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Support schemes and ownership structures – the policy context for fuel cell based micro-combined heat and power

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ABSTRACT

In recent years, fuel cell based micro-combined heat and power (mCHP) has received increasing attention due to its potential contribution to European energy policy goals, i.e., sustainability, competitiveness and security of supply. Besides technical advances, regulatory framework and ownership structures are of crucial importance in order to achieve greater diffusion of the technology in residential applications. This paper analyses the interplay of policy and ownership structures for the future deployment of mCHP. Furthermore, it regards the three country cases Denmark, France and Portugal. Firstly, the implications of different kinds of support schemes on investment risk and the diffusion of a technology are explained conceptually. Secondly, ownership arrangements are addressed. Then, a cross-country comparison on present support schemes for mCHP and competing technologies discusses the national implementation of European legislation in Denmark, France and Portugal. Finally, resulting implications for ownership arrangements on the choice of support scheme are explained. From a conceptual point of view, investment support, feed-in tariffs and price premiums are the most appropriate schemes for fuel cell mCHP. This can be used for improved analysis of operational strategies. The interaction of this plethora of elements necessitates careful balancing from a private- and socio-economic point of view.

1. Introduction

Fuel cells can reach large production numbers by attaining different mass markets, e.g. in the automotive sector, as a decentral storage technology for fluctuating generation from renewable energy sources or as a decentral cogeneration technology. In all of these potential markets, they face a number of competing technologies. Price projections based on learning curves for PEM fuel cells reveal that the necessary economies of scale can hardly be achieved without subsidies before 2025 [1]. Until today, related scientific literature covers mainly operational strategies of mCHP fuel cells [2] or integration into existing liberalised power markets. One of the results is that the ability for variable operation is desirable if mCHP units should be able to participate in different kinds of electricity markets and adjust to market signals [3,4]. However, this requires aggregating a large number of units to fulfil some market participation rules such as minimum capacities. Furthermore, an aggregation offers the advantage to reduce transaction costs in comparison to a situation where single units participate independently. A detailed case study for an application in California relates the necessary change of external parameters, as the electricity price, to operational schemes [2]. An integrated utility that owns both the grid and is also responsible for balancing generation and demand is assumed. In liberalised electricity markets, as in most EU countries, these actors can be separated and therefore, their interests are more differentiated. In general, a combination of building efficiency standards and mCHP support schemes has been suggested if certain dimensioning parameters are fulfilled [5]. Studies on the advantageousness of mCHP fuel cell systems arrive at different conclusions: some demonstrate that fuel cell systems have benefits in comparison to competing technologies [6]. Contrarily, others show that in comparison with other heating technologies for a system with a large share of wind generation, mCHP fuel cell systems based on natural gas are not among the cheapest options [7]. Along with the explanations for this divergence is the dimensioning of the mCHP unit, i.e. whether it is dimensioned to cover the full heat demand or only part of it. Lately, a number of different initiatives and pilot projects lead to installations in e.g. Germany and Denmark, new Japanese buildings and in South Korea, where a 80% investment subsidy is granted. Further projects in the Netherlands and the United Kingdom have been considered if technology viability and reliability were proven [6], but did not evolve further. These are contracts regarding solid oxide fuel cells (SOFCs), whereas

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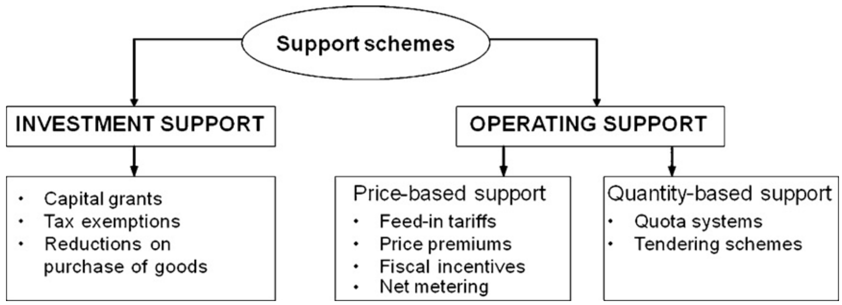

Fig. 1. Categories of support schemes.

the majority of installed units in Asia are based on PEM fuel cells. Overall, it seems that it is time to analyse support scheme options for mCHP fuel cells. To the authors' knowledge, this has hitherto only been addressed to a limited extent [8], but would help the deployment considerably [5].

