CODE2

Cogeneration Observatory and Dissemination Europe

Micro-CHP potential analysis European level report

Partner Name: Energy Matters

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1 Executive Summary

Summary
This micro-CHP study has been developed in the frame of the CODE2 project, which is co-funded by the European Commission (Intelligent Energy Europe – IEE) and will launch and structure an important market consultation for developing 27 National Cogeneration Roadmaps and one European Cogeneration Roadmap. This document contains the background and methodology used to project the European micro-CHP market until 2030.

Micro-CHP has the potential to reduce CO_2 emissions and reduces primary energy consumption compared to a conventional boiler with electricity drawn from the grid. They are heating appliances and can be considered as a boiler replacement technology. Current cost prices are high, but major cost reduction is expected through learning and scaling up. Manufacturers state that cost-price reductions are strongly coupled to the number of installations produced and implicitly states that with strong political will an economic cost-competitive product can be achieved.

With the proposed commercial program, a cost-competitive price of €4,000 per kWe of micro-CHP systems for households could be reached in 2025. It must be noted, that this cost-competitive price is from the end-user point of view, and does not include additional benefits that can arise due to increased value of the building, abated grid costs etc.

In 2030, around 1,7 million systems will have been sold, thereby making the average subsidy € 700 per unit. The commercial program as a whole would cost approximately 1,200 M€ in total, leading to annual primary energy savings of approximately 240 PJ and annual CO2 reduction of 14 Mton.

2 The micro-CHP technology

Micro-CHP is a principle to achieve energy efficiency, by converting primary energy to heat and electricity at the end-user level. Energy losses are minimized since heat losses at central electricity production facilities and network losses in the electricity grid are avoided.

Micro-CHP products produce heat and electricity simultaneously based on a range of technologies. They can be categorized in three groups (see also figure 2):

1. Internal combustion
2. External combustion
3. Chemical conversion (fuel cells)

Each technology has its unique properties and thereby serving different kinds of end-users and markets.

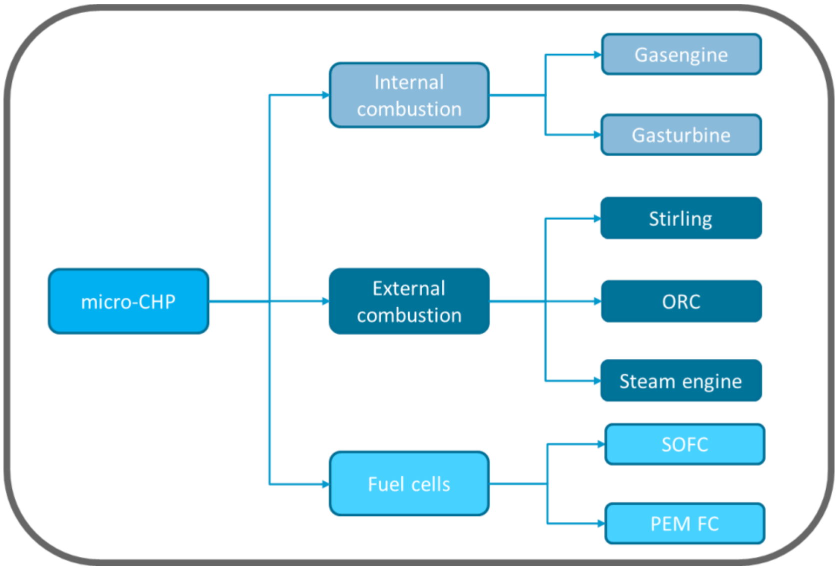

Figure 1: Micro-CHP technologies.

Since a micro-CHP produces relatively high temperature heat, it can easily be implemented in the heating systems of existing buildings. Furthermore, it fits well into the existing gas and electric infrastructure. In Table 1, a comparison is made between different heating technologies for the built environment showing that micro-CHP has the same application areas as a (condensing) boiler and has a unique fit to the market for existing buildings.

	Application			Existing connection		Fit with existing heat exchangers	Other remarks
	Low temperature space heating	High temperature space heating	Hot tap water	Fit with gas connection	Fit with electric connection		
Condensing boiler	v	v	v	v		v	No major efficiency improvements to be expected
Ground source heatpump	v	x	x		v	x	Yearly balance of ground source
Air source heatpump	v	x	x		v	x	Feasible in new buildings or renovation projects
Solar heat	x	x	v	v		x	Seasonal availability
micro-CHP	v	v	v	v	v	v	
Biomass boiler	v	v	v			v	Biomass (source) availability
District heating	v	v	v			v	Heat network needed

Table 1: Comparison of different heating technologies for the built environment.

The development of micro-CHP systems is in an early phase of commercialisation. In the residential sector, electrical capacities are up to 5 [kW_e] and heat capacity depending on technology up to 20 [kW_{th}].
In the SME & collective sector, gas engine systems of capacities from 5-50 [kW_e]/2,5-250 [kW_{th}], are used, with over 100,000 systems already installed. These systems are usually implemented as an 'add-on' to the existing heating system. This means that the system will provide the base load heat demand and that peaks in heat demand are covered by a 'conventional' boiler, which is placed separately.
In the residential sector, most manufacturers that develop fuel cell and Stirling engine micro-CHP systems try to position their products as a 'replacement' product of an existing boiler system. Thereby integrating the auxiliary boiler in the system.

