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Support Schemes and Ownership Structures

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Risø-R-Report

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Risø-R-1730(EN)
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FC4Home
ERA-HY-CO/001/2008
FC4Home – Socio-Economic and Energy Systems Analysis of Micro Combined Heat and Power (Fuel Cell Technology)

Work Package 1 Report

Risø DTU
National Laboratory for Sustainable Energy

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Title: 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 has received increasing attention due to its potential contribution to energy savings, efficiency gains, customer proximity and flexibility in operation and capacity size. The FC4Home project assesses technical and economic aspects of the ongoing fuel cell based micro-combined heat and power (mCHP) demonstration projects by addressing the socio-economic and systems analyses perspectives of a large-scale promotion scheme of fuel cells. This document constitutes the deliverable of Work Package 1 of the FC4Home project and provides an introduction to the policy context for mCHP. Section 1 describes the rationale for the promotion of mCHP by explaining its potential contribution to European energy policy goals. Section 2 addresses the policy context at the supranational European level by outlining relevant EU Directives on support schemes for promoting combined heat and power and energy from renewable sources. These Directives are to be implemented at the national level by the Member States. Section 3 conceptually presents the spectrum of national support schemes, ranging from investment support to market-based operational support. The choice of support scheme simultaneously affects risk and technological development, which is the focus of Section 4. Subsequent to this conceptual overview, Section 5 takes a glance at the national application of support schemes for mCHP in practice, notably in the three country cases of the FC4Home project, Denmark, France and Portugal. Another crucial aspect for the diffusion of the mCHP technology is possible ownership structures. These may range from full consumer ownership to ownership by utilities and energy service companies, which is discussed in Section 6. Finally, a conclusion (Section 7) wraps up previous findings and provides a short "preview" of the quantitative analyses in subsequent Work Packages by giving some food for thought on the way.

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SUPPORT SCHEMES AND OWNERSHIP STRUCTURES

The Policy Context for Fuel Cell Based Micro-Combined Heat and Power

Work Package 1

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May 2010

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The FC4Home Project

The scope of the FC4Home project is to assess technical and economic aspects of the ongoing fuel cell based micro-combined heat and power demonstration projects by addressing the socio-economic and systems analyses perspectives of a large-scale promotion scheme of fuel cells. This will be carried out by means of energy systems analysis and studies on central cases for each of the participating project partners.

Project objectives:

The objectives of the FC4Home Project are to

- State the socio-economic consequences of different constellations of promotion schemes and ownership conditions.
- Analyze the current national regulatory frameworks and policy conditions.
- Perform energy system analyses of fuel cell based micro-combined heat and power systems as a function of the chosen operational strategies including the economic and environmental consequences.
- Outline stakeholder interests as well as potential impacts and consequences.
- Disseminate the results of the project to relevant stakeholders.

Project Partners:

- Risø National Laboratory for Sustainable Energy, Technical University of Denmark (Denmark)
- EDF / EIFER (France)
- Simbiente (Portugal)

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Acronyms

Art.	Article (*law*)
cf.	compare with
ct.	(Euro)cent
CHP	Combined Heat and Power
CO_2	Carbon dioxide
DSO	Distribution system operator
e.g.	*exempli gratia* (for example)
ESCO	Energy service company
EU	European Union
FC	Fuel cell
GWh	Gigawatt-hour
i.e.	*id est* (that is)
ISO	Independent system operator
kW	Kilowatt
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
MC	Marginal cost
mCHP	Micro-Combined Heat and Power
MW	Megawatt
MWh	Megawatt-hour
n	unit
NES	National energy strategy
p_C	Certificate price p_C
p_E	Electricity wholesale market price p_E
p_P	Price premium p_P
PEMFC	Proton Exchange Fuel Cell
	Polymer Electrolyte Fuel Cell
PV	Photovoltaic
q	Output q
q_{RES}	Renewable output q_{RES}
R&D	Research and development
RCM	Resolution of the Council of Ministers (Portugal)
RES	Renewable energy sources
SOFC	Solid Oxide Fuel Cell

T	Feed-in tariff *T*
TGC	Tradable green certificate
toe	Tonne of oil equivalent
TJ	Terajoule
TSO	Transmission system operator
TWh	Terawatt-hour
UK	United Kingdom
VAT	Value added tax

1 Introduction

In recent years, fuel cell based micro-combined heat and power (mCHP) has received increasing attention due to its potential contribution to energy savings, efficiency gains, customer proximity and flexibility in terms of operation and capacity size. Although the advantages of the combined characteristics of fuel cells (FC) and combined heat and power (CHP) are well acknowledged, the technology still cannot compete on equal terms with conventional thermal production of electricity and heat.

Especially, in early stages of the development process of a technology the technological risk associated with newly designed plants is relatively high. In order to stimulate technological learning so that future cost savings and experience curve effects can materialize, Member States in the European Union (EU) may adopt support schemes for the promotion of renewable energy and combined heat and power.

This document constitutes the first deliverable of Work Package 1 of the FC4Home project [1]. The aim of the FC4Home project is to assess technical and economic aspects of the ongoing fuel cell based micro-combined heat and power demonstration projects by addressing the socio-economic and systems analyses perspectives of a large-scale promotion scheme of fuel cells. In doing so, the FC4Home project analyzes the situation in the country cases of Denmark, France and Portugal, taking the specific regulatory, structural and ownership conditions in the energy sectors of these EU Member States into account. This deliverable gives an introduction to the policy context for fuel cell based micro-combined heat and power. This comprises the rationale for promoting mCHP, existing support schemes, and possible ownership arrangements for a future deployment of mCHP. The report thereby provides necessary qualitative background information as a basis for the quantitative analyses on support schemes and ownership structures conducted in subsequent Work Packages.

This deliverable is structured as follows: the remainder of the introductory section lays down definitions by the EU on combined heat and power, and micro-cogeneration in particular. Thereafter, the rationale for the promotion of mCHP and its potential contribution to the three goals of EU energy policy are described. Section 2 addresses the policy context at the supranational European level by outlining relevant EU Directives on support schemes for promoting combined heat and power and energy from renewable sources. These Directives are to be implemented at the national level by the Member States. Section 3 conceptually presents the spectrum of national support schemes, ranging from investment support to market-based operational support. The choice of support scheme simultaneously affects risk and technological development, which is the focus of Section 4. Subsequent to this conceptual overview, Section 5 takes a glance at the national application of support schemes for mCHP in practice, notably in the three country cases of the FC4Home project, Denmark, France and Portugal. Another crucial aspect for the diffusion of the mCHP technology is possible ownership structures. These may range from full consumer ownership to ownership by utilities and energy service companies, which is discussed in Section 6. Finally, a conclusion (Section 7) wraps up previous findings and provides a short "preview" of the quantitative analyses in subsequent Work Packages by giving some food for thought on the way.

1.1 Definitions

At the European level, Directive 2004/8/EC [2] (in the following, also denoted as "CHP Directive") lays down the legal provisions on the promotion of cogeneration based on a useful heat demand.

Cogeneration, frequently referred to as combined heat and power, means "the simultaneous generation in one process of thermal energy and electrical and/or mechanical energy" ([2], Art. 3a) instead of the separate production of heat and electricity. "High-efficiency cogeneration" is defined as cogeneration achieving energy savings of more than 10 percent ([2], (11)).

Furthermore, in the CHP Directive, an important definition for the purposes of this project is made by distinguishing different types of cogeneration units based on their capacity sizes. According to Directive 2008/4/EC (20), "small scale cogeneration" encompasses, *inter alia*, micro-cogeneration and distributed cogeneration units, such as cogeneration units supplying isolated areas or limited residential, commercial or industrial demands. In particular, Art. 3 (m) defines "micro-generation units" as cogeneration units with a maximum capacity below 50 kWe. In Art. 3 (n), "small-scale cogeneration units" are defined as cogeneration units with an installed capacity below 1 MWe.

This project dealing with the deployment of residential fuel cell powered mCHP focuses on the deployment of these micro- and small-scale cogeneration units.

1.2 Rationale for the Promotion of mCHP

The rationale for a possible promotion of fuel cell powered (micro-)CHP is rooted in its potential contribution to the three major objectives of European energy policy: sustainability, security of supply and competitiveness [3].

1.2.1 Objectives of European Energy Policy

The goal of **sustainability** has received increasing attention in recent years. The energy sector accounts for 80 percent of all greenhouse gas emissions. In light of the problems of climate change and air pollution, the EU is committed to a European and worldwide reduction of greenhouse gas emissions [3]. In March 2007, the European Council endorsed four ambitious policy targets to be achieved by 2020 [4]: a reduction in greenhouse gas emissions by at least 20 percent compared to 1990 levels, an increase in energy efficiency in order to save 20 percent of the EU's energy consumption as compared to projections for 2020, a mandatory target of a 20 percent share of renewables in overall EU energy consumption, and a binding minimum target of 10 percent for renewable energy in transport.

While striving for the fulfilment of these 2020 targets, the EU simultaneously needs to ensure the **security of future energy supply**. Rising energy consumption (with an estimated annual growth rate of approximately 1.5 percent) combined with a growing dependency on oil and gas imports imply a greater risk of energy supply failure. With "business as usual", the EU's import dependency will increase from 50 percent of total EU energy consumption at present to 65 percent in 2030. Simultaneously, rising energy demand will necessitate investments in generation capacity in the order of magnitude of 900 billion Euros [3]. Hence, security of supply concerns encompass both greater diversity and lower external dependency on primary energy supply as well as the provision of adequate generation capacity. Furthermore, operational network security and network investments need to be ensured (cf. [5]) so as to safeguard network reliability in electricity transmission and distribution.

Finally, with respect to the energy policy objective of **competitiveness**, the internal market in electricity aims to deliver real choice for all consumers so as to realize efficiency gains, competitive prices and higher standards of service (cf. [6], (1)). As part of the Third Liberalization Package, the EU adopted Directive 2009/72/EC [6] concerning common rules in the internal electricity market, repealing the previous Internal Electricity Market Directive 2003/54/EC [7]. The new Directive introduces reinforced unbundling provisions for transmission system operators as well as extended powers and independence for regulators. Furthermore, it includes provisions aspiring for the enhancement of cooperation among network operators and among regulators for the purpose of integrating the national markets.

1.2.2 Contribution of mCHP

In general terms, the diffusion of *cogeneration as a technology* yields various advantages that may contribute to the goals of European energy policy: the utilization of combined heat and power can serve as a measure to achieve primary energy savings while avoiding network losses and reducing emissions, in particular greenhouse gas emissions ([2], (1)).

An increased deployment of *fuel cell powered mCHP* may contribute to the three objectives of EU energy policy by combining the advantages of combined heat and power as a generation technology and of fuel cells as distributed generation units[1].

Fuel cells have several benefits that can be attributed both to their technological characteristics as well as to their modular capacity sizes. Fuel cells are based on electro-chemical energy conversion and allow for the usage of different types of fuel, such as natural gas, biogas or even hydrogen. The modularity of fuel cells implies that stacks can be installed in different capacity sizes. Due to both of these properties, fuel cells provide great amount of flexibility in application and enable the development of a variety of fuel cell systems both in the commercial and in the residential sector.

The flexibility in fuel use may lead to a greater diversification of the EU's primary energy sources, thereby enhancing **security of supply**. At the same time, fuel cells in residential applications, such as fuel cell powered micro-CHP, are located in close proximity to the load, i.e., to energy consumers. An important characteristic of these distributed energy units is that network losses

[1] The following enumeration of potential benefits is inspired by and partially based on the key advantages of fuel cells and distributed generation given by the Commission of the European Communities in [8] and [9].

can be avoided: a large share of electricity is produced at the point of consumption so that it does not have to be transported over transmission and distribution networks. This may contribute to congestion relief on higher voltage levels and improve network reliability.