Based on this assessment, the objective of the FC4Home project is to assess the application of fuel cells as micro combined heat and power (mCHP) units in individual dwellings. More precisely, this covers the socio-economic consequences of different promotion schemes and ownership constellations as well as energy system analyses. The latter will reveal the interaction with the overall system of energy supply as well as possible operation modes of mCHP units. Furthermore, the project deals with current national regulatory frameworks and policy conditions in several European countries and analyses national stakeholder interests – which can be vital for the implementation of fuel cells as a mCHP technology in a country. In conclusion, the project will recommend support scheme constellations that can promote mCHP fuel cells in such a way that it leads to a mass production. This paper presents first results: namely the conceptual analysis of support schemes and ownership constellations and the current regulatory framework for mCHP fuel cells in selected countries [9]. Scenarios for following quantitative analyses are derived from this work.

The article is structured as follows: the first section on support schemes discusses the legitimation of support for individual technologies and presents the single support schemes. Second, it turns towards ownership possibilities of mCHP units. Third, the interdependence of support scheme choice and ownership is addressed. Existing regulatory frameworks for country studies are presented before turning towards the discussion and conclusion.

2. Support schemes

2.1. Rationale for support

Policymakers can decide to support energy generation technologies that are expected to yield long-term benefits in comparison to existing technologies, but are not commercially viable yet. One reason is that a number of existing, fossil-fuel based technologies have higher external costs such as negative effects on climate and health. Thus, from a societal point of view, a level playing field for renewable energy technologies and innovative CHP technologies can be attained. Another reason is that yet immature technologies can gain operational experience and benefit from economies of scale if a support scheme induces a certain market penetration. After a maturation period, these technologies can become competitive. Emission-free electricity generation or considerably more efficient fuel use, as for instance in a CHP unit, can also increase a country's security of supply. Other possible goals are the creation of local employment and strengthening national competitiveness. Fig. 1 gives an overview of widespread support schemes that can be categorised as either investment support or operating support [10]. After regarding the European legislatory framework, the following sections discuss the single support scheme options in greater detail.

2.2. European legislation on support

Possible promotion of mCHP fuel cells is rooted in its potential contribution in fulfilling the major objectives of EU energy policy: sustainability, security of supply and competitiveness [11]. The Directives 2004/8/EC ("CHP Directive", [12]) and 2009/28/EC ("Renewables Directive", [13]) constitute the core of relevant legislation with regard to support schemes at EU level. Notably, implementation of EU Directives is at the discretion of the Member States.

The CHP directive provides definitions for cogeneration, efficiency and capacity sizes – micro-cogeneration being defined with an electrical generation capacity below 50 kW. Direct or indirect support may be provided to different categories of CHP units. Furthermore, priority access to the grid and priority dispatch of qualified units can be issued. Most importantly for fuel cells, the CHP directive states that "Member States may particularly facilitate access to the grid system of electricity produced from high-efficiency cogeneration from small scale and micro cogeneration units". Most of the support schemes were however issued under the Renewables Directive and its predecessor, which provide the legal framework for reaching a compulsory share produced from renewable energy sources.