Although fuel cell technology is in its infancy in Europe, in Japan 100,000 fuel cell systems have been placed as part of a government supported Ene-farm project. The two common fuel cell types for micro-CHP are PEM and SOFC fuel cells.

Figure 2: A variety of micro-CHP systems.

		Household systems				SME & Collective systems			
		Stirling	ICE	PEM FC	SOFC	Stirling	ICE	PEM FC	SOFC
electrical efficiency	**%**	20%	25%	40%	60%	20%	35%	40%	60%
thermal efficiency	**%**	80%	65%	55%	35%	80%	60%	55%	35%
present retail price	**€/kWe**	€ 10 000	€ 15 000	€ 150 000	€ 17 000	€ 10 000	€ 1 500	€ 10 000	€ 10 000
future cost price	**€/kWe**	€ 3 000				€ 2 000			
units installed worldwide 2013	**-**	1000s	10000s	10000s	10000s	100s	10000s	1000s	100s

Table 2: technical and economic properties of micro-CHP.

Estimating the potential for micro-CHP in Europe

2.1 *Objective of the micro-CHP potential analysis*

The goal of this study is to evaluate reasonable uptake scenarios and thus the implementation potential, not the theoretical maximum potential, for micro-CHP in the (former) 27 EU-member states (MS). From these scenarios, potential energy savings and greenhouse gas reductions are derived.

2.2 *Desired output*

- Number of newly-installed micro-CHP appliances (sales) per sector per year (per MS), related to number of conventional boilers.
- Number of total installed micro-CHP appliances (stock) per sector (per MS).
- Primary energy savings in 2030 in EU.
- GHG-emission reductions in 2030 in EU.

2.3 *Scope & assumptions*

- All member states (MS) of the EU-27.
- Micro-CHP up to 50 [kW_e]/250[kW_{th}]. Division in two sectors:
    - Household/residential micro-CHP (0,1-5 kWe)
    - SME & collective micro-CHP (> 5-50 kWe)
- For the SME & collective sector micro-CHP is seen as an add-on on the existing heating system.[1]
- Implementation potential up to 2030 is defined, not the technical potential.
- Control strategy: Heat-led. Micro-CHP is primarily seen as a replacement product in the domestic heating market.[1] This holds true for Stirling and internal combustion engines. They will produce electricity when there is a heat demand. Fuel cells, especially SOFCs, are designed to run continuously. The produced heat is converted to domestic hot water.
- Trigeneration (combined heat, power and cooling) is not taken into account. Though it can be a useful addition especially for Southern EU-countries with a long cooling season, the focus will remain on standard CHP. Furthermore, the technology (i.e. absorption chillers) is limited in efficiency and availability in micro-CHP size range.
- Effects of fuel shifts, such as H2-injection or using green gas instead of natural gas, are not taken into account but will only benefit the environmental savings.

[1] A 'replacement' product is defined as a product that completely replaces the existing boiler. Depending on the micro-CHP technology, an auxiliary boiler and or hot water tank is integrated in the product. The product will cover the whole heat demand. An 'add-on' product is defined as a product that is added to the already existing heating system and part of the heating demand.

3 Approach of estimating the micro-CHP potential

This study aims to give an outlook on the potentials of micro-CHP in the former 27 EU Member states until 2030. The chosen approach to conduct this micro-CHP potential analysis is shown in Figure 3. Three core steps are defined and detailed in the following paragraphs: Defining the boiler market in 2030, estimating the market penetration rate and establishing a market diffusion S-curve.

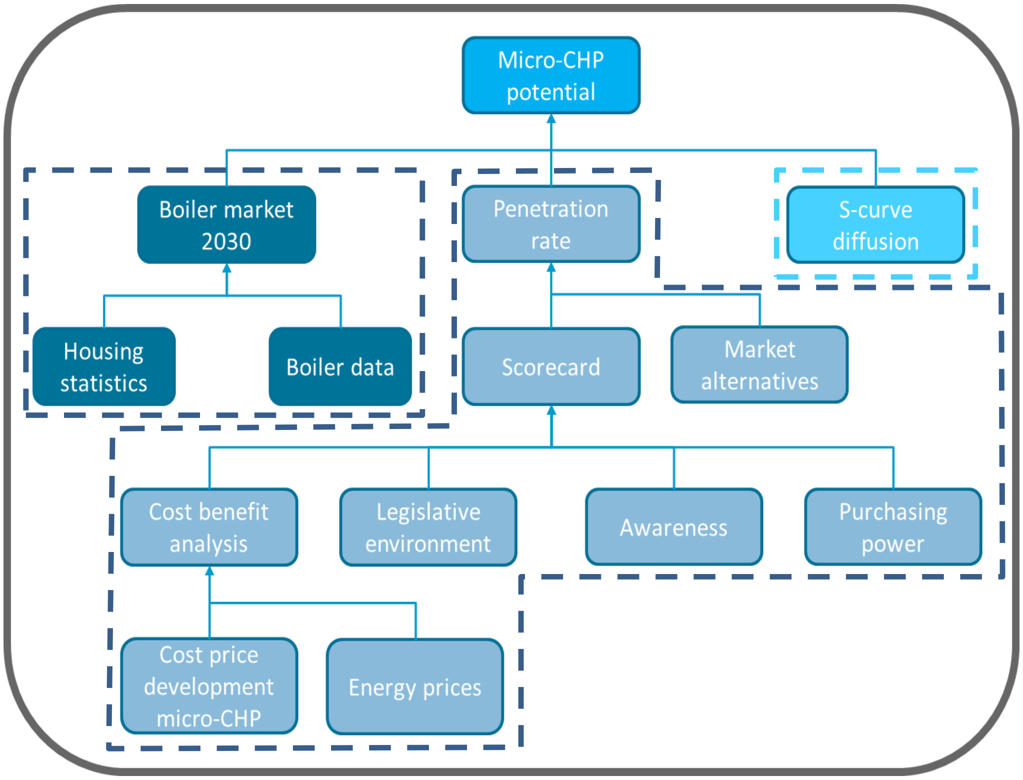

Figure 3: Approach of the micro-CHP analysis.