Depending on the type of fuel used, fuel cells may also contribute to the reduction of pollutants and greenhouse gas emissions if they are based, e.g., on biogas instead of conventional fuels. **Sustainability** may further be improved by means of energy savings and efficiency gains achieved by combined heat and power.

Regarding **competitiveness**, the diffusion of fuel cells reinforces the trend towards decentralized electricity supply. Combined with decentralized ownership structures, this may lead to a stimulation of competition in electricity markets as the number of market agents increases. At the same time, the smaller or modular size of fuel cells as distributed generation installations implies reduced capital exposure and investment risk for investors as compared to large-scale conventional thermal generation units. New market opportunities resulting from progress in technology development may additionally enhance industrial competitiveness within the European Union and lead to export opportunities.

Despite the abundance of potential benefits of fuel cell based mCHP, it needs to be highlighted that the impact of a positive contribution to the three objectives of European energy policy objectives cannot be generalized, but is highly technology and site-specific. This includes the type of fuel used, the efficiency and specific technological attributes of a fuel cell (solid oxide fuel cells (SOFC) and proton exchange membrane fuel cell (PEMFC)) as well as their location in the network and the type of ownership structure. Ideally, the design of support schemes accounts for these factors both in the choice of the mechanism and the level of financial support.

2 European Legislation on Support

In the European Union, electricity producers may be entitled to support schemes based on technological characteristics of production. In 2001, the first Directive was adopted to promote the generation of electricity based on renewable energy sources (Directive 2001/77/EC [10]). Three years later, Directive 2004/8/EC [2] was passed to create a legal framework at the European level for the promotion of cogeneration based on a useful heat demand ("CHP Directive"). Very recently, in 2009, the previous Directive 2001/77/EC was repealed by a new Directive for the promotion of renewable energy [11] (in the following also referred to as "Renewables Directive").

Notably, the implementation of these Directives is to the discretion of Member States which may choose the type of support schemes to promote different technologies at the national level. Prior and subsequent to the adoption of these Directives, different traditions of support instruments have developed across EU Member States, ranging from price-based to more market-based support.

2.1 Support for Combined Heat and Power

Directive 2004/8/EC [2] creates a framework for the promotion and development of high efficiency cogeneration of heat and power based on a useful heat demand and primary energy savings. The purpose of the "CHP Directive" is to increase energy efficiency and improve security of supply as well as primary energy savings, while accounting for specific national circumstances especially concerning climatic and economic conditions (Art. 1). Art. 3 of the Directive provides definitions related to cogeneration, efficiency and cogeneration units of different capacity sizes as the ones aforementioned.

Importantly, the CHP Directive [2] lays down that *direct or indirect support* may be provided to producers of cogeneration subject to evaluation by the Commission (Art. 7(2)).

Directive 2004/8/EC [2] lays down a harmonized method for the calculation of electricity from cogeneration and necessary guidelines for its implementation (e.g., specifying rules on the efficiency criteria for cogeneration in Art. 4 and providing calculation methodologies in the Appendixes). Furthermore, the CHP Directive establishes rules relating to guarantees of origin (Art. 5), administrative procedures (Art. 9), and electricity grid system and tariff issues (Art. 8). In analogy to Art. 7 of Directive 2001/77/EC [10] for electricity based on renewable energy sources, Member States may provide for priority access to the grid system and priority dispatch of qualified cogeneration installations by transmission system operators as long as system operation permits to do so (cf. Art. 8(1), Directive 2004/8/EC). Also referring to Art. 7 of the Renewables Directive [10], the CHP Directive [2] (Art. 8 (1)) stipulates for Member States to establish a legal framework or to require transmission and distribution system operators "to set up and publish their standard rules relating to the sharing of costs of system installations, such as grid connections and reinforcements, between all producers benefiting from them". The bearing of the costs shall be shared using a mechanism based on objective, transparent and non-discriminatory criteria that takes into account the benefits that accrue to the different agents involved, i.e., subsequently connected producers as well as transmission and distribution system operators. Such an allocation mechanism for cost sharing can be crucial for small producers with a positive network impact.

Finally, of particular relevance for small-scale and micro-cogeneration units is Art. 8 (3) of the CHP Directive [2]: it states that "subject to notification to the Commission, Member States may particularly facilitate access to the grid system of electricity produced from high-efficiency cogeneration from small scale and micro cogeneration units".

2.2 Support for Energy from Renewable Energy Sources

The first Directive that contained legal provisions on the promotion of electricity based on renewable energy sources was Directive 2001/77/EC [10]. Based on this Directive, Member States were allowed/encouraged to give direct or indirect support to renewable electricity producers. Also, they could provide for priority access to the grid system for electricity produced from renewable energy sources and priority dispatch as outlined above. The purpose of support mechanisms was to contribute to the attainment of the national indicative targets in order to reach the indicative share of 22.1 percent of electricity[2] produced from renewable energy sources in total Community electricity consumption by 2010, as stipulated by Directive 2001/77/EC [10].

As aforementioned, in March 2007, the European Council endorsed a new mandatory target of a 20 percent share of energy from renewable sources in overall Community energy consumption by 2020. Note that the new target encompasses all energy sectors, and that there is no longer a specific target to be attained in the electricity sector only. The recently adopted Directive 2009/28/EC ("Renewables Directive") [11] provides a common framework for the promotion of energy from renewable sources in order to attain this ambitious 20 percent target. Notably, this target is legally binding and no longer indicative. The new Directive amends and subsequently repeals Directives 2001/77/EC [10] and 2003/30/EC [12]. It lays down differentiated national targets for the different Member States to achieve the Community target of 20 percent.

Under the new Directive, Member States may apply support schemes and, furthermore, take measures of cooperation among them and/or third countries. The measures of cooperation encompass arrangements for the statistical transfer of a specified amount of energy from renewable sources from one Member State to another Member State (Art. 6, Directive 2009/28/EC [11]), joint projects between Member States and/or third countries (Art. 7-10, *ibid*), as well as joint support schemes among two or more Member States on a voluntary basis (Art. 11, *ibid*).

3 Types of Support Schemes

The implementation of Directives is to the discretion of EU Member States: Directives "shall be binding, as to the result to be achieved, upon each Member State to which they are [it is] addressed, but shall leave to the national authorities the choice of form and methods" (Art. 249 (ex 189) E.C.). Inherently, the national implementation of Directives allows Member States to account for specific national circumstances. For the promotion of renewable energy and combined heat and power, the EU-27 Member States have adopted promotion schemes that differ in their general qualitative features and detailed design as well as in the financial levels of support granted to individual technologies.

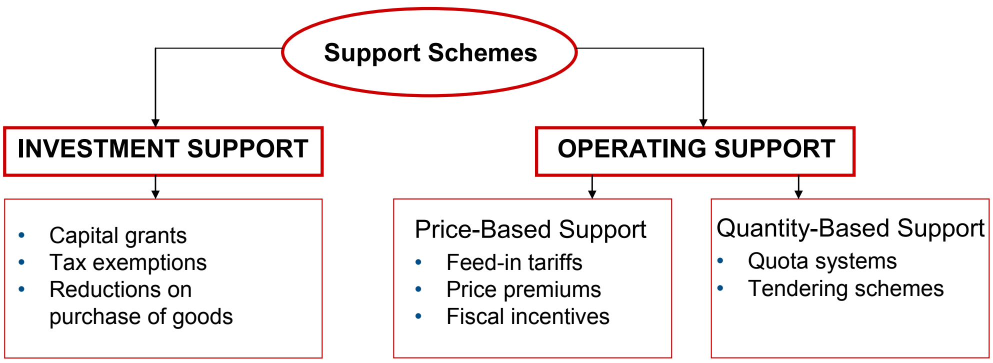

Figure 1: Overview of support schemes (based on [13])

[2] and a global target of 12 percent renewables of gross national energy consumption

In broad terms, support schemes can be differentiated into **investment support** and **operating support**[3]. Investment support is provided upfront for the erection of generation capacity, whereas operating support is paid for actual production, i.e., for the amount of electricity in Megawatt-hours (MWh) fed into the network. Operating support can further be subdivided into **price-based support** and **quantity-based support**.

Under price-based promotion schemes, the regulator sets the financial level of support per MWh *ex ante*, for example in the form of a fixed feed-in tariff or in the form of a premium paid to qualified generators on top of the electricity wholesale market price. By contrast, under quantity-based promotion schemes, the regulator stipulates the quantity of renewable electricity or CHP to be achieved whereas the price formation for support is left to market forces. Figure 1 gives a schematic overview of the major support schemes in place and of the support categories they can be assigned to.

3.1 Investment Support

Investment support is frequently adopted to stimulate technologies in early development stages or to finance demonstration projects for launching new technologies. Since the associated technical risk is rather high, investment support delimits or prevents the investor's additional exposure to market risk.

Investment support encompasses capital grants, tax exemptions and reductions on purchase of goods. Notably, capital support is provided upfront to the investor so that a large portion of the initial investment is directly reimbursed and does not have to be recuperated over time, as it is the case for operating support. Capital support can be given per unit [n] or per installed capacity [kW]. Typically, the allocation of this support involves some kind of selection process for determining the eligibility of a project for an investment grant. The selection criteria are hence crucial for the technology projects chosen.

By the same token, tax exemptions and reductions on the purchase of goods correspond to a decrease of the upfront investment cost and may thereby foster technological development.

Alternatively, the different types of investment support can be used in combination with operating support, e.g., by providing a lower upfront payment to the investor and supplementing it with support for actual production instead.

3.2 Operating Support

As for operating support, two major sub-categories are to be distinguished: price-based support and quantity-based support. As aforementioned, the crucial difference between these two support categories lies in whether the regulator fixes the price or the quantity *ex ante*. Price-based support schemes comprise feed-in tariffs, price premiums and fiscal incentives; quantity-based support encompasses quota systems with tradable green certificates and tendering schemes.

[3] The following categorization of support schemes is based on [13], pp. 4ff.

In an idealistic, perfectly competitive setting, an equivalent market outcome can be achieved under all these different types of support schemes (as Weitzman (1974) [14] demonstrates, the same economic efficiency can be obtained both under price-based and quantity-based support schemes).

From a more practical point of view, the crucial difference between the different support schemes is the degree to which the investor’s revenue is exposed to the volatility of market prices and, hence, the market risk involved. This will be illustrated by the following explanation of the different types of support.

3.2.1 Price-Based Support Schemes

The classical **feed-in tariff** consists of a fixed price per kWh of electricity production paid to qualified electricity generators. The financial support is guaranteed for a duration laid down by law, with considerable time spans of, e.g., 15 to 20 years, so as to provide investment certainty. Typically, feed-in tariffs are coupled with priority access to the grid system for producers entitled to the support scheme. This implies that transmission system operators shall give priority to these qualified electricity producers when dispatching generating installations as long as network operation permits to do so[4].