2.3. Investment support

Investment support can be granted per unit [n] or installed capacity [kW]. Capital grants, tax exemptions and reductions on the purchase of goods fall under this category. These provide upfront payment and thus, can help to reduce the cost of capital. Tax exemptions have lower transaction costs than capital grants, but capital grants can lead to a higher psychological momentum for the target group. Investment support can be granted if a technological risk is still remarkable, e.g. for pilot projects [8]. However, it should be analysed if investment support alone leads to an incentive to operate the unit over a longer time span and thus, gain operational and long-term fatigue experience. If a project abides with defined technical eligibility criteria, investment support is a transparent and easily understandable support scheme. A combination with the following operating support schemes is possible.

2.4. Operating support: price-based

Price-based support is subdivided into feed-in tariffs, price premiums and fiscal incentives. Net metering constitutes a special case and is not a direct support scheme, but can have similar effects. Therefore it will be addressed at the end of this section.

Under a feed-in tariff, eligible units receive a fixed tariff for each kWh supplied to the electricity network. This tariff is above market prices and guaranteed over a certain time span, e.g. 10 or 20 years, or a fixed number of operation hours. Furthermore, the tariff rate can be technology- and site-specific, and it can be digressive to reflect technological improvements. Typically, a feed-in tariff is combined with priority access to the grid. The costs for a feed-in tariff can be levelled over all electricity consumers or tax payers. For the operator of the eligible facility, a feed-in tariff reduces the exposure to market price fluctuations and sets a strong incentive to generate as much energy as possible. This implies also that feed-in remunerated units do not react to current generation demand of the overall system, reflected through electricity prices.

A price premium scheme corrects for this fault: operators do not receive a fixed total income per kWh, but a fixed premium on top of electricity market prices. The overall income level can be the same as under the feed-in tariff, but the operator is responsible of marketing the electricity. Using this mechanism, there is a strong incentive to fulfil the planned generation schedule and thus, to have a high forecast accuracy for fluctuating RES. In the short term, eligible units react to market price fluctuations. The drawback of this scheme is that self-marketing requires active participation in energy markets and that the overall income per kWh is unknown due to the uncertain electricity price level [14]. Special regimes of price premiums compensate for this by guaranteeing an overall income level. Both feed-in and price premium support can be administered as fiscal incentives, though it is common that a third party is responsible of direct payments.

Net metering remunerates distributed generation indirectly: it is connected over the standard meter of the household and reduces the electricity bill by the amount of self-generated energy. Whenever the own generation exceeds own consumption, the meter runs backwards. It is therefore a rather implicit support, in contrast to the aforementioned explicit schemes. The operator benefits because network charges and taxes are levied over the metered amount of electricity. As this number decreases under a net metering scheme, the overall income from network charges and taxes is reduced. Nonetheless, it is a very simple and understandable mechanism for house owners. This is why net metering is a prominent support scheme at an early stage of technological development, when only few units are installed and overall income from taxes is hardly affected.

2.5. Operating support: quantity-based

In quantity-based operating support schemes, the total amount of energy generated from a class of technologies is defined. This can be either project-based with a tendering scheme, or a quota scheme with tradable certificates. A certificate is issued per energy unit produced. The quantity target can be given in absolute (MWh) or relative terms (e.g. percent of electricity consumption). One party, e.g. the electricity supplier, is mandated to fulfil the target and can either install own units or buy certificates from a third party. The income for every unit is composed of the electricity sold at market prices plus the certificate price. For small-scale generation, such a scheme requires institutional aggregation of units. It is furthermore a scheme where operators are subject to price fluctuations on both the electricity and the certificate market.

3. Ownership concepts

All actors in the electricity value chain are potentially interested in operating a mCHP unit because it could be complimentary with their main interests or business models. If the mCHP unit is operated with natural gas, this extends also to actors in the natural gas value chain. More precisely, house owners and long-term tenants as traditional heating facility operators constitute the first potential owner group. Second, electricity suppliers (traders) and network operators could benefit from a large number of mCHP units to optimise their operation within electricity markets and according to network limitations. The same applies in principle for natural gas stakeholders. Finally, neutral energy service companies specialised in the construction and operation of CHP facilities could extend their business activities to mCHP.

