the winning design becomes something like a "Volks heat pump", with all governmental sourcing and subsidies restricted to it. The design would be accessible to all manufacturers, who have to pay license fees to the designing company. A common sourcing platform would invite additional suppliers to join the game and reduce cost through better prices

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[301] see [HYR-1]

[302] [BIR-3] estimates the value of lost load to 2600 GBP/MWh, [SEI-2] refers to spot market prices of \$7000/kWh$_e$ in the US. Transients and other disturbances cause additional problems. [HAL-1] assesses total cost of electric power problems to \$26 billion per year.

[303] [JAK-1]

and optimized logistics. Manufacturing experts could design a state-of-the-art production process that as well is openly communicated to everybody.[304]

A couple of discriminations against heat pumps should be ended, like

¶ The one-sided charging of electricity by the ARE[305] and the new act on cogeneration[306]

¶ Ecotax being paid on natural gas and oil, but not on coal or nuclear fuel

¶ The exceptions on ecotax[307] for several technologies, including night-storage-heaters, but not for heat pumps.[308]

¶ And electricity and therefore heat pumps. Other forms of heating are not hit.[309]

In this project, speed is important. More than two million heating systems have to be replaced, currently[310]. Some of them will be targets for heat pumps.

The "Volks heat pump" would be cheaper, reliable and an easy decision for consumers:

¶ Cheaper, because the size of the project would attract large foreign competitors and because of all the design and process improvements described above.

¶ Reliable, because heat pumps are so today anyway and because a special effort has been paid in the course of the project.

¶ This leads to an easy decision for consumers, because information costs are significantly reduced. The heat pump of their choice would have a label or be the official "Volks heat pump".

Hence, the trust into its reliability and competitiveness would be high, regarding the effort that has been paid to it. Here, again, it is absolutely crucial to deliver to expectations, create and communicate success cases and sharply survey publications attacking it.

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[304] The US Department of Energy sets an example of how to use external consultants in steering national R&D projects with their engagement on PEMFC [GEY-1].

[305] Act on Renewable Energies, "EEG-Gesetz". [SCHU-2] criticizes that district heat customers or consumers of natural gas and oil do not have to pay. The financial burden is totally laid on electricity and its customers.

[306] "KWK-Gesetz". See [BUN-1].

[307] "Ökosteuer"

[308] see [GAI-1]

[309] see [SCHU-2]

[310] see [REH-1]

5 Summary

Public opinion and government politics are strongly in favor of cogeneration. When they say "cogeneration", what they more specifically mean are "1/2-cogeneration"-technologies: units with an electrical efficiency half as important as their thermal efficiency, mostly reciprocating engines, but principally also microturbines or Stirling engines. The electric efficiency of those technologies is rather low, around 30%. Government and some lobbies see those technologies as a major building block of a more sustainable energy policy. They are wrong.

Due to a number of principal mistakes in assumptions and calculations both the ecologic and the economic evaluation of energy generation technologies is generally not correct. The largest defects are the non-understanding of decision relevancy of costs, the choice of the wrong reference technologies and a misleading way of handling combined production.

Investing today, most "1/2-cogeneration"-technologies do not significantly contribute to a reduction of emissions, or even do the contrary. For the remaining ones this will be the case soon. Anyway, none of their performance justifies the amount of money and public mind share directed to it.

Instead, electricity generation should be based on pure electricity technologies or "2/1-cogeneration"-technologies: CCGTs or, later, combined systems of high-temperature fuel cells and microturbines[311]. Their electric efficiency is twice as high as their thermal one. Whether they are run in cogeneration or not does not impact their ecological and economical superiority. Of course, using the waste heat is still preferable than not doing so. Electric heat pumps or high-efficiency boilers best generate heat.

But government not only supports the wrong technologies, it also does it in a very unsophisticated way. It either guarantees fixed output prices or even grants fixed sums per machine or per output unit. It does not consider the actual profitability gap of those investments. It also does not look at strategic interests of market players involved in order to team up or to attenuate resistance.

A more effective energy policy tries to develop markets. It uses derivatives, gas-indexed electricity retail prices, auctions, design contests, most-favored-subsidee-clauses, industry-wide supply platforms, licenses or certificates. It takes advantage of the state's huge buying power and allows landlords to cash on a part of the

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[311] SOFC ultra

savings when investing into new generation capacity. Especially three ideas have been developed further in this study.

1. Derivates on the gas/electricity spread guarantee operating margins independent of market price fluctuations and put an end to the tiresome discussion of reference technologies. As risks for heat pumps and highly efficient electricity generation technologies are inverse, the residual risk position for a government supplying those derivates would be close to zero (see chapter 4.1).
2. Ultra-efficient district electricity generation plants (Ultra DIPPs) consist of high-temperature fuel cells and microturbines as "2/1-cogeneration" technologies with an exceptionally high electric efficiency and a revolutionary small minimal size. They supply a commercially sized heat consumer with waste heat and a small city district with premium quality electricity. They enjoy streamlined grid access and approval procedures and a low grid access tariff (see chapter 4.2).
3. A design contest for heat pumps can raise efficiency and industry-wide learning by developing a "Volks" heat pump with streamlined production and supply chain processes, joint branding and communication and a common supply platform (see chapter 4.3).

In addition to that, the current discrimination of electricity as an energy form and the unconditional support of "1/2-cogeneration" have to be stopped.

A major replacement of generation capacity will take place in the next two decades: for residential heating until 2010 and for electricity generation between 2010 and 2020. For political reasons it seems unlikely, that government will turnaround its current policy in that respect fast enough, if at all. Industry could be able to push through heat pumps and CCGT/SOFC ultra instead of 1/2-cogeneration on their own, though. Apart from corporate responsibility, the possibility to cash on the generated value-added should be a stimulating reward.

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