Under the feed-in tariff regime, the entire revenue of eligible producers is covered by the support scheme. Figure 2 and Figure 3 provide an illustration of the application of feed-in tariffs for technologies with two different underlying marginal cost curves *MC*. The level of the wholesale market price for electricity is indicated by p_E and the level of the feed-in tariff by T on the vertical axis. The corresponding output level is denoted by q and shown on the horizontal axis. In a perfectly competitive market, producers choose their output level at the point where price equals marginal cost. Figure 2 depicts a case in which the feed-in tariff induces eligible producers to generate more output than they would if they sold electricity at the market price p_E. In the absence of support, producers would still supply the output $q_{RES,E}$. However, the adoption of a feed-in tariff T leads to an increase in production to q_{RES}, where the marginal cost curve and the feed-in tariff intersect. Since the entire revenue of entitled producers is fully covered by the support scheme, producer surplus stemming from the support scheme corresponds to the green area in Figure 2 and Figure 3.

[4] Cf. definition of priority access given by Dir. 2001/77/EC [10], Art. 7 (1).

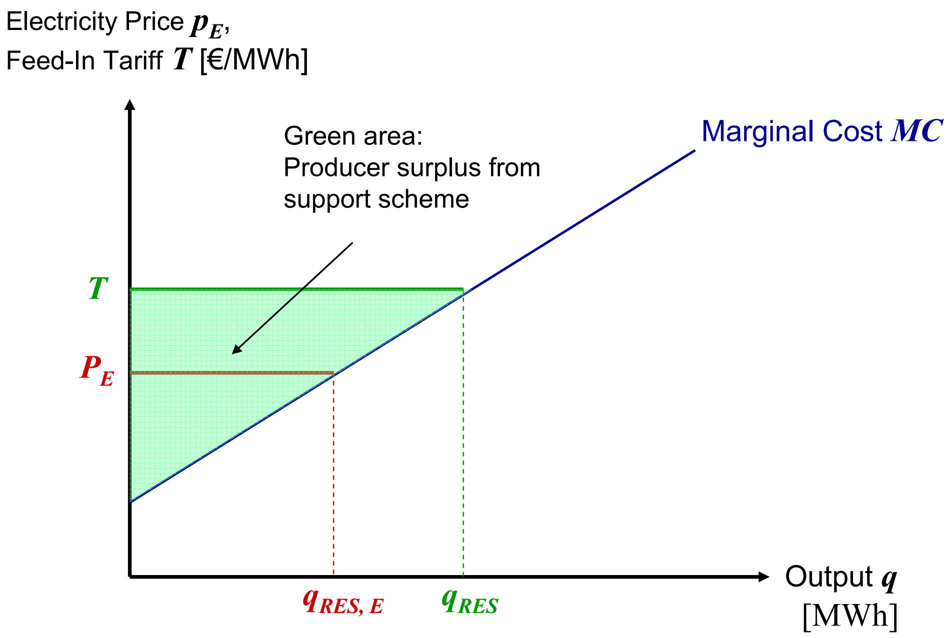

Figure 2: Feed-in tariff - Example 1

By contrast, Figure 3 illustrates the case of a very immature production technology where marginal cost is above the market price. Here, in the absence of financial support by means of the feed-in tariff T, no investment and production would occur at all since the investor could not break even. It is first the support scheme that makes the investment project viable so that the quantity q_{RES} is produced[5]. Notably, in both cases, the producer surplus (profit) of eligible renewable generators is entirely financed by the support scheme.

Technological progress can be reflected by a downward shift of the marginal cost curve. To account for technological learning and to stimulate process innovation, regulators frequently adjust feed-in tariffs over time so that new installations receive lower tariff levels than plants commissioned earlier. This may be incorporated into national support legislation by stipulating a percentage factor for the annual degression of support levels. Furthermore, differentiation across technologies may be introduced by choosing different tariff levels for individual technologies, thereby accounting for their maturity. Additional design elements of a feed-in tariff scheme may comprise time-variable tariffs (e.g., differentiation according to seasons or peak load) and system services bonuses for specific technical requirements of an installation. The costs arising from feed-in tariffs are typically financed by means of cross-subsidies among all consumers or taxpayers.

While the feed-in tariff is associated with high investor confidence due to fixed, guaranteed price levels, the regulator has no exact knowledge in advance how much investment in renewable electricity or CHP will be induced by the support scheme. This is because in reality there is no

[5] Note that in perfectly competitive markets, producers adapt their quantities so that price equals their marginal cost. In a long-run time perspective, investment costs need to be covered as well so that the concept of long-run marginal cost is applied, including investment.

perfect information on behalf of the regulator on the actual marginal cost curve of a specific technology. For the deployment and diffusion of new technologies, the two crucial determinants are the underlying marginal cost curve and the financial level of support. Therefore, great care needs to be attached to the choice of the latter since this is where the regulator can directly exert influence.

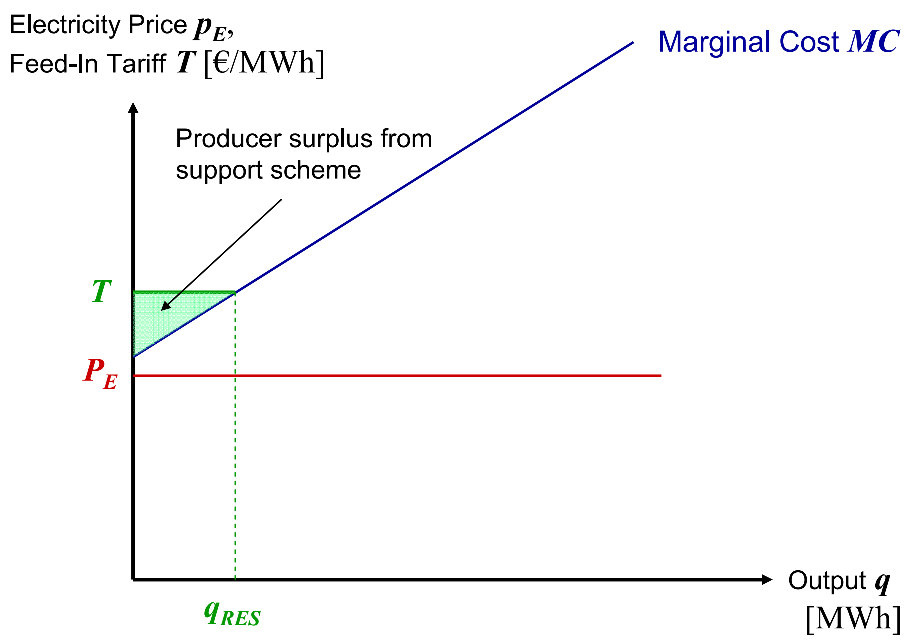

Figure 3: Feed-in tariff - Example 2

In contrast to the classical fixed feed-in tariff, the **price premium scheme** consists of two price components: eligible producers sell electricity at the wholesale market price and obtain additionally a fixed premium on top of it. The underlying idea is that the exposure to fluctuations in wholesale market prices will incentivize generators to follow load patterns. Frequently, eligible producers additionally obtain a premium for balancing costs since there is no more purchase guarantee for their electricity as under the feed-in tariff.

Figure 4 illustrates the price premium scheme. Entitled electricity generators obtain the electricity wholesale market price p_E plus the fixed premium p_P so that their total revenue is composed of $p_E + p_P$. Notably, the producers' income is partially financed through the electricity market and partially by the support scheme (i.e., the premium). Producer surplus is indicated by the shaded areas in red and green, respectively.

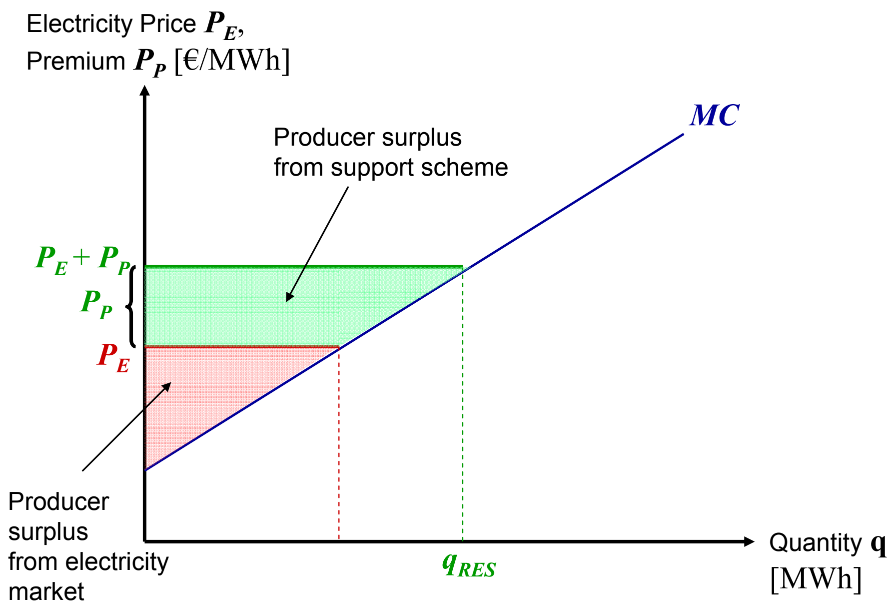

Figure 4: Price premium

In analogy to the feed-in tariff scheme, technology differentiation can be introduced by means of setting the premium at different levels for individual technologies. Since the premium is also typically financed by means of cross-subsidies among consumers or taxpayers, the price premium scheme can become costly during periods of very high electricity wholesale market prices. This is in particular the case when electricity market prices are already at a sufficiently high level even in the absence of the premium for eligible generators to stay economically viable. The regulator can delimit the exposure to wholesale market price fluctuations by introducing maximum and minimum revenue levels for generators entitled to the price premium. This means that the regulator guarantees qualified producers a minimum level of support that they obtain even if the sum of the wholesale market price plus the premium falls underneath it. By the same token, the regulator can set an upper bound of support that serves to control the costs for financing the premium scheme during periods of high electricity prices.

3.2.2 Quantity-Based Support Schemes

Quantity-based support schemes adhere to the opposite philosophy compared to price-based support: the regulator stipulates the quantity level to be achieved and leaves the formation of the price to the market. The two major types of quantity-based support schemes are quota systems with tradable green certificates and tendering/bidding schemes.

In **quota systems** with **tradable green certificates** (TGCs), the regulator imposes a green quota on either consumers[6] or producers. The quota represents a percentage requirement of renewable electricity in total electricity consumption or production, respectively, for one regulatory period (e.g., one calendar year).

[6] Frequently, the quota obligation imposed on consumers is to be fulfilled by the respective retail company on their behalf.

In quota systems with a *consumer obligation*, entitled producers receive for their renewable electricity generation the wholesale market price p_E (Figure 5) and the corresponding amount of green certificates. Typically, one green certificate is issued for one MWh of qualified renewable electricity production. The green certificates constitute a financial product and generate a second revenue stream for renewable producers. In order to comply with their quota obligation, consumers need to purchase the amount of tradable green certificates that corresponds to the percentage requirement imposed on their electricity consumption. This creates the demand for tradable green certificates, whereas renewable producers represent the supply side on the green certificate market. The total income of eligible green electricity producers is hence composed of two prices: the electricity price p_E and the certificate price p_C, which is formed on the certificate market. This implies that the producer surplus from renewable electricity production is entirely financed by two markets (Figure 5).