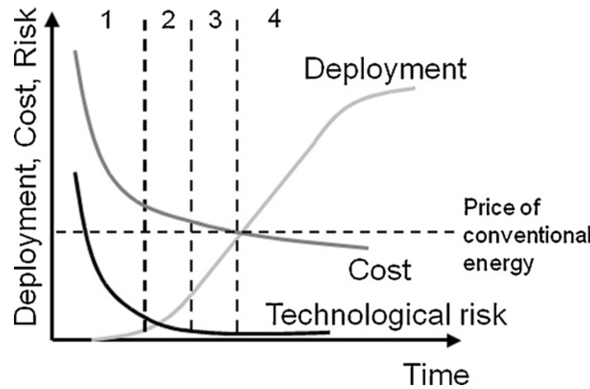

Fig. 2. The four phases of market integration.

A model that is applied in several studies distinguishes three alternative micro-generation deployment models [15,16]. They represent different relationships between the company and the consumer. Each of them has specific operation patterns according to the owner's priority and this needs to be taken into account when determining support levels:

- "Plug&Play": consumers own and finance the mCHP unit and gain more independence of conventional energy suppliers. Depending on the remuneration mechanism, they choose onsite power consumption or export to the grid.
- "Company Control Model": energy companies use a cluster of mCHP plants as a substitute for central power generation, i.e. the mCHP units constitute a virtual power plant.
- "Community Micro-Grid": as part of a micro-grid, consumers exert primary control over their mCHP plant, while ensuring supply/demand balance in their micro-grid.

In principle, the range of companies potentially interested in the company control model extends to all energy companies benefitting from owning mCHP units, i.e. both electricity suppliers and electricity network operators. If the technology is fuelled with natural gas, the same holds for gas suppliers and network operators. Neutral energy service companies could also discover mCHP operation as a business opportunity. The third case, the community micro-grid, requires a special setting (island case) or a highly different incentive structure. For the remainder of this paper, it is therefore disregarded – though it could be an interesting case in the long run, if local hydrogen grids with central electrolysers should show to be a beneficial option in the long run.

4. Combinations of support schemes and ownership arrangements

4.1. Applicability of different support schemes

In a development from invention to economic maturity, i.e. commercial viability on the free market, a number of support instruments can be applied. Fig. 2 [17] divides the process into several stages and attributes preferable support schemes. While costs and technological risk are still high during phase 1, research funding is the most appropriate support and currently dominant for fuel cells. For the transition towards phase 2, a feed-in tariff proved good in the development of other technologies, such as wind turbines. The level of the feed-in tariff needs to be adjusted progressively and finally, before the technology is fully competitive in phase 4, either a price premium or a quota scheme can be adopted. As deployment is already considerable in phase 3, this change of support scheme towards a more efficient, market-based solution keeps support expenses low.

However, this general transition path concept is not adapted for the characteristics of a mCHP technology that can be operated as a virtual power plant. One of the key factors during phase 1 is the transition to mass production in order to benefit from economies of scale. A feed-in tariff would encourage the private "plug&play" ownership concept, whereas a price premium could induce an energy company to acquire a large amount of mCHP units and install these at their customers under the company control regime. As this example shows, it could be possible to reach a large integration into the electricity market with a mCHP technology while still being in one of the early phases. Another indication that this could be advantageous is that energy companies showed an early interest to buy large amounts of mCHP units and install them at their customer's dwellings in some cases.