3.1 Boiler market 2030

The boiler market in 2030 is estimated by combining boiler data and housing statistics (see Figure 3). Extensive boiler market data for boilers between 10-500[kW_{th}] is available for most EU countries for 1990 and 2004. This data is adapted to 2013 and used as a basis for the boiler market predictions. No boiler market data was available for some countries, for these countries an estimation was made of the boiler market by collecting housing statistics and analyzing the share of central heating in households. In this way, an expected boiler market for each member state in 2013 could be derived. This derived 2013 boiler market is taken as reference for 2030 projections. More information can be found in Appendix A.

3.2 Penetration rate in 2030

The penetration rate of micro-CHP in each MS in 2030 will be assessed by analyzing the market alternatives, and creating a score card based on economics, legislative environment, awareness and purchasing power of each MS. In this score card, the following aspects are being assessed and weighted:

- Market alternatives, such as bioenergy, heat pumps, district heating, solar.
  - Based on Primes data, Heat roadmap Europe & other sources
- Economic Analysis; a cost benefit analysis in which per MS the simple payout time is calculated by dividing the product price by the cost savings on energy. Since most of the micro-CHP technologies are still in its infancy a mass market product price is assumed.
  - The CBA will be expressed in terms of Simple Pay-out time (SPOT
- Legislative environment
  - Based on CHP support mechanisms and taxes (CODE-project)
- Awareness among stakeholders
  - Based on awareness studies per MS (CODE2-project)
- Purchasing power (only for the household sector).
  - Based on Gross Domestic Product per capita.

For market alternatives, a maximum score of 3 points can be given. For every other aspect, a maximum of 4 points can be given. The score card to estimate the penetration rate is presented in Table 3.

Weighting aspects	Maximum points	
	Household sector	SME & Collective sector
Market alternatives	3	3
Economic analysis	4	4
Legislative environment	3	3
Awareness	2	2
Purchasing power	3	
Total points	**12**	**9**

Table 3: Score card used to estimate country specific penetration rate.

The maximum market share or penetration rate in an EU-member state depends on the score for the aspect market alternatives and is as follows:

Weighting aspect	Points & maximum market share		Weighting factors
	Household sector	SME & Collective sector	
Market alternatives	3 – 90% 2 – 77% 1 – 63% 0 – 50%	3 – 50% 2 – 43% 1 – 35% 0 – 28%	No competition Few competition Some competition A lot of competition

Table 4: Points on aspect market alternatives and specific penetration rate on the boiler market.

3.3 S-curve diffusion

The third parameter used to predict the market potential of CHP is the S-curve diffusion. The penetration rate is coupled to the so-called S-curve, a standard diffusion curve for innovation. The S-curve defines different phases in technology diffusion (see Figure 4) and is based on a logistic, rather than linear process of market diffusion.

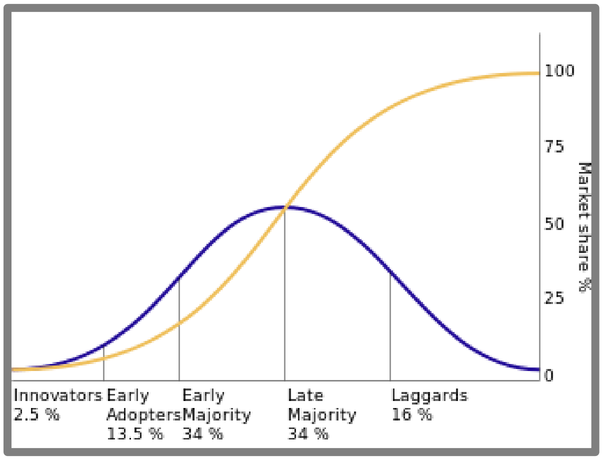

Figure 4: S-curve diffusion for innovations is adopted to predict the market penetration of micro-CHP systems.

3.4 Scenario's; Maximum potential, expected potential and low expectations

At the moment, micro-CHP is still in the 'innovators' stage. In the potential analysis, it is assumed that micro-CHP will break through and will take a share of the existing boiler market. For each EU member state the market potential of micro-CHP is assessed for three different scenarios. Each scenario reflects a different penetration rate in the boiler market. This penetration rate will be reached in 2030 following the S-curve diffusion.

- **Maximum potential scenario**
  - The maximum potential scenario projects the potential in the case of strong market adoption. The maximum potential scenario for a MS depends on the size of the boiler market and on the market alternatives to CHP in that country (see Table 4).
- **Expected potential scenario**
  - This scenario is modeled using the size of the boiler market and the market alternatives, but also includes the MS specific aspects of the score card: 'economic analysis', 'legislative environment', 'awareness' and 'purchasing power'. Each member state will score a certain number of points which is divided by the maximum points on these aspects. The resulting ratio is multiplied by penetration rate of the maximum potential scenario.
- **Low expectations scenario**
  - In this scenario, the scores on 'market alternatives' and 'economic analysis' are set to 0, but the other parameters remain at their estimated value. Depending on the scores already given in the analysis, this will result in lower penetration rate than in the expected potential scenario. N.B. The low expectations scenario is not a minimum potential scenario. The minimum potential scenario is one where there is no market diffusion at all.