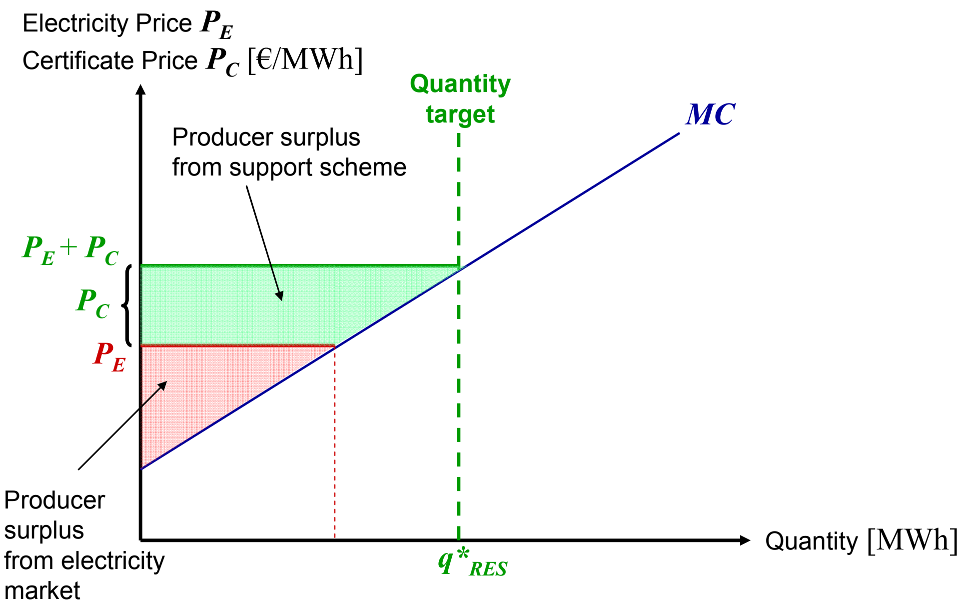

Figure 5: Green quota system

By contrast, in quota systems with a *producer obligation*, producers are obliged to generate a certain percentage of their total electricity production from renewable energy sources. Producers can meet the percentage requirement, i.e, the quota, in two ways: they can either generate the stipulated amount of renewable electricity themselves or they can buy the corresponding amount of green certificates from other renewable producers on the certificate market. From a theoretical perspective, quota systems with consumer and producer obligations lead to equivalent market outcomes.

Technology-neutral quota systems in which one green certificate is issued per MWh of renewable production, irrespective of the generation technology deployed, introduce inter-technology competition. That is, the different renewable energy generation technologies face direct competition from one another. The underlying idea behind this approach is that the most cost efficient technologies will prevail in the market. However, this may impede dynamic efficiency by excluding technologies that are immature at present, but may become commercially viable in the long run. As an alternative, technology differentiation can be introduced through technology bands, i.e., one green certificate is issued for different amounts of renewable production differentiated according to technologies.

Notably, in green quota systems, entitled producers obtain no fixed component of support. Their revenue is subject to fluctuations both in the electricity wholesale market price and in the certificate price. The exposure to market risk is hence the highest under this type of support scheme.

Finally, another quantity-based mechanism for the promotion of renewable energy consists of **competitive bidding** or **tendering schemes**. Here, the regulatory authority issues a public call for tender for a selected generation site. Investors can then submit bids in response to the call for tender. Based on certain selection criteria (e.g., lowest-bid-tendering procedure), the offers are evaluated and the contract is awarded to the bidder whose proposal has been determined to best meet the stipulated requirements. Technology differentiation is automatically introduced when the call for tender for a selected generation site is specified to apply to one technology, e.g., an offshore wind farm.

3.2.3 Net metering

Net metering is an indirect way of remunerating generation from a distributed generation unit at a consumer's place. Its underlying principle is that the DG unit does not have a separate meter to account for its production, but that own consumption is reduced by own generation. In an extreme case, it makes the main household meter run backwards whenever generation is in excess of demand. This leads to the effect that the consumer pays only for her net consumption (i.e., consumption – own generation) for a given metering period. Each kWh of own generation has therefore the same value as the retail electricity tariff, including all taxes and transmission tariffs. This implies the main characteristics of net metering: while being extremely easy to administer and therefore attractive to single households, tax and transmission tariff income are reduced by every unit of net metering support for a technology. This may be acceptable for a new technology, but needs to be discussed once a technology reaches a certain market penetration level.

4 Support Schemes and Technological Development

As outlined above, for stimulating technological development, various kinds of support schemes may be adopted. This section focuses on the specificities when designing a support scheme for mCHP. It provides an initial brief discussion on the provision of support in the electricity and the heat sector, respectively. This is supplemented by a brief literature review on support for mCHP. Thereafter, the implications of support schemes and risk for technology deployment will be discussed.

4.1 Implications for Support in the Electricity Sector

Electricity is a homogenous good that is metered at all connection points between the network and generators or consumers. This is a key requirement for operating support: the amount generated in a certain time span must be metered with approved technical equipment if this is to be the basis for the remuneration of a production unit. Investment support reduces upfront the investor's capital costs; simultaneously, investment support induces the risk that less electricity will be generated than under operating support because there is no incentive for maintenance. However, it might be considered as an option if the operator of a generation unit uses the equipment extensively dictated by external constraints, e.g., in a heat-demand driven CHP facility.

Experience with operating support schemes for electricity from renewable energy sources (RES) shows that a reduction of the volatility and risk in revenue can cause large growth rates, possibly in combination with distributed ownership.

4.2 Implications for Support in the Heat Sector

The promotion of RES or highly efficient technologies to cover heat demand is not as advanced and widely practised as for electricity. This can partially be attributed to the fact that usually, there is no heat network between the single demand units and therefore no standardized metering at the network connection. The discussed instruments for the promotion of RES/CHP in the heat sector are more widespread than for the electricity sector[7]:

- Administrative rules, e.g., that 20% of all heat demand have to be covered with RES.
- Non-discriminatory network access to district heating networks as a base for a feed-in tariff.
- Bonus payments per heat unit generated from RES/CHP. This can be network-independent and technology-specific, but requires standardized metering equipment.
- Fiscal incentives
- Direct investment support
- Loans with special interest rates
- A quota model that imposes a certain share of RES generation on a party in the heating value chain, e.g., heating fuel traders. These can meet the targets by buying certificates from RES operators.

A special difficulty in the heat sector is that better insulation and a change to RES can lead to equivalent CO_2 saving effects, however, that better insulation can be considered the more economical solution in many cases. In other words, subsidizing RES heat technologies in private homes is controversial if the house owners can reach similar results with far lower investments. Some national energy efficiency programs grant investment support (e.g., direct subsidies or cheap loans) for better insulation.

4.3 Support Schemes and mCHP – A Brief Literature Review

A general introduction to effective and efficient support schemes is provided by Haas *et al.* (2004) [16]. One of the numerous conclusions is that a carefully tailored support scheme is more important than the general kind of support scheme. Good results have been achieved with well-designed feed-in tariffs for mature technologies. Menanteau *et al.* (2003) [17] provide a general comparison of price-and quantity-based support schemes and comes to the result that price-

[7] In analogy to [15].

based schemes are preferable. Hawkes and Leach (2008) [18] model the operation of different mCHP technologies – in itself a rather technical issue – and derive recommendations on the combination of energy efficiency standards and support for mCHP technologies. Two other sources with a regional focus on the UK are [19] and [20]. The first one is the Department of Trade and Industry's microgeneration strategy, elaborating on a number of interesting initiatives in the field and deriving various actions as answers to a number of obstacles. The second one is an article on economic, regulatory and policy issues. It considers investment by energy service companies as well as private households and compares the economics of a mCHP technology with micro-wind and PV. The article argues for technology-specific support and a level playing field for mCHP technologies. A holistic approach on the relevant aspects of mCHP technologies is pursued by [21]. It can be classified as a rather early, general article with a country focus on Finland. Possible decision-making problems are classified along the mCHP production value chain. Fuel cells have a number of comparative advantages apart from financial aspects. The development of PEMFC costs over time is treated in [22] with the help of empirical experience curves for a Japanese data set. The authors conclude that for every doubling in production, costs have fallen by about 20%. Before reaching a cost target of 1000€/kW, several dozen million units are required with such a progress. This is why unsubsidised economic viability is hard to achieve before 2025. Regarding social acceptance of mCHP technologies, two sources shall be highlighted: Sauter and Watson (2007) [23] address social acceptance issues under three different combinations of consumer and company involvements. A more active consumer is desirable to support the acceptance of mCHP technologies. Fischer (2004) [24] provides a comprehensive view of the socially relevant aspects of mCHP integration, especially pioneering users. Their efforts can be valued with the help of support schemes.

Hawkes and Leach (2005) [25] focus on the SOFC technology and conclude that under 2005 conditions in the UK, larger properties are likely to be the first market. If considerable support is given or other central economic parameters change, also smaller dwellings could benefit. Staffell *et al.* (2008) [26] determine cost targets for a range of domestic mCHP fuel cell technologies. The conclusions are favourable for SOFC. Several country-specific studies complement this view: for Germany, Krewitt *et al.* (2006) [27] analyze the perspectives of stationary fuel cells under different policy scenarios. A political agenda with a focus on a sustainable energy sector would be highly beneficial for stationary fuel cell technologies. Based on interviews with relevant stakeholders, Peters and Powell (2004) [28] derive that government support and test facilities are necessary to foster the development of mCHP fuel cells in the UK. The rather early study of Tsay (2003) [29] focuses on PEMFC and SOFC in the USA and discusses a broad range of issues. The role of mCHP fuel cells in a large-scale interconnected hydrogen pipeline network in the Netherlands is addressed in [30]. In the long run (2050), the erection of a hydrogen network can yield a cheaper energy infrastructure than the existing system. 30% of the houses in the study region could then be heated with hydrogen. Mathiesen *et al.* (2008) [31] analyze different heating technologies with the help of an energy system modelling tool; under all cases, 50% of electricity stem from wind power. Hydrogen fuel cells in combination with reformers are more expensive than all other decentralized technologies. However, fuel cells operating on natural gas or biogas are not much more expensive than the cheapest competitive solution that has been analysed.

4.4 Support Schemes and Risk

The choice of support scheme has to account for various factors. Above all, a project developer's decision to invest in a new technology depends on the expected return on investment, and hence implicitly on the costs and risk associated with the project.

When a technology competes on the wholesale electricity market, the expected revenue is dependent on the evolution and volatility of future electricity prices. This in turn is influenced by electricity supply and demand, commodity prices (fuel prices of primary energy sources for conventional thermal generation units), availability of generation capacity[8] and transmission constraints (congestion), amongst various other factors. Market risk captures the risk that the value of an investment will fluctuate or decline due to economic changes or shocks affecting large parts of the market, and the implied volatility of prices and revenue.

As illustrated above, the implementation of support mechanisms may mitigate market risk by delimiting to different degrees the investor's exposure to the volatility of wholesale market prices. In the case of a fixed feed-in tariff at one end of the spectrum of operational support, market risk is completely removed for the investor as he obtains a pre-specified price per produced MWh irrespective of the evolution of market prices. At the other end of the spectrum, quota systems with tradable green certificates expose the investor both to changes in the wholesale market price for electricity as well as the certificate price.

Both technological and market risk affect the diffusion of an innovation. Rogers (2003) [32] defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (p.5).

In the pioneer phase or early stages of the development of a technology with a correspondingly low diffusion, the technological risk and associated cost of the technology is very high. In this stage, technological risk dominates market risk. Due to the high level of uncertainty for the investor how quickly technological process, experience curve effects and cost reductions will materialize, support schemes providing a high degree of investment certainty may be preferable to stimulate new technologies. Upfront investment support gives a strong signal to investors when project costs for the installed capacity are reimbursed immediately and do not have to be recuperated over time.