5. Country studies: existing regulatory frameworks

5.1. Denmark

Denmark has a considerable share of electricity generation from wind energy (>18%) and CHP units, among them a large number of decentral CHP plants in smaller towns. The majority of all CHP installations are fired with natural gas, though almost half of the CHP facilities for private heat supply use biomass [18]. In total, 55% of all electricity from thermal units stems from cogeneration. This has been achieved with a well-coordinated use of energy policy instruments over time [8,19]. In the early phase, individuals and local cooperatives invested in wind energy under a feed-in tariff. Today, after having reached a considerable market penetration, onshore wind is supported with a price premium scheme. With regard to CHP, the Electricity Act [20] and the Act on Heat Supply [21] set the framework for a liberalised electricity market. Notably, municipalities can enforce connection to district heating networks. A three-tier tariff for decentral CHP units on natural gas and industrial units was defined in 2000. This feed-in tariff was time-dependent (low/high/peak demand). Later, in 2006, this scheme for decentral CHP units was mitigated towards an index-regulated price premium for up to 20 years. This change from the discrete-step to a more continuous incentive structure increased their integration into electricity markets and simultaneous on/off-effects between the three tiers could be avoided. Special regimes for small units below 3 or 4 MW of electricity generation capacity exist as well. Notably, in one case, an operation support scheme was converted into an equivalent investment support scheme. Currently, a strong focus is put on the installation and system integration of heat pumps. In combination with a rising share of electricity production from renewable energy, namely wind, they are a core measure of reducing Denmark's CO2 emissions [22]. However, as they are mainly considered to replace oil burners, natural gas fired mCHP technologies have a market potential in areas where connection to the natural gas network is compulsory, provided that the technology becomes cheaper or is supported temporarily. Regarding the fact that Denmark has comparatively high per capita expenses for fuel cell research, policymakers might have an interest in demonstrating the application of fuel cell mCHP to promote exports in a further step.

5.2. France

Electricity generation in France is dominated by nuclear power plants (75%), while the share of renewable electricity amounts to almost 15% and the electricity from CHP does not exceed 5%. In absolute terms, the electrical capacity of CHP units is about 6400 MW, from which 4500 MW benefit from feed-in tariffs. A third of the plants have been developed though the first support contracts which have been introduced in 1997 and prolonged in 1999 for a period of 12 years without restrictions on power output. It has encouraged the development of large installations mostly in the industrial sector and in urban district heating, which is allowed to sale their electricity from November to March. From 2001 onwards, a new feed-in tariff has replaced the previous ones with much less favourable conditions and restricted to power plants below 12 MW [23]. In consequence, the growth of CHP has slowed down dramatically since then. Small generators under 36 kVA benefit from a much simpler feed-in tariff [24]. It amounts to the price of the electricity supplied by the energy company without taxes and is granted over a period of 15 years. Despite this, it is currently not attractive enough to develop the market of mCHP in France. Further support comes from the new building efficiency law, recognising since 2009 that mCHP devices bring an energy saving of 20% in comparison to their reference value. The definition of mCHP is however limited to Stirling engines with a power range between 0.5 and 1.5 kW [25] and following heat demand. Disregarding the power range, additional tax credits are available until 2012, but it is uncertain if they will be extended in the future because the promotion of natural gas use is contrary to the reduction of fossil fuel dependency. In addition, they may not contribute to the target to divide greenhouse gas emissions by factor 4 in France until 2050. By contrast, the use of biomass is strongly supported by the French government to meet the future environmental targets [26]. Biomass will mostly be used to increase the exclusive production of renewable heat. An important development is that the feed-in tariff for CHP fuelled by biomass has also been reviewed [27] recently to enhance the development of installation with an electrical capacity above 5 MW and using wood chips.