4 Micro-CHP potential in Europe

In this chapter, the results of the potential analysis are presented. First the results of the present boiler market are presented. Next, the micro-CHP potential for the residential market and the SME & collective market is projected. For each sector, results are shown for the potential development of sales and stock and the potential energy savings and GHG emission reduction. A comparison is made with research done by Delta-EE and Frost & Sullivan in Paragraph 3.5.

4.1 Present boiler market (2013)

In this potential analysis, the present boiler market is taken as reference for the future boiler market. In the figures below, the growth of the boiler market between 1990 and 2004 is clearly visible. Growth is expected to continue, at least until 2013. For 2013, total boiler sales including heat pumps and wood pellet boilers are expected to be around 9.1 million. The total boiler stock in the formerEU-27 is expected to be around 115 million systems in 2013.

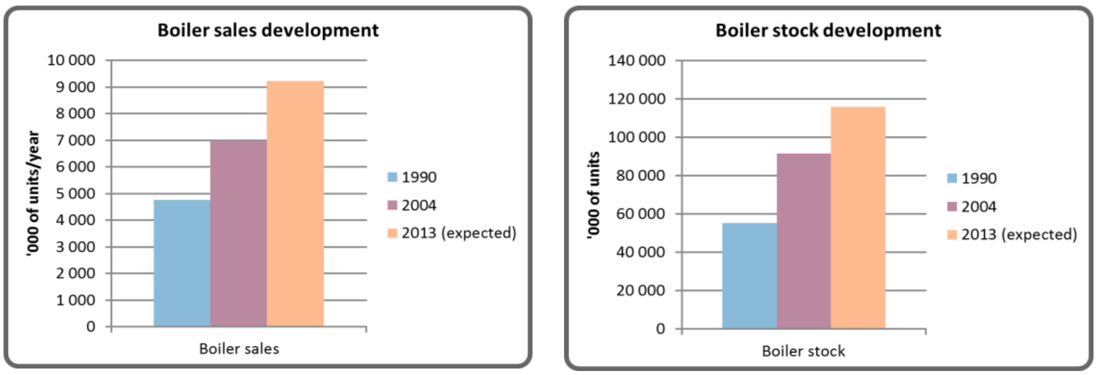

Figure 5: The development of boiler sales and stock in the EU-27.

The total boiler sales of 9.1 million systems per year can be split up in 8.1 million gas and oil boilers sales in the residential sector (88,5% share of total sales), 0.60 million gas and oil boilers sales in the SME & collective sector (6,5% share of total sales) and 0.55 million other fuel boilers, like heat pumps and wood pellet boilers. In the boiler stock roughly the same shares are found, with a stock of 100 million and 8 million boilers in the residential and SME & collective sector, respectively.

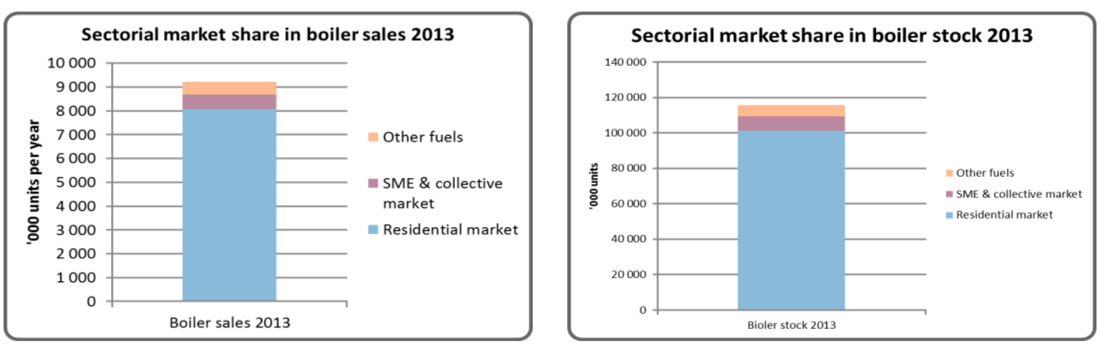

Figure 6: The sectorial market share for the expected boiler market in 2013.

For the potential analysis, the sales of 8.1 million systems per year in the residential sector and 0.6 million systems per year in the SME & collective sector are taken as reference for the future boiler market and thus for the potential market of micro-CHP.

4.2 Micro-CHP potential in residential sector

In the residential sector approximately 100 million gas and oil fired boilers are placed in EU-households. Per year, roughly 8.1 million systems are installed in the former EU-27.

4.2.1 Micro-CHP sales potential in residential sector

The potential development of the yearly micro-CHP sales in the EU for the residential sector are defined using the boiler market forecast and the score card method as detailed in Paragraph 3.2. The results of the micro-CHP market potential analysis are show in Figure 8.