As a technology becomes more mature (Figure 6), technological risk relatively decreases so that the migration to operational support schemes such as feed-in tariffs or price premiums may be considered. It is then regulatory risk that becomes the dominating factor, i.e., if present support legislation and financial support levels may become subject to political changes. As a technology enters the competitive stage compared to conventional technologies, the transition to green

[8] in particular if there is a high share of technologies exhibiting natural variability, such as wind or solar thermal energy; in long-run considerations also the amount of precipitation in hydro-dominated power systems, such as in Norway or Sweden, exerts considerable impact on electricity prices

quota systems may be implemented before the technology will be able to compete on a level playing field on the wholesale market.

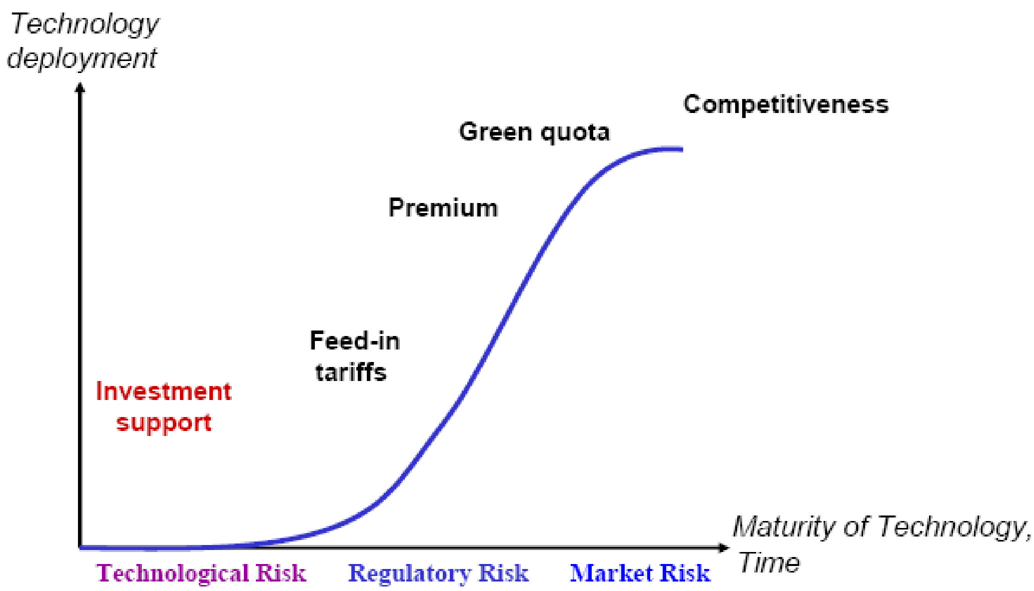

Figure 6: Support schemes and maturity of technology

Finally, it should be highlighted that for an evaluation of risk, there are two natural ways in which random outcomes can be compared: according to the level of returns and according to the dispersion of returns (cf. [33], pp. 194ff.). This means that for the revenue of an investor, both the actual level of the support is decisive (depending on the scheme in place), but also the degree to which the support mechanism may expose the investor to market fluctuations (feed-in tariff vs. green quota). In a perfectly competitive microeconomic setup, an equivalent outcome could be achieved under all different types of support schemes. However, in practice, the dispersion of returns and associated risk also has a price.

5 Application of Support Schemes in Practice

Historically, EU Member States have applied different designs of support schemes for the promotion of renewable energy as well as combined heat and power, notwithstanding that some general trends may be well observable. Previous national experience and current practice are deemed as important qualitative parameters in developing recommendations for a future promotion mechanism for mCHP. This section elaborates on the general application of support for renewable energy in Denmark, France and Portugal in order to outline current national practice in the three countries. Thereafter, it turns more specifically and in greater detail to relevant national legislation with respect to mCHP.

5.1 General National Application[9]

Traditionally, feed-in tariffs have constituted the predominant support scheme for the promotion of renewable electricity in the European Union.

In **Denmark**, three major support mechanisms can be distinguished: the feed-in tariff/price premium scheme, subsidies and loan guarantees. Notably, two variants of the feed-in tariff/price premium scheme have been implemented by the Danish Renewable Energy Act [34]: firstly, there exists the guaranteed *price premium*, which is paid on top of the wholesale market price, irrespective of the evolution of the latter. This type of support is granted to installations based on onshore wind and biomass (§36, §45, [34]). Secondly, there is the variant of a price premium in which the sum of the premium and the market price may not exceed a pre-specified amount, i.e., where the support is limited to a *maximum payment* consisting of premium plus market price by law. Biogas, solar energy and electricity stemming from other renewable energy sources are eligible for this kind of promotion (§44, §46, §47, [34]). The support for offshore wind installations is allocated by means of a *tendering procedure* and then subject to offshore site-specific feed-in tariff schemes (§37, [34]). The duration of support typically amounts to ten years; though, the maximum period corresponds to 20 years. The financial level of support is differentiated across technologies. Furthermore, based on §49 of the renewable energy law, a pool has been established for giving subsidies to small-scale renewable energy production units with a lower production capacity. This pool encompasses photovoltaic, wave power plants and other renewable installations of importance for the future diffusion of renewable electricity (see also 5.2.3) Finally, the Danish transmission system operator Energinet.dk may decide to provide *loan guarantees* to local initiative groups for the financing of pilot surveys on the siting, technical and economic assessment prior to the erection of one or more wind turbines. The costs for financing the provision of renewable electricity support are borne by consumers.

The predominantly applied support mechanisms in **France** consist of the classical feed-in tariff scheme (including tenders for large projects), fiscal regulation, and subsidies provided at the regional level. Wind, solar energy, geothermal energy, biogas, biomass and hydroelectricity constitute eligible technologies that are entitled to receive the *feed-in tariff* (though, frequently subject to certain maximum capacity sizes). Depending on the technology, the fixed feed-in tariff is guaranteed for a period of either 15 or 20 years. The financial level of the tariff is differentiated across technologies. Inherently to the feed-in tariff scheme, the network operator is obliged to purchase generated electricity from qualified renewable producers and can pass on incurred costs to end users. In addition, the Ministry can issue *calls for tender* for the installation of systems based on renewable electricity generation so as to attain the target capacity laid out in the multi-annual investment plan. Under the tendering scheme, special feed-in tariffs with a higher amount of payment are given to producers that have been awarded a contract. *Fiscal regulation* comprises a deduction in income tax for natural persons according to a certain percentage of their investments in renewable energy systems (solar energy, wind energy, hydraulic energy and biomass energy generation).

[9] This sub-section is based on information and data retrieved at [35] provided by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

In **Portugal**, two major promotion schemes find application so as to promote renewable electricity: feed-in tariffs and fiscal regulation. The *feed-in tariff* is coupled with a purchase obligation of renewable electricity imposed on the network operator. Similarly to France, the grid operator may pass on the costs of the feed-in tariff to consumers. The following technologies are eligible for support: wind, geothermal energy; solar, biogas, biomass and hydropower (the latter four technologies being subject to certain capacity limitations). The financial level of support is differentiated according to technologies and energy sources; depending on the generation technology, support is granted for a time span of 12 to 25 years (additionally, there are also special tariff regimes for small systems). The *fiscal regulation* consists of a tax rebate granted to investors dealing with products and machines that are used in the generation of renewable electricity.

Table 1: Major support schemes (promotion of electricity)

Country	Major Support Schemes (Electricity)
Denmark	Premium/feed-in tariffs; tenders for offshore wind; guaranteed loans.
France	Feed-in tariffs; tenders for large projects; fiscal regulation.
Portugal	Feed-in tariffs; fiscal regulation.

5.2 Support Policies in Denmark

Combined heat and power constitutes an important share of Danish electricity production. In the year 2008, 80,645 TJ of total gross electricity generation was produced in central CHP plants and 17,105 TJ in decentralized CHP units [36]. With a total gross electricity production of 131,011 TJ in 2008 [36], this implies that 74.61 percent of electricity generation were covered by CHP.

The central CHP generation units were originally erected for the sole production of electricity and are located in larger cities, whereas the decentralized generation facilities were initially used for heat generation only and can be found in towns of smaller and medium size [37]. Table 2 provides an overview of the composition of the Danish heat supply sector.

Table 2: CHP and district heating plants in Denmark, based on [37]

Collective heat supply sector (towns and cities)	Private heat supply sector (business and institutions)	In total
16 central CHP plants	380 CHP plants	665 CHP plants
285 decentralized CHP plants		
130 decentralized district heating plants	100 district heating plants	230 district heating plants

Most of the decentralized district heating plants and one quarter of decentralized CHP plants use environmentally friendly fuels; however, the majority of CHP installations are based on natural gas [37]. Nearly half of the CHP plants for private heat supply utilize biomass [37].

5.2.1 Generally Relevant Legislation on Support

In Danish legislation, combined heat and power is encompassed by the Danish Electricity Act [38] and by the Act on Heat Supply [39]. The Electricity Act was adopted in 1999 to implement liberalization of the Danish electricity market. Prior to this Act, feed-in tariffs had been applied as the predominant support scheme for electricity based on renewable energy. Under the reform, the feed-in tariffs were first maintained for a restricted time and subsequently replaced by a price premium scheme. The Act on Heat Supply has the objective of promoting the most socio-economically efficient and environmentally friendly use of energy for the heating of buildings and hot water supply as well as reducing the dependency on oil in energy supply. It includes legal provisions on the planning of heat supply in municipalities, expropriation, composition of prices and regulatory supervision. The planning of heat supply is to the discretion of municipal authorities in cooperation with utilities and other affected parties. Municipalities can enforce connection to district heating networks, which are quite common in Denmark.

5.2.2 Relevant Provisions for CHP

Danish legislation on decentralized combined heat and power has undergone various changes since the advent of liberalization of the Danish electricity sector in 1999. In the year 2000, a three-tier tariff was implemented for decentralized CHP installations based on natural gas and industrial CHP plants [40]. The price for power paid to decentralized CHP plants under this three-tier tariff regime depends on the actual time of electricity production (peak load, high load, low load), which is then reflected in the level of the tariff paid to producers. Network operators are obliged to purchase the electricity stemming from qualified decentralized CHP installations at a price reflecting costs for the production and transport of electricity. Since January 2006, the calculation of the three-tier tariff has been valid for Denmark as one electricity supply system and no longer been split according to regions [41]. In 2004, market conditions for the sale of electricity were introduced for large decentralized CHP installations with a capacity of more than 10 MW [42]. The Order *Bekendtgørelse af lov om elforsyningen* [43], amending the Danish Electricity Act, included further provisions for the setting of the minimum amount of price support for electricity produced in decentralized combined heat and power installations as well as electricity plants using waste commissioned at the latest on 21st of April 2004 (§58, 58a). A price premium was granted for 20 years after the connection of a qualified plant to the grid. The premium was index regulated in relation to the market price.

Electricity producers deploying decentralized CHP units based on natural gas and/or biogas, industrial CHP production based on natural gas as well as CHP production based on waste are entitled to financial support for the generation of electricity [44]. Industrial natural gas based CHP units and waste based CHP units commissioned prior to 2004 receive a price premium of 0.9 ct/kWh (7 øre/kWh, §2a). Subsequent to this period, for the replacement of these industrial CHP units a premium of 0.3 ct/kWh (2 øre/kWh) is granted. For electricity production by industrial CHP, the support is limited to six years after the commissioning of the individual installation.

Irrespective of this, industrial CHP units with an aggregate capacity of not more than 4 MW obtain support for a period of 8 years. Notably, the Ministry of Transport and Energy can decide to provide the support for natural gas based industrial CHP as an upfront lump sum payment. Decentralized CHP installations based on waste with an aggregate electricity production capacity of not more than 3 MW and which were commissioned by the 1st of January 1997[10] obtain a premium of 1.3 ct/kWh (10 øre/kWh). Natural gas based decentralized CHP installations with a total electricity production capacity of 25 MW or less receive a premium of 1.1 ct/kWh (8 øre/kWh) for power generation (§2b). The support is provided up to an annual electricity production of 8 million kWh.