5.3. Portugal

Investment in renewable energy sources in Portugal is mainly based on wind, photovoltaic and solar thermal panels. Fuel cells are currently not considered by most of the companies, but could be an option in the future. In recent years, alongside this strategy in energy policies and promotion of the use of renewable energy, came the necessity for a legislative development for Combined Heat and Power (CHP) [28]. Portuguese legislation on CHP is included in renewable energy policies. Since 2001, fixed, fuel-specific feed-in tariffs are granted if certain operating conditions are fulfilled [29]. For fuel cells, the tariff is the one that applies to the renewable energy source used for hydrogen production. According a Governmental Order of February 2008 [30], prices for renewable equipments benefit from a 12% VAT, while any other tariff is taxed at the normal VAT rate of 21%. The limits of energy produced and sold subject to these tariffs is 2400 kWh year^{-1} kW^{-1} installed in the case of solar energy, 4000 kWh year^{-1} kW^{-1} installed for all other energies. The maximum power connected to the grid in this regime for 2009 was set at 12 MW, with an increase of 20% per year thereafter. Microgeneration installations are limited to half of the installed rate power in the households [31], with a maximum limit of 5.75 kW in the general regime and 3.68 kW in a preference regime (except in the case of installations for condominiums). The reference tariff applied depends on the conversion technologies that use renewable energy sources. It is 100% of the tariff for solar, 70% for wind, 30% for hydro, fuel cells, cogeneration and

Table 1
Gas and electricity prices in selected countries.

Electricity (eurocent kWh^{-1})				Natural gas (eurocent kWh^{-1})			
Household Dc, incl. taxes	Denmark	France	Portugal	Household D3, incl. taxes	Denmark	France	Portugal
Basic price	11.70	9.21	14.20	Basic price	4.91	4.11	4.76
Other taxes	8.93	1.25	0.10	Other taxes	3.97	/	/
VAT	5.16	1.65	0.70	VAT	2.22	0.73	0.24
Sum	25.79	12.11	15.00	Sum	11.10	4.85	5.00
Industry Ie, excl. VAT				Industry I3-1, excl. VAT			
Basic price	6.38	5.41	8.60	Basic price	2.08	2.75	2.79
Other taxes	0.68	0.46	/	Other taxes	0.27	0.07	/
Sum	7.06	5.87	8.60	Sum	2.35	2.82	2.79

biomass. Recently, EDP, the leader mixed public/private company in the energy sector in Portugal, also promoted a microgeneration service called MyEnergy program, an integrated solution for particular use of renewable energy, with economic and environmental benefits. Besides that, this product also offers benefits in terms of tax deductions. Up to about €800 can be deducted from taxes, maximally 30% of the value of the renewable energy equipments (installation not included). Feed-in tariffs and tendering schemes are used principally for larger-scale renewable applications.

5.4. Electricity and gas price levels in focus countries

Table 1 gives an overview of relevant economic parameters that differ between focus countries, namely gas and electricity prices [32,33]. They are a central factor for assessing the benefits of co-generation in different countries. For both gas and electricity customers, data is presented for representative, standardised customers – a household customer of the category Dc buys e.g. 3500 kWh $year^{-1}$, of which 1300 kWh are consumed at night. Industry consumer prices might play a role if mCHP units are operated as virtual power plants and the central coordinator purchases gas for all of them. In this case, mainly wholesale benefits could be grasped, whereas the network charges for transmission to the single units would still be due.

For both electricity and gas, household customer prices are considerably higher in Denmark than in France and Portugal. This is mainly due to a significant addition of other taxes and a comparatively high VAT. For industry customers, the price differences between the selected countries are smaller. In conclusion, the remarkable price differences can yield the result that the least-cost support option needs to be chosen carefully for each country because opportunity costs differ.

6. Results and discussion

Fuel cell mCHP units are currently still a comparatively expensive technology and support would be beneficial for their timely dissemination. This issue requires weighting the possible advantages of several competing fuel cell technologies, namely PEMFC and SOFC, with costs for society arising from a support scheme. Using renewable electricity as fuel for hydrogen production requires an electrolyser and hydrogen storage possibilities. Using natural gas in a PEMFC requires a reformer, and PEMFC have a lower electricity generation share. All of these options constitute additional technical and financial risk factors that can be excluded by focusing on natural gas fired SOFC mCHP units. For this reason, the remainder of this article focuses on this option without claiming that it is the best choice in the long run. Risks are limited in the short run and later, when first experience has been gained, the other options can benefit from spillover effects and can be revisited.