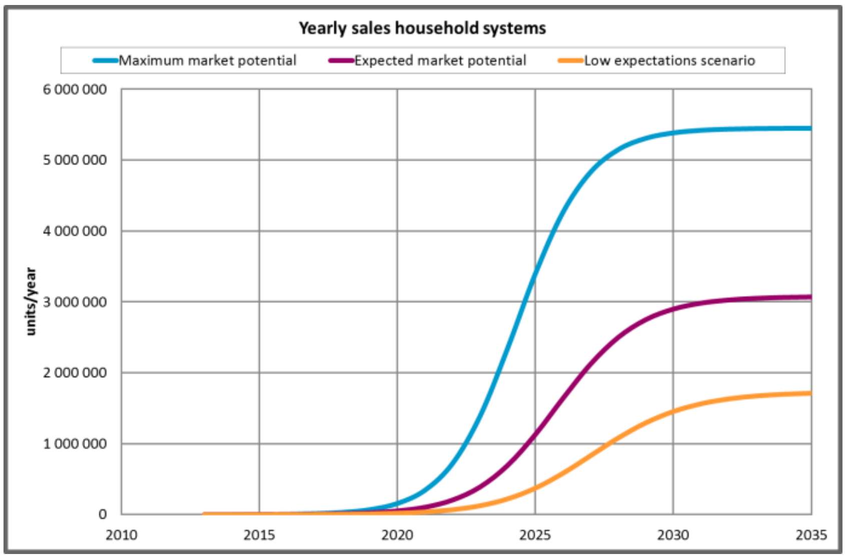

Figure 7: Development of the yearly sales potential of micro-CHP in the residential sector in the EU-27 member states for three scenarios.

For all scenarios, the uptake of micro-CHP systems in the residential sector is limited till 2020. In 2020, potential micro-CHP sales are estimated to be between 20 000 and 150 000 units per year depending on which scenario is taken. Hereafter, it is expected that micro-CHP will make its breakthrough in the market.

In the 'maximum potential' scenario (blue line), maximum penetration of residential micro-CHP is reached in 2030 with a sales potential of 5.4 million systems yearly, which is 68% of the total residential gas and oil boiler market. In the 'expected potential' scenario (purple line) the penetration rate is corrected for all 5 weighting factors as described in Paragraph 2.2. In this scenario, approximately 3 million micro-CHP systems will be installed annually in 2030 (37% of residential boiler market).
For the 'low expectations' scenario (orange line), in which the penetration rate of the 'expected potential' is downgraded by lowering the score on the weighting factors 'market alternatives' and 'economic' analysis, full penetration is expected in 2035. In 2030, almost 1.5 million micro-CHP systems will be sold yearly in the residential sector following this scenario (19% of residential boiler market).

4.2.2 Potential micro-CHP stock development in the residential sector

The potential stock of micro-CHP systems is shown in Figure 8. The stock in 2020 is still relatively small with 100 000 systems installed in households in the 'expected potential' scenario. From 2035 on the micro-CHP market is becoming 'saturated', that means that most of the new micro-CHP systems are installed to replace the old micro-CHP systems. In the 'low expectations scenario' approximately 15 million EU-households are served by a micro-CHP system on the long term. For the 'expected potential' scenario, 30 million households will be served by a micro-CHP system and 55 million households in the 'maximum potential' scenario, which means that approximately 1 on the 4 houses in the EU has a micro-CHP system installed in 2035.

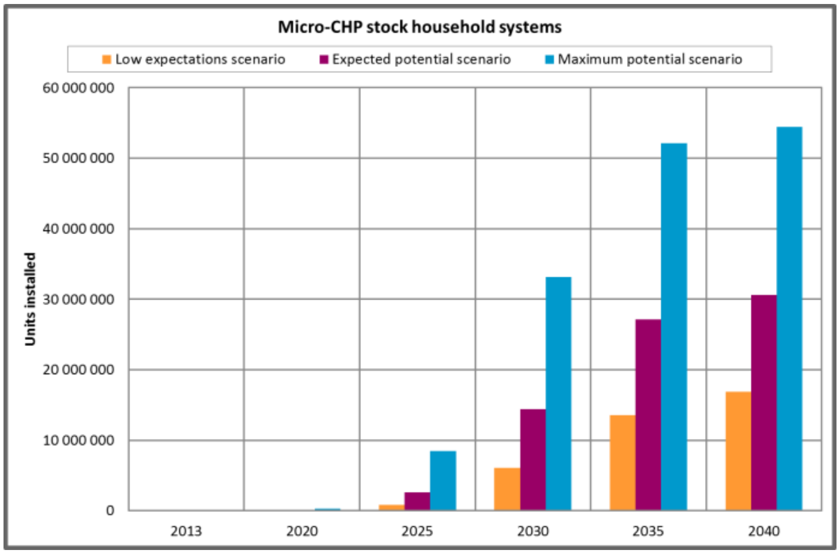

Figure 8: Potential micro-CHP stock development in the residential sector in the EU-27 member states for three scenarios.

4.2.3 Potential energy savings and GHG emission reduction

Following the 'expected potential' scenario, micro-CHP systems have the potential to save approximately 300 [PJ] primary energy per year compared to conventional boilers. This is approximately 0.6% of the total energy used in the EU-27 in 2010. Greenhouse gasses can be reduced by 13 [Mton of $CO_{2,eq}$/year] by using micro-CHP systems instead of gas boilers. This is equivalent to 0.3% of the total EU-27 GHG emissions in 2010.

4.3 Micro-CHP potential in the SME & collective sector

In the SME & collective sector approximately 8 million gas and oil fired boilers are installed in the EU in 2013. Annual sales are around 600 000 systems in 2013.