5.2.3 Relevant Legislation on the Promotion of Renewable Energy

As aforementioned, approximately every fourth decentralized CHP power plant in Denmark is based on environmentally friendly fuels, i.e., straw, tile, pellets, biogas or waste [37]. Furthermore, half of the plants of the private heating supply sector utilize biomass [37], thus qualifying for support when feeding renewable based electricity into the grid. Electricity production based on the burning of biomass obtains a premium of 2 ct/kWh (15 øre/kWh, §45, [34]). Eligible generation units using biogas receive a premium adjusted in such a way that the sum of the latter and the market price do not exceed 10 ct/kWh (74.5 øre/kWh §44, [34])

The renewable energy law [34] additionally lays down that the transmission system operator Energinet.dk bears the costs for system imbalances incurred by electricity production from decentralized CHP installations (§78 (16)). Also, Energinet.dk is obliged to sell the electricity generated by decentralized CHP units at Nord Pool[11] and to pay the corresponding sum to the owners of the CHP installation (§78 (33)).

Another legal provision which may become relevant for (biogas based) CHP is contained in §49 on the establishment of a pool for promoting small renewable energy technologies: Energinet.dk provides support for enhancing the diffusion of installations with low electricity production capacities, including solar cells, wave power plants and other renewable plants that use energy sources or technologies with importance for the future deployment of electricity based on renewable energy sources. The support pool amounts to 25 million Danish kroner annually for four years.

5.2.4 Support for Competing Technologies to mCHP

In recent years, there has been considerable growth in the sale of heat pumps to private households; this has in particular been the case for air-air heat pumps. There is only limited statistical evidence on the deployment of small-scale heat pumps in Danish households. However, it is estimated that more than 50,000 small-scale heat pump systems are installed for heating in houses and approximately 5,000 larger heat pump installations for block heating systems, in agriculture and industry [45]. The energy production by heat pumps corresponds to at least 3 percent of district heating consumption [45]. In order to facilitate consumers' choice to

[10] or, alternatively, where a project proposal for the conversion of an installation to CHP has been sent to the municipal authority by this date
[11] Nord Pool is the Nordic wholesale power market.

purchase a heat pump with a high efficiency, *Energistyrelse* (the Danish Energy Agency) published a list with energy certified heat pumps. The diffusion of heat pumps has predominantly been promoted by governmental campaigns. In 2007, a campaign was initiated to support the use of small, privately used heat pumps replacing oil burners in areas without district heating or natural gas. In connection with the Energy Agreement [46] concluded on the 21st of February 2008, 30 million Danish kroner were devoted to promote the most efficient heat pumps for two years. At present (December 2009), the Danish Energy Agency is looking for participants (300 test housings) in a new project whose aim is to measure the efficiency of energy certified heat pumps [47]. Under this scheme, residents of housings in areas not connected to natural gas or district heating supply can obtain support for a new heat pump installation. The support amounts to 15,000 Danish kroner for a geothermal heat pump, whereas 10,000 Danish kroner are granted to air-water heat pumps, plus another 11,000 Danish kroner (excl. VAT) of support provided for the meter, installation of the meter as well as data collection. In return for obtaining the investment support, the participants permit the Danish Energy Agency to collect metering information of their heat pump installation. The support is granted only to the purchase of heat pumps fulfilling specific technical requirements. The support programme itself is part of a larger research project on the efficiency of heat pumps [47].

5.3 Support Policies in France

The CHP sector in France comprehends 832 installations, amounting to a total of 6,669 MWe and 20,489 MWth.

5.3.1 Generally Relevant Legislation on Support

Most of these schemes have been installed between 1997 and 2000 and in the industry sector, thanks to the introduction of a purchase obligation without any capacity limit. Since 2002, this purchase obligation does not apply anymore to cogeneration schemes >12MW (except for those feeding a district heating network). Combined with a very low feed-in tariff, this new limit strongly curbed the development of cogeneration installations and until now, the most efficient incentive for the promotion of CHP has been the regular calls for tenders organized by the regulatory authority to encourage the uptake of biomass-cogeneration.

Since 2007, the *Grenelle de l'Environnement* has put the emphasis on the development of biomass and the reinforcement of district heating. The 2009 multi-annual investment plans for heat set the objective of an additional 2,400 toe (27,912 GWh) of biomass used for CHP heat production.

However, no concrete new incentive has been put into place in favour of cogeneration. Indeed, cogeneration is not eligible to the financial aid of the "Fonds Chaleur".

Suppliers of energy (electricity, gas, heating oil, LPG, heat, refrigeration) must meet government-mandated targets for energy savings achieved through the suppliers' residential and tertiary customers. Those exceeding and undercutting their objectives can trade energy savings certificates as required for common compliance. A first objective of 54TWh of cumulated energy savings was set for the three-year period running between July 2006 and July 2009. This obligation was distributed between all the energy suppliers according to their market share.

Energy suppliers who did not meet their obligation over the period must pay a penalty of €ct 2/kWh. The MEDDEM, in the frame of the *Grenelle de l'Environnement* (*Grenelle 2*), announced that the Energy Savings Certificates System would be considerably reinforced, with an annual objective of at least 100 TWh of energy savings/year (compared to 18TWh until now), to be met by the energy suppliers and the fuel suppliers in the transport sector.

On 24 May 2006, the French Government adopted the minimum requirements for new buildings. The requirements came into force for building permits requested after 1 September 2006. The type and level of requirements are governed by the function of the type of building, the type of heating and the climatic zone.

On May 2007, the French Government adopted the minimum requirements for existing buildings, which came into force on 1st of November 2007. These minimum requirements concern the installation of new building components during building renovation and for extensions to existing buildings, in particular hot water production systems and energy production equipment using renewable energy sources.

5.3.2 Relevant Provisions for CHP

The Order of 3 July 2001 fixes the technical characteristics required to CHP plants for the eligibility to the purchase obligation: only stations that achieve at least a 5% primary energy saving (compared to the reference values for separate thermal and electric production processes) (cf. Annex).

The tariff ranges from 6.1 to 9.15 c€/kWh and consists of:

- a fixed premium (PF), which depends on the connection voltage and the compliance with the guaranteed power output in winter,
- a payment for the active electric energy composed with :
    - Proportional payment (RP), which depends on the connection voltage and the guaranteed power output
    - Payment for gas (best STS tariff for the reference combined cycle/0,54)
    - An energy efficiency premium, calculated proportionally to the primary energy savings (1 €ct/kWh for a 12.5% saving above the 5% contained in the definition of cogeneration → overall efficiency of approx. 82.5%)

Since 1 November 2008, some flexibility has been introduced regarding the compliance with the guaranteed power output in winter, so that CHP installations can better adapt their production to the thermal needs.

The tariff includes a financial compensation for the consumption of gas, which is based on the STS tariff. The decree had initially introduced a ceiling to this compensation, but given the increase of gas prices, the limit has been almost entirely removed since 2005 (by 92.5%).

Pursuant to the provisions of article 39AB of the French Tax Code, the objective of this tax credit, introduced in 2005, is to favor high-efficiency equipments that use renewable energies. The system is valid to end 2012 and provides for tax credits. Cogeneration equipment (various types of turbines[12]) can benefit from a 12-months 25% tax-rebate on the total cost of the equipment.

Owners of CHP stations can benefit from a 50% reduction of the business tax.

In France, natural gas suppliers pay a tax on natural gas[13], collected from their customers and due monthly to the Customs.

Cogeneration schemes commissioned before 31 December 2007 can benefit from a 5-year exemption of TICGN on the gas used for the combined generation of heat and electricity (or mechanical energy) (article 266 quinquies A of the Customs Code).

But in accordance with Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity, schemes commissioned after 31 December 2007 can only be exempt from the TICGN on the gas used for the generation of electricity, provided that they do not have a purchase contract with EDF. The tax is set at a level of 1.19 €/MWh.

5.3.3 Relevant for Micro-CHP

The order of 13 March 2002 is fixing the purchase conditions of electricity produced by installations below 36 kVA. The purchase tariff is equal to the buying tariff without VAT for the duration of the contract (15 years) below 8400 h of operation and equals to 4.42 c€/kWh above.

5.3.4 Relevant Legislation on the Promotion of Renewable Energy

A new feed in tariff for electricity produced from biomass is now available since January 2010. This tariff would be valid for 20 years and consist of a base tariff (~ 4.5 c€/kWh) and two premiums: the first one (8 c€/ kWh) would depend on the resources used and the second one (5 c€/kWh) on the overall efficiency of the installation. Those two premiums rely on the use of at least 50% of woodchips and an efficiency of at least 50%. Operators could receive a maximum tariff of 12,5 to 15 c€/kWh, i.e almost twice as much as today. This new feed in tariff will only be available for schemes > 5 MW .

Law 2000-108 of 10 February 2000 concerning the modernisation and development of the public service of electricity enables the French government to call for tenders to install new generation capacities, in order to reach the objectives set in the multi-annual investment program, when those can not be met by a free functioning market or by the purchase obligation mechanism.

Two calls for tenders have already been organised to encourage the generation of electricity from biomass (in 2003 and 2006 – in this latter one, projects amounting to 314MW of new capacity were selected, with an average price of 128€/MWh). The most recent call for tenders was launched in December 2008 by the regulatory authority and calls for 250 MWe of new installed capacity (with installations ≥ 3MW), to be operated in 2012. Selected projects will

[12] In French : turbine de détente de vapeur en contre-pression, turbine de détente de fluides utilisés dans des cycles binaires de production d'électricité à partir de rejets thermiques à bas niveau, turbine de détente de haute pression utilisée en place de vanne de laminage ou de détente, turbine à gaz et moteur thermique avec équipements de récupération de l'énergie sur les gaz d'échappement et/ou les fluides de refroidissement

[13] TICGN: Taxe Intérieure de Consommation sur le Gaz Naturel

benefit from their proposed feed-in tariff during a 20-years period (starting from the commissioning date).

Conditions of eligibility:

- New plants, or existing schemes that produce heat from biomass but would start using part of this heat for additional electricity generation, or existing plants that increase their capacity by at least 3 MW.
- Annual availability ≥ 3,000 hours.

District heating is one of the priorities of the "Grenelle de l'Environnment". According to the first law that has already been adopted on 23 July 2009 in this framework ("Grenelle 1"), and the draft law that should be adopted this year ("Grenelle 2"), several measures will be implemented in favour of district heating, including:

- Simplified procedures for the classification of district heating networks: the classification is decided by the prefect and leads to defining a priority network area within which the authority in charge has the option of requiring all new industrial installations or building heating plants to be hooked up to the network. However, this measure does not apply to heating networks that are connected to a cogeneration installation.
- Extension of the concession periods for district heating.
- Reduced VAT rate for heat supplied from a heat network, if at least 50% of this heat is produced from biomass, geothermal, waste or energy recovery (instead of 60% before).

5.3.5 Support for Competing Technologies to mCHP

The financial law of 2005 put in place a tax credit for energy efficiency measures. The tax credit for condensing boilers is 25% of investment cost, and 50% for air/water heat pumps with Performance Ratio above 3.

5.4 Support Policies in Portugal

Nowadays, the energy sector is of vital importance for the economy. Particularly, aspects such as the security of supply and the dependence of foreign sources are of total importance for the stability of growth and the creation of welfare.