Attaining sufficiently large installation numbers is necessary to reach economies of scale for natural gas SOFC. For the countries analysed, this can hardly be reached with new, highly energy-efficient buildings only. The support scheme should be dimensioned in such a way that the installation of a mCHP fuel cell unit is also beneficial in older dwellings. From a practical point of view, the installation of natural gas based mCHP fuel cell units could take place simultaneously with the exchange of an old natural gas boiler [8]. As the economics of a mCHP fuel cell system is strongly dependent on the number of operation hours, the authors suggest that further analysis should not focus on the replacement of natural gas boilers. Instead, the mCHP unit should be supplementary, e.g. with a capacity of 1 kW [6]. This setup offers also the advantage that a conventional backup technology is installed and could therefore help to overcome scepticism from house owners. For all possible support schemes, additional eligibility criteria as e.g. a heat-to-power ratio could be defined by policymakers. Innovation will mainly follow the defined set of eligibility criteria. For this reason, the criteria need to be defined carefully, also with regard to fuel cell applications apart from mCHP.

It has been argued that investment support could be favoured in comparison to feed-in tariffs because it avoids a misleading incentive structure with regard to electricity markets [8]. This neglects the fact that due to its simplicity, investment support could induce house owners to buy mCHP units and operate them according to thermal demand. As a consequence, this operation mode disregards system demands, expressed through hourly variable electricity prices, as much as a feed-in tariff. Nevertheless, investment support is an option that can be considered for further analyses, also to allow comparison with current progress under the 80% investment support scheme in Korea.

Feed-in tariffs are a price-based operation support scheme that is easily understandable and also attractive for risk-averse actors [14]. As long as a technology's share of hourly electricity generation is sufficiently small, the negative impact on the system is negligibly small. When considerable market shares are reached, a timely change towards a more market-based mechanism should be considered. This process can also assist keeping the total subsidy amount low.

Price premiums support operation modes that respond to hourly electricity prices. In practice, it is realistic to assume that this will be implemented by aggregators such as electricity companies, which is why institutional ownership could be triggered by choosing this support scheme.

A quota scheme does not seem very promising for the early support of a mCHP technology, mainly because quota price fluctuations are an additional source of uncertainty and because the regarded countries do not have a tradition of quota systems in their energy legislation. By contrast, net metering is an indirect support scheme that seems promising for an early support phase. It is transparent and easy to administer. The downsides are decreasing network charges and tax incomes, but this might be acceptable in an early phase with a low penetration. Furthermore, a combination of net metering and investment support is possible.

Table 2
Adequate support schemes for mCHP fuel cell systems.

Support mechanism	Investment support	Feed-in tariff	Price premium	Quota	Net metering
Low market risk	++	++	–	––	+
Transparency	++	++	–	––	++
Reaction to market signals	–	––	++	++	––
Efficiency	–	–	–	++	–
Household ownership	++	++	–	––	++
Company ownership	+	+	++	++	–
Experience in	DK, F, PT	DK, F, PT	DK	/	DK

Table 2 gives an overview of the main support schemes and a qualitative indication how they fulfil different criteria. Investment support and feed-in tariffs absorb the investor from market risks, and net metering does this as well to a certain extent. Price premiums and quota schemes cannot ensure that the owner is subject to only low market risks. The image is the same for transparency, which can be regarded as the generic understandability of the support mechanism. However, price premiums and quota mechanisms encourage to react to market signals and thus, to respond to overall system demand. Efficiency can be defined as to have the effect that over-subsidisation of single units is avoided. This can be ensured best with a quota scheme. Household ownership correlates with low exposure to market risks. Depending on different business strategies, company ownership could be encouraged by all support schemes except net metering. Finally, all countries have applied some kind of investment support, e.g. through tax incentives, or feed-in tariffs. This aggregated overview depends on a number of design parameters for the single support schemes, but it can be concluded that efficiency and market integration considerations do not have to play a major role for a first mCHP support scheme. Nevertheless, this benefit could be exploited when mCHP units are aggregated to virtual power plants. In conclusion, it is advocated to concentrate quantitative support scheme design and levels on mechanisms that have already been used in the regarded countries. Investment support, feed-in tariffs and price premiums could help the further commercialisation of mCHP fuel cells. Furthermore, net metering could easily be combined with investment support.