4.3.1 Micro-CHP sales potential in the SME & collective sector

In Figure 10, the potential development of the yearly micro- CHP sales in the EU for the SME & collective sector are shown for the three scenarios.

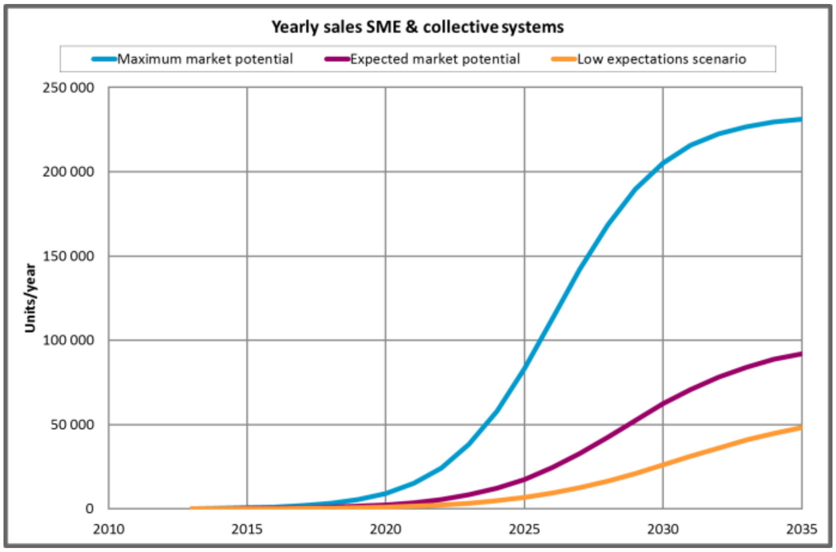

Figure 9: Development of the yearly sales potential of micro-CHP in the SME & collective sector in the EU-27 member states for three scenarios.

The uptake of micro-CHP systems in the SME and collective sector is modest till 2020 in all scenarios. Thereafter, it is expected that micro-CHP will make its breakthrough in the market.

In the 'maximum potential' scenario (blue line), in which the penetration rate is only corrected by the expected market alternatives in each EU member state, full penetration of micro-CHP systems is reached in 2035 with a sales potential of 230 000 systems yearly, which is 38% of the total gas and oil boiler market in this sector.
In the 'expected potential' scenario (purple line) approximately 62 000 micro-CHP systems will be installed annually in 2030 (10% of SME & collective boiler market). However the market is still growing. Reason for this is
For the 'low expectations' scenario (orange line), in which the penetration rate of the 'expected potential' is downgraded by minimizing the points on the weighting factors 'market alternatives' and 'economic analysis'. In 2030 almost 26 000 micro-CHP systems will be sold annually in the SME & collective sector following this scenario (4% of residential boiler market).

4.3.2 Potential micro-CHP stock development in the SME & collective sector

The potential stock development of micro-CHP systems is shown in Figure 10. The stock in 2020 is still relatively small with 10 000 systems installed in the SME & collective sector in the 'expected potential' scenario. The micro-CHP market in the SME & collective sector is still not 'saturated by 2030. In the 'low expectations scenario' approximately 500 000 micro-CHP systems are installed in the SME & collective sector in 2040. For the 'expected potential' scenario 900 000 micro-CHP systems will be installed and 2.3 million micro-CHP systems in the 'maximum potential' scenario in the SME & collective sector by 2040.

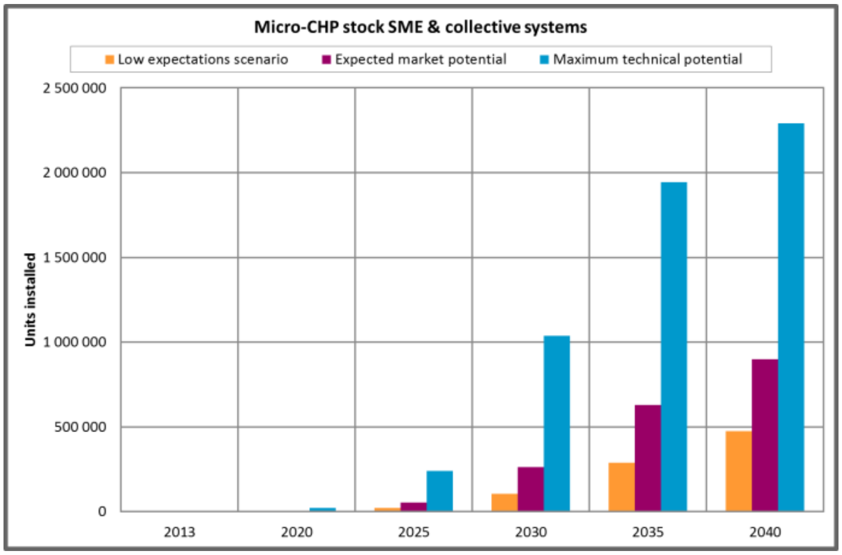

Figure 10: Potential micro-CHP stock development in the SME & collective sector in the EU-27 member states for three scenarios

4.3.3 Potential energy savings and GHG emission reduction

Following the 'expected potential' scenario micro-CHP systems have the potential to save approximately 240 [PJ] primary energy annually if gas boilers and central electricity production are taken as reference in the SME & collective sector. This is approximately 0.5% of the total energy used in the EU-27 in 2010. Greenhouse gasses can be reduced by 14 [Mton of $CO_{2,eq}$/year] by using micro-CHP systems instead of gas boilers. This is equivalent to 0.3% of the total EU-27 GHG emissions in 2010.

4.4 Summarized results of the micro-CHP potential for the EU-27

In the table below the results of the micro-CHP potential analysis are summarized for the residential and SME & collective sector.

Residential systems (±1 kWe) ***Boiler replacement technology***	***SME & Collective systems (±40 kWe)*** ***Boiler add-on technology***
Present market (2013) Boiler stock: 101 300 000 units Boiler sales: 8 100 000 units/year	**Present market (2013)** Boiler stock: 8 200 000 units Boiler sales: 599 000 units/year
Micro-CHP potential (expected potential scenario)	***Micro-CHP potential (expected potential scenario)***
Yearly sales	***Yearly sales***
Sales in 2020: 52 000 units/year **Sales in 2030: 2 900 000 units/year**	Sales in 2020: 2 700 units/year **Sales in 2030: 68 000 units/year**
Stock	***Stock***
Stock in 2020: 103 000 units **Stock in 2030: 14 400 000 units** Stock in 2040: 30 500 000 units	Stock in 2020: 18 000 units **Stock in 2030: 290 000 units** Stock in 2040: 950 000 units
Potential savings in 2030	***Potential savings in 2030***
Primary energy savings: 300 PJ/year 7 100 ktoe/year (0,6% of EU-27 PEC[2] (2010)) **GHG-emissions reduction:** 13 Mton $CO_{2,eq}$/year (0,3% of EU-27 GHG emission (2010)	**Primary energy savings:** 240 PJ/year 5 800 ktoe/year (0,5% of EU-27 PEC) **GHG-emissions reduction:** 14 Mton $CO_{2,eq}$/year (0,3% of EU-27 (2010)

Table 5: Summarized results of the micro-CHP potential analysis for the EU.

[2] PEC; Primary Energy Consumption

4.4.1 Summarized results of the potential analysis per member state

EU-27		Sales in 2030				Stock in 2030		
		'000 units/year				'000 units		
Member state		Residential	SME & collective	Total		Residential	SME & collective	Total
Austria		27	0	27		139	2	141
Belgium		89	4	93		488	18	506
Bulgaria		0	0	0		1	0	1
Cyprus		0	0	0		0	0	0
Czech Republic		26	0	26		103	1	104
Denmark		6	0	6		29	0	29
Estonia		0	0	0		0	0	0
Finland		0	0	0		1	0	1
France		289	2	291		1 323	8	1 331
Germany		215	16	231		1 076	71	1 147
Greece		10	3	13		44	13	57
Hungary		22	0	22		88	1	89
Ireland		35	0	35		156	3	159
Italy		742	9	751		3 739	45	3 784
Latvia		0	0	0		0	0	0
Lithuania		0	0	0		3	0	3
Luxembourg		1	0	1		6	0	6
Malta		0	0	0		0	0	0
Netherlands		303	0	303		1 843	3	1 846
Poland		27	0	27		101	0	101
Portugal		22	2	24		106	11	117
Romania		18	0	18		67	1	68
Slovakia		9	0	9		38	2	40
Slovenia		1	0	1		3	0	3
Spain		276	16	292		1 325	69	1 394
Sweden		0	0	0		0	0	0
United Kingdom		763	7	770		3 717	37	3 754

Total EU-27		**2 881**	**59**	**2 940**		**14 396**	**285**	**14 681**

Table 6: Sales and stock of micro-CHP systems in the EU-27 member states in 2030 according to the expected potential scenario.

4.5 Comparison to other micro-CHP potential studies

Following the scenarios presented in this study, 2020 micro-CHP sales will still be limited with approximately 160 000 units sold per year. But from 2030 onwards, micro-CHP can really take-off and an annual multi-million euro sales market for micro-CHP systems can be expected by 2030. But is this in line with other potential studies?

In 2011 Delta Energy & Environment, an indepent research and consulting company, statet that the European micro & mini CHP market could reach over 600 000 systems per year.[3] Micro-CHP is defined as systems between 0-5 [kW_e] and mini-CHP as systems between 5-100 [kW_e]. The range is different as taken in this potential analysis in which micro-CHP is defined as systems below 50 [kW_e]. However, the main part of these 600 000 systems are expected to be sold in the micro-CHP range (0-5 [kW_e]).

Frost & Sullivan reported that over 5 million conventional boilers sold annually can be replaced with micro-CHP units. However, they are also warning about developments that are threatening this prospect of the European micro-CHP market. A mixed policy outlook, fickle government support and the lack of initiatives educating consumers about the benefits of the technology are seen as threats. In their opinion favorable government policies, financial backing and aggressive promotion will be necessary to kick-start the market.[4]

The potentials presented by Delta Energy & Environment and Frost & Sullivan show that the potentials presented in this study are not on their own.

[3] Delta market projection: European combined Mini & Micro CHP annual sales can reach 600,000 by 2020; Delta Energy & Environment; 22 March 2011.

[4] European Micro-CHP Market will Perish without Strong Government Support; Frost & Sullivan; 5 March 2013.

5 Micro-CHP roadmap: getting out of the niche

Following the expected potential scenario, 3 million units can be installed per year by 2030. This means a micro-CHP stock of more than 30 million micro-CHP systems installed in Europe by 2040. These systems will result in enormous energy savings. However, to be able to reach this scenario the technology needs to be scaled up from a niche product to a mass market product. The challenge is to survive the period where micro-CHP as a starting technologies has to compete with incumbent technologies that already passed their learning curve and have reached an acceptable mass-market price, the so-called 'valley of death'. This brings a big challenge for companies that are considering new investments to expand the use of micro-CHP. Therefore micro-CHP faces two paths; one in which it remains a niche high priced product and one in which it becomes the de facto standard in existing buildings.

Figure 11: The two paths micro-CHP is facing.

The European Union is setting strong targets for increasing energy efficiency and sustainable energy and decreasing greenhouse gasses. A part of this ambition has to be realized in the built environment and implementing micro-CHP is a possible way that contributes to the targets of increasing energy efficiency and decreasing greenhouse gasses.

Micro-CHP has to compete with other emerging technologies, like solar heating and (hybrid) heat pumps. These systems are gaining more ground in the EU but face the same challenge as micro-CHP. Assuming a sharp decline in cost price, the outlook for micro-CHP is quite positive since it can be implemented easily in the existing heating infrastructure.

Programmes and incentives on residential micro-CHP

In Europe, but also in Japan, activities are on-going to stimulate the micro-CHP market. They are presented below.

Ene-Farm scheme (Japan)

The aim of the Ene-Farm scheme has been to make fuel cell micro-CHP systems cost-competitive. After four years of demonstration and customer trials the scheme became commercial and the Japanese government made a subsidy available of ¥1.4 million (€10,700) per unit to contribute to the purchase price in 2009. Since it should become cost-competitive the government has reduced its financial contribution (per unit) in each successive year with an aim to remove it by 2015.[5]

Callux (Germany)

The Callux programme is a field test programme for residential fuel cells in Germany. It was launched by the German Ministry of Transport, Construction and Urban Development together with nine industrial partners in 2008. Goals of the project are among others to demonstrate technical maturity, developing

[5] http://www.fuelcelltoday.com/analysis/analyst-views/2013/13-02-27-latest-developments-in-the-ene-farm-scheme

supply chains, enhance product profile and validate market requirements. In the programme up to 560 fuel cell heating appliances are to be installed by the end of 2013.[6]

Ene.field (Europe)
The ene.field project is a demonstration programme which is launched in 2012. The project is scheduled to run for five years and will deploy and monitor approximately 1,000 new installations of residential fuel cell CHP across 12 key European Union Member States. By learning the practical implications of installing, operating and supporting a fleet of fuel cells with real world customers, ene.field will demonstrate the environmental and economic imperative of micro FC-CHP, and lay the foundations for market exploitation.[7]

The German Cogeneration Act (KWK-G) and investment subsidy programmes
In Germany (micro-)CHP systems are well supported now-a-days. As part of the German Cogeneration Act (KWK-G) micro-CHP systems (up to 50 kW_e) will get a CHP-premium of 5,41 €cent/kWh_e produced for 10 years or 30 000 operational hours. Besides the CHP-premium, an additional investment subsidy is available for micro-CHP which can add up to € 20 000 per kW_e installed dependent on used micro-CHP technology and incentives offered by federal and state governments.[8]

5.1 The next step – a commercialisation program?

To reach the potential millions market different kind of elements have to be aligned, and technical and economic performances of micro-CHP systems still has to be improved in the next coming years.
Success in upscaling requires proper incentives:

Manufacturers state that cost-price reductions are strongly coupled to the number of installations produced and implicitly states that with strong political will an economic cost-competitive product can be achieved. However, without proper incentives the technology doesn't have the chance to show these expected cost-price reductions.

The programmes in Europe, like Callux and ene.field, show that there is activity in the market, but are these activities ambitious enough? Comparing the steps taken by the government of Japan to those in Europe, activities in Europe are modest and this raises the question if and what we can learn from the Japanese experiences. Japan shows that some micro-CHP technologies are ready for market entry. Can Europe make a quick leapfrog to a commercialisation program in which manufacturers can show the proposed cost price reductions?

Europe is supporting technologies into commercialisation in order to assist the EU in achieving its energy and climate target. The incentives in the European Union or in individual member states should be narrowly targeted to bring the product set to volume production and market competitiveness and to some extent to showcase the possibilities of the technology to end-users and other stakeholders.

5.1.1 Expected cost price development

In the study, it is assumed that a cost-competitive price would be around €3,000/kW_e for a household system. However at this moment (2013) the technology is still too expensive for mass market introduction,

[6] www.callux.net
[7] http://enefield.eu/
[8] Incentives for fuel cell technology in a "booming" German market, Nymoen Strategieberatung, 2012, presented at the Fuel Cell Expertise Network Conference in Amsterdam on 27 November 2012.

approximately €10,000/kW$_e$ for Stirling/combustion engines and €20,000/kW$_e$ for fuel cells. It is expected that for every doubling of production, fuel cell micro-CHP prices will go down with approximately 15% (learning rate).[9] But is it realistic to get a cost price of €3,000/kW$_e$, knowing the expected sales from this potential analysis, and if so, how long will it take to get an acceptable cost price?

To answer these questions, a market analysis has been performed by analysing the 'expected market potential' assessed in this study. For the European micro-CHP market, it is expected that approximately 10 manufacturers will be present in the long term. The expected sales in the European Union have been divided evenly over these manufacturers, so every manufacturer should produce approximately 300,000 systems per year by 2030. Each manufacturers will have produced around 1.5 million systems in total