Given this and according to the National Energy Strategy (NES) approved by Resolution of the Council of Ministers (RCM) No. 169/2005 [48], it is necessary to implement the objectives set for the Portuguese energy policy, as: the consolidation of a liberalized market, the reduction of energy intensity in national production, the reduction of the overall energy bill, the improvement of the quality of services related to energy supply, the security of supply, the diversification of energy sources as well as the utilization of endogenous resources, the minimization of environmental impact and the contribution of the energy sector to the enhancement of the national economy growth. The Portuguese energy policy is therefore based on three strategic axes: ensure the security of national supply, promote sustainable development and promote national competitiveness.

5.4.1 Generally Relevant Legislation on Support

The RCM (2005) [48] lays down the objectives of the NES for the energy sector and defines eight guidelines that are translated into laws, regulations and measures to be developed throughout the legislature:

- Proceed with the liberalization of the natural gas, electricity and fuel markets;
- Define a structural framework for competition in the electricity and natural gas sectors;
- Consolidate renewable energy production;
- Promote energy efficiency in consumption;
- Public provisioning that is "energy efficient and environmentally relevant";
- Reorganize the incentive's framework in the energy sector;
- Provide for innovation in energy;
- Ensure the communication, dissemination and evaluation of the national energy strategy goals.

These advances in energy policies and the promotion of the use of renewable energy induced the necessity for a legislative development for Combined Heat and Power (CHP). The Portuguese legislation on CHP is included in renewable energy policies.

The legal framework for electricity generation from renewable energy and from co-generation is established in Decree-Law (DL) No. 189/88 of 27 May [49] as amended be DL No. 168/99 of 18 May [50], and DL No. 538/99 of 13 December [51]. Nevertheless, the rules for CHP utilization were described only in this last DL.

Governmental Order (GO) No. 399/2002 of 18 April [52] provides that, pursuant to Article 7 of DL 538/99 (as amended by DL 313/2001of 10 December [53], operators can choose to sell to the national grid either (i) all energy produced by the facility (apart from that consumed by internal equipment), or (ii) the surplus energy after the consumption needs of interconnected entities have been met. The DL 313/2001 adds the review of the norms related to operating conditions of co-generation units and the fixing rates of CHP generation activity like fuel-specific CHP tariff differentiation in the network for the Portuguese Electric System (SEP). This review can be done by only establishing the principles necessary to internalize the environmental benefits provided by these facilities and in recognition of these benefits for all co-generated electricity, even when intended for domestic consumption of facilities associated with existing co-generation.

The experience derived from its application revealed the need to make some adjustments in several Articles, in order to promote the further development of existing co-generation activities and giving more opportunities to the producer-consumers of low voltage electric power (following the objectives and recommendations established by the European Commission (EU)).

This adaptation of legislation to new solution for decentralized energy production and technological innovation comes with the DL No. 68/2002 [54], that regulated the operation of power generation at low voltage for predominantly their own consumption and without having prejudice in the connection to public distribution or supply to third parties.

On 15 February of 2006, the DL No. 29/2006 [55] established the general basis to the organization and operation of the National Energy System (SNE). The electricity production was classified as an ordinary system and a special system. The special regime relates to the generation of electricity from endogenous, wind, solar, and biomass sources. Special regime generation is subject to different licensing requirements and benefits from special tariffs. The ordinary regime is based in the centralized energy production but is increasingly devalued. In autumn 2007, the DL No. 363/2007 [57] established the framework for the electricity production by micro-production. The promotion regulated by this DL predicted that the produced energy should be aimed predominantly for own consumption and the surplus that can be sold to third parties or to the public grid, with the limit of 150 kW of installed power only in case of delivery in public grid.

This legislation (No. 363/2007) provides a simplified licensing process for any entity with a contract for purchasing low-voltage electricity. An electronic platform was developed by the Portuguese Ministry of Economy and Innovation, which can be accessed by producers to register their installations. Each application is subject to technical compliance inspection. The micro-generation installations are limited to half of the contracted power installed in the households, with a maximum limit of 5.75 kW in the general regime and 3.68 kW in the beneficed regime (except in the case of installations for condominiums). The tariff under the general regime is equal to the cost of electricity sold under the purchasing contract. As an alternative, the benefited tariff regime establish a special reference tariff of 650 €/MWh valid during the first 5 years following the installation year, decreasing 5% for each additional 10 MW registered in the SRM. The reference tariff applies differently depending on the conversion technologies that use renewable energy sources. It is 100% of the tariff for solar, 70% for wind, 30% for hydro, cogeneration and biomass. For fuel cells based on hydrogen from micro-renewable energy, the percentage is provided in the preceding percentages (solar, wind, hydro) depending on the type of energy sources used for the production of hydrogen.

Recently, EDP, the leader mixed public/private company in the energy sector in Portugal, also conceived a micro-generation service called MyEnergy, an integrated solution for particular use of renewable energy, with economic and environmental benefits. Besides that, this service the installation of renewable energy also has benefits in terms of tax deductions. You can deduct from IRS up to 30% of the value of the equipment (installation not included), with a limit of € 796. The sale of energy is exempt from taxes up to a maximum of € 5.000 per year. The micro-generation equipments also can benefit from a reduced VAT rate of 12% In Portugal, the standard rate is 20% (there also exists a reduced rate at 5% and an intermediate rate at 12% (Article 18 of the Tax Code).

The DL No. 33-A [58] modified the system of feed-in tariffs from the DL No. 339-C/2001 of 29 December [59], establishing a new calculation system. The formula for calculation of the feed-in tariffs takes in account the technology, the environmental aspects and the inflation rate. There is also minimum and maximum tariffs renewable energies utilization, according to the variations of load on demand to the grid.

5.4.2 Relevant Legislation on the Promotion of Renewable Energy

The Portuguese Government also promotes Renewable Energy System (SER) that principally assurances feed-in tariffs for renewable electricity, direct subsidy payments and tax incentives. Beginning in 2005, a tendering/concession process was also been established until today. Subsidy payments and tax incentives have been largely, though not entirely, used for smaller-scale renewable energy production (until 3, 68 kW) applications. Feed-in tariffs and tendering schemes are used principally for larger-scale renewable applications.

In February 2006, the Portuguese Government launched the DL No. 29/2006 [55] that established an integrated national electric system where the activities of generation and supply are to be conducted henceforth on the basis of free competition, following the award of a license. The activities of transport and distribution of electricity at low tension are exercised by the attribution of concession of public utilities. These activities are executed taking into account the rational use of environment and the environmental protection by energetic efficiency and renewable energy promotion without compromise the public service obligations. As an initiative by the Economic and Innovation Ministry of the Portuguese Government, a simplified general system applied to electricity micro production called "Renewable at the Time" (Renováveis na Hora) included in SIMPLEX Programme presented in 2007, was formed. The SIMPLEX is a programme aimed at correcting and simplifying the rigidity of administrative processes, procedures and practices. The overall objective is to reduce the bureaucratic burdens imposed on citizens, improving their quality of life and the overall environment for businesses, thus promoting development and economic growth. This programme was included on the DL No. 363/2007 aforementioned.

According to the GO No. 201/2008 of 22 February [56], prices for renewable tariff benefit for a 12% VAT, while any other feed-in-tariff is taxed at the normal VAT rate of 20%. The limits of energy produced and sold benefiting from these tariffs is 2.400*103 KWh/year per kW installed in the case of solar energy, 4.000*103 KWh/year per kW 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.

Commitment to renewable energies, as a relevant mean of limiting the economy's carbon intensity and as a significant contribution to the diversification and sustainability of the energy sector, is particularly based on the development of hydro and wind power, biomass, biofuels and solar power.

In August 2009 the Portuguease Governement reaffirms a new plan for renewable energies. In this plan was stated that "about 60 percent of electricity consumption in 2020 will be generated by renewable sources, which will be approximately 31 percent of the total energy consumed in our country".

This objective will include Portugal in the list of countries that contributed to the carbon emissions per capita, expected by 2010 in emissions of 7.6 tonnes per capita when the average EU-15 will be 10 tonnes.

In order to double the electricity generation by renewable energy bey 2020, was announced that on hydro, will be implemented the National Plan of Dam and the creation of the National Plan for the development of small hydro.

In terms of wind, the aim is to "consolidate and increase the bet to 8,500 megawatts (MW) capacity in 2020.

In solar energy, the goals of the Government are the "multiply by 10, 10 years, the current target of solar energy from 150 to 1,500 megawatts, while the geothermal intends to" proceed with a new line of 250 megawatts by 2020.

In biomass, the objective is to "ensure that landfills have energy recovery and with regard to micro-generation, it is intended to simplify procedures, to facilitate the accession of the citizens and businesses.

Also for the micro-generation, plans to launch a specific program for schools and health centers, and "finish the term with the sale of incandescent light bulbs with low energy efficiency." The latter is indeed the most visible socialist measure for energy efficiency. A more ambitious goal is set for the smart grid electricity distribution networks (new generation) in 2020 must be accessible to 80 percent of consumers.

The Government also intends that by 2020, 750 thousand of vehicles on the road are hybrids or electric.

With regard to electric vehicles, the PS wants to meet that measure both the implementation of the supply chain as incentives to scrapping.

5.4.3 Support for Competing Technologies

In 2001, the Portuguese government launched a new instrument – the E4 Programme (Energy Efficiency and Endogenous Energies), consisting of a set of multiple, diversified procedures aimed at encouraging a consistent, integrated approach to energy supply and demand. By promoting energy efficiency in consumption together with the use of endogenous font, this program aims to improve the competitiveness of the Portuguese economy and to modernize the country's social structure, while reducing GHG emissions, especially the carbon dioxide responsible.

The initiatives (legislation, incentive schemes) introduced in 2001/2002 (DL No. 33-A/2005 [58]), aiming at stimulating the market (private investors), not only for RES electricity, but also for CHP, solar thermal use and building energy efficiency, are growing increasingly.

The DL No. 225/2007 [60] introduced new tariffs for emerging technologies for the production of energy, such as wave energy and concentrated solar power, providing the legal basis for government use of public maritime areas for producing electricity from sea-wave power. The present Portuguese feed-in tariffs DL also explains a specific procedure for minimize local opposition towards new wind projects, having in consideration of the crucial role of wind power within Portugal's energy strategy (National Energy Strategy) and the substantial increase (from 114 MW in 2001 to 3.535 MW in Feb 2010 in installed capacity required to meet Portugal's wind energy targets (5.700 MW until the final of 2010). Under this procedure, municipalities in which a wind farm is located will automatically benefit a share of 2.5 percent of the monthly remuneration paid to the wind project operator. As expected, municipalities have responded with support for wind power projects in their region. A similar procedure for other renewable technologies does not exist under the Portuguese regulation until now.

European Directive 2003/30/EC was transposed into Portuguese law by Decree-Law No 62/2006 of 21 March 2006 [61], which sets the potential introduction of mandatory minimum quotas of biofuels in fossil fuels. This Directive aims to set the objectives for biofuels in the market of each Member State, calculated on the basis of energy content, the reference value of 5,75% of all fuel and for transport purpose, until the end of 2010.

Additionally, the Decree-Law No 66/2006 of 22 March 2006 [62] targets the promotion of the use of biofuels presenting total exemption of the fuel tax (in the case of small dedicated producers) or partial exemption in the fuels (more specifically the ISP Tax - Tax on Petroleum and Energy products) up to a target set annually.

The most recent legislation about renewable energies, GO No. 1463/2007 of 15 November [63], defines the Incentive System applicable to SME (Smal and Medium Enterprises). Art. 12, no.1, a) acquisition of renewable equipments. Art. 15, no.1) states maximum incentive rate.