Experience with different support schemes differs between countries: Denmark has supported large- and small-scale CHP facilities e.g. with time-differentiated feed-in tariffs for units with certain fuels and later, with price premiums. The same development can be observed for the support of wind energy. For small-scale CHP, one operation support scheme was converted to investment support. Denmark has a strong focus on the application of heat pumps for individual homes at present. In France, CHP units were mainly supported with guaranteed feed-in tariffs, though a share of CHP units can only benefit from this between November and March. Current support for mCHP results from efficient building standards and tax incentives, but the technology in focus for mCHP is Stirling engines. Another recent development is that regulations for biomass-fired CHP (>5 MW) units have been revised. In Portugal, CHP support is strongly intertwined with support for renewable energies. Operation support is granted through tax incentives up to annual maximum generation amounts. Feed-in tariffs are applied for other generation technologies with larger capacities. Support schemes to be considered in single countries should both have a positive track record in this country and allow reaching a certain market penetration under comparatively low costs, i.e. adapted for the national electricity and gas price levels.

From a political point of view, mCHP-FC fired with natural gas face several legitimation obstacles: first, a long-term benefit of supporting this technology must be likely, especially in comparison to competitors that are cheaper today, e.g. heat pumps. This long-term benefit covers also spillover effects into other application areas of fuel cells, such as transportation. Second, SOFC is implicitly preferred because it has a higher electrical efficiency and investment costs for a reformer can be saved. It should be analysed how spillover effects also to other FC technologies, such as PEMFC, can be reached. Third, a support for natural gas fired units should only be a first, transitory step towards a CO2-free mCHP system. This could be reached by either using biogas from the natural gas network, which could be ensured by accounting mechanisms, or a shift towards hydrogen-based systems.

7. Conclusions

This article presents support schemes that could possibly be applied in the early commercialisation phase of mCHP fuel cells. Virtually all renewable energy source technologies and CHP technologies were initially supported by a legislative framework defining special conditions and financial support. Support schemes can constitute a helpful mechanism in the early market integration and their implementation can be decisive for the question whether mCHP fuel cells can become competitive for stationary applications. In contrast to historical developments for other technologies, price premiums might be an attractive option already in an early phase because they induce company ownership. This, in return, could lead to single companies installing large numbers of mCHP units at their customers' dwellings. Investment support and feed-in tariffs constitute other, more traditional, support mechanisms that are alternative options and more likely to induce individual mCHP unit ownership. It is not possible to prove that one of them is generally superior to the others; their selection rather represents a toolkit for policymakers. The choice depends also on political side-goals, such as a possible preference for strong consumer interaction with energy technologies, while the detailed implementation is the key success factor for all of them. Furthermore, the interaction with the existing energy legislation is important, and countries might opt for instruments they are experienced with. Until now, research mainly concluded that large production numbers can hardly be reached without support within the next years [1] or focused on operation patterns according to an incentive structure without support schemes [6]. The present article provides a qualitative analysis of support schemes and contributes to filling this gap in the commercialisation of fuel cells in stationary applications. As a next step, operation regimes under these 3 schemes will be analysed in successive work performed under the FC4home project. The operation regime is necessary for determining a reasonable level of support as a compromise from both a socio-economic and private-economic viewpoint. It can be regarded as a drawback that the country legislation section deals with 3 countries only. However, this choice allowed a more in-depth stakeholder analysis during the project and conclusions on possible implementation barriers [34].

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Glossary

mCHP: micro-combined heat and power generation
PEMFC: proton exchange membrane fuel cell
SOFC: solid oxide fuel cell