6 Ownership Structures

Traditionally, both the electricity and the gas sector developed as vertically integrated industries. The different stages of the value chain, i.e., production, transmission, distribution, storage (gas) and supply, used to be in the hands of vertically integrated gas and electricity undertakings. Figure 7 provides a sketch of the traditional value chain.

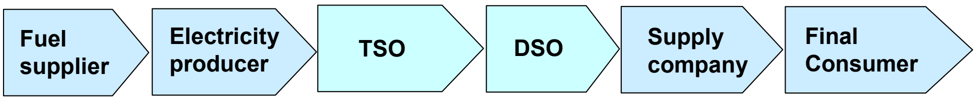

Figure 7: Traditional value chain of the energy sector

With the advent of liberalization of the European electricity and gas sectors in the middle of the 1990s, these historically existing structures were broken up. The segments of generation and supply were opened for competition (cf. Directive 2009/72/EC [6] for electricity and Directive 2009/73/EC [64] for the gas sector, respectively), and non-discriminatory third party access to LNG facilities and electricity networks became major prerequisites to enable market entry by new firms. In the electricity sector, Directive 2009/72/EC [6] stipulates unbundling for transmission system operators (TSOs) and distribution system operators (DSOs) from the segments of generation and supply. At the transmission level, this implies the implementation of ownership unbundling as the preferable option, or, alternatively, the establishment of independent system operators (ISO model). For DSOs, there exists the possibility of an exemption from the unbundling requirements for DSOs serving less than 100,000 connected customers or small isolated systems. In an analogous fashion, unbundling requirements are stipulated for TSOs, storage system operators and DSOs in the gas sector [64].

With the completion of liberalization, customers and/or consumers, being at the final stage of the value chain, can freely choose their supplier. The possibility to switch suppliers along with technological advancements that incentivize a higher level of demand side participation, such as real time metering, entail a shift from passive to more proactive consumer behavior.

The implementation of mCHP in residential applications takes consumer involvement one step further as these generation facilities are directly installed in homes. An mCHP unit enables auto-production, i.e., electricity produced can be consumed onsite or, alternatively, be fed into the grid. This implies that consumers simultaneously will become producers, so-called “prosumers”. Eventually, the degree of *consumer participation*, i.e., the consumers’ role in the financing, the operation and maintenance of the mCHP plant, hinges on the *ownership structure* in place. There exists a wide spectrum of possible ownership arrangements, ranging from ownership of the mCHP unit by a utility or energy service company (ESCO) to full consumer ownership. ESCOs are private companies offering energy services to energy consumers. These services may encompass consulting, financing and operating lease, and even extend to the actual installation, operation and maintenance of an mCHP installation. Utility, ESCO and consumer ownership entail the integration of the respective actor across different functions of the traditional value chain and may thereby yield new cross-cutting constellations.

Inherently, each of the different ownership structures has far-reaching implications for the operation strategy of the mCHP plant (heat- or electricity-led, private cost-minimizing vs. grid system-optimizing) as well as for the allocation of cost and risk. Notably, when tailoring a support scheme for promoting mCHP, this necessitates careful coordination with the envisaged ownership arrangements. Similarly to support schemes, the ownership regime may also change as a wider diffusion of the mCHP technology materializes.

6.1 Different Ownership Models for mCHP

Various ownership models for the implementation of residential mCHP applications have been discussed in literature attributing different degrees of involvement of utilities and energy service companies on the one hand and consumers on the other hand.

6.2 Stakeholders

In general, for the discussion of possible ownership arrangements, four different stakeholder groups can be differentiated:

- House owners (this also includes long-term renters with similar interests for a cheap provision of heat and electricity).
- Electricity suppliers (traders) and network operators (TSO and DSOs), representing three stages of the electricity value chain.
- Gas suppliers (traders) and network operators, representing two/three stages of the gas sector's value chain.
- ESCOs/contractors that are different from the above mentioned parties and that are specialized in the construction and operation of heat and electricity providing facilities (this also covers local craftsmen that could see additional business possibilities in extending their business concept towards an ESCO).

Notably, further differentiations can be made within each individual stakeholder group. House owners constitute a rather heterogeneous group, depending on the type of house and ownership (single-family vs. multi-family houses, stand-alone vs. (semi-) detached houses vs. apartments, old houses vs. new houses (in particular, with respect to heat insulation)). Also, there may be varying degrees of vertical integration within the other stakeholder groups. Distribution system operators serving less than 100,000 connected customers or small isolated systems can be exempted from the unbundling requirements – and hence can still be active in the segments of production and supply (cf. Art. 26, Directive 2009/72/EC [6]).

6.3 Ownership Models Proposed in Literature

Watson (2004) [65] and Sauter and Watson (2007) [23] distinguish three alternative micro-generation deployment models. These three models are based on different relationships between the energy company and the consumer, and their respective roles (active vs. passive):

- *"Plug & Play"*: consumers, i.e., homeowners, own and finance the mCHP unit, thereby becoming partly independent of conventional energy suppliers. Depending on the remuneration mechanism for feeding electricity into the grid, the consumers opt for onsite consumption or for exporting as much electricity as possible to the network.
- *"Company Control Model"*: energy companies use a cluster of mCHP plants as a substitute for central power generation, i.e., as a virtual power plant owned and operated by an ESCO or a utility.
- *"Community Micro-Grid"*: being part of a micro-grid, consumers exert primary control over their mCHP plant, while ensuring the supply-demand balance in their micro-grid.

Similarly, van den Oosterkamp and van der Laag (2003) [66] distinguish the *Privately-Owned Scenario* in which the end-user buys and operates the mCHP system and the *Energy-Company Scenario* in which the energy company may buy and install the system at the end-users' premises. In the Private-Owned Scenario, it is the avoided cost for purchasing electricity from the utility company that constitutes the basis for profitable operation. In addition to household ownership and leasing arrangements by ESCOs or energy suppliers to households, Houwing *et al.* (2008) [67] point out the possibility of *aggregators* trading electricity from distributed energy sources, as well as the formation of economically coordinated clusters, such as micro-grids and virtual power plants. A *virtual power plant* consists of distributed generation units of different technologies (e.g., mCHP, wind, photovoltaic, gas turbine) that are centrally coordinated and controlled by one entity. *Micro-grids* are small distribution systems through which multiple customers are connected to multiple distributed sources of generation and storage [9], e.g., in remotely located regions or on islands.

6.4 Ownership Structures, Diffusion of Innovation and Support

A new technology is not adopted by all individuals in a society at the same time, but rather sequentially depending on individual innovativeness, i.e., "the degree to which an individual (or other unit of adoption) is relatively earlier in adopting new ideas than other members of a system" (p. 267 [32]). Rogers (2003) [32] proposes to use different adopter categories in order to characterize individuals with a similar degree of innovativeness. Based on a normal adopter distribution for the diffusion of an innovation, Rogers (2003) suggests a subdivision into five ideal adopter categories [32]:

- *Innovators*: the first group in a system to adopt the new technology. They are venturesome, interested in new ideas and entertain cosmopolite social relationships.
- *Early adopters*: they are more integrated in the local social system and have the highest degree of opinion leadership in most systems, thereby helping to trigger the critical mass for the diffusion of an innovation.
- *Early majority*: adopts innovation before average member of a system and plays a vital role in providing interconnectedness in the system's interpersonal networks.
- *Late majority*: they adopt an innovation just after the average member of a system.
- *Laggards*: they adopt an innovation as the last group in a system, are the most localite, and typically interact with individuals that share traditional values.

According to Rogers' (2003) [32], the distribution of these ideal adopter categories is not symmetrical, with the early and the late majority accounting for the largest part of the distribution, making up around one third of the distribution each.

Households that may implement mCHP solutions hence cannot be regarded as a homogeneous group in society, but rather as a heterogeneous group of actors, ranging from early pioneers to late adopters. The rationale of a homeowner for opting for the purchase of an mCHP installation, e.g., a general openness to new technologies for energy efficiency improvements vs. seeking immediate profit, may further influence under which adopter category an individual household falls. Notably, financial resources at disposal and associated costs with the adoption of an innovation may constitute significant determinants for the readiness of individual consumers to assume risk.

The diffusion of an innovation is closely aligned with the technological lifecycle, i.e., with the development stages of a new technology outlined in Section 4.4. In the pioneer and introduction phase, the degree of diffusion of a new technology is rather low. It then successively increases when costs and technological risk get reduced as the market and competition phases are reached. During this process of transition, it is the task of regulation to trigger the technology push by means of R&D support or to induce the demand pull through the design of appropriate support schemes. The choice of support schemes for heat and electricity generation does not only impact technological development, but simultaneously sets incentives for inducing certain ownership structures. For example, rather risk-averse house owners would be attracted by a feed-in tariff for electricity generation or by a mandatory renewable share for heat if mCHP-FC is eligible and proves to be cost-efficient. Also, net metering might be a simple, easy-to-understand option that has a direct impact on the final consumer's electricity bill. The choice of more market-based support instruments, e.g., a green quota obligation for electricity, would in the longer run most likely attract professional investors, such as utilities. Irrespective of ownership structure, a support instrument providing a high degree of investment certainty is crucial for the promotion of a new technology in the beginning when technological risk prevails. In the medium term, the interactions between different adopter groups, ownership structures and choice of support schemes need to be considered in policy design to enhance technology diffusion.

7 Conclusions

Due to the combined attributes of cogeneration and fuel cells, fuel cell-powered mCHP may contribute to the objectives of European energy policy, i.e., sustainability, competitiveness and security of supply. At present, the main challenge for designing a support scheme for mCHP lies in choosing an instrument that makes the technology economically viable on its own as early as possible.

One key for achieving this goal lies in accounting for possible *ownership structures*. A Plug & Play approach where single households own and finance the unit is induced by a support scheme that is easy to understand and administer, e.g., a straightforward feed-in tariff or net metering. The company control model would rather be adopted under a support scheme where the aggregation of mCHP units is useful, such as under a price-premium scheme. Aggregation and accompanying professionalization entail that support scheme rules could be more advanced. Community micro-grid ownership constitutes a hybrid of the two aforementioned ownership structures.

Simultaneously, experience curve and scale effects play a major role for a dynamic *reduction of the production price* for a mCHP unit. This implies that a support scheme leading to considerable production volumes and inducing greater diffusion of the technology might be desirable. Ownership of heating devices can differ between countries. Keeping traditional ownership structures in this sector might increase people's willingness to consider a mCHP fuel cell as their new heating device and make them more prone to becoming early adopters.

Furthermore, it is relevant whether the support scheme of a microCHP unit is based only on the *electricity or heat* output, or on both products. Existing support schemes for CHP tend to focus on electricity generation because electricity is considered as the by-product that is to be encouraged in comparison to the traditional case (heat-only generation). With the increasing support for heat generation from renewable energy sources, an integration of support approaches is desirable: can an mCHP unit be financed best by being eligible for either heat or electricity support, or is there an optimal combination of the two?

The exact support level that could be granted to mCHP fuel cells depends on a number of nationally, or even regionally, different factors: apart from installation costs, fuel costs, the unit's efficiency, the expected number of operation hours and opportunity cost, i.e., the provision of heat and electricity through competing technologies, are among the main influencing factors.

The interaction of this plethora of elements – from historically grown ownership structures to experience curve effects and technical determinants for financial viability – necessitates careful balancing from a private and a socio-economic point of view. A quantification of these elements will be provided in the subsequent Work Packages of the FC4home project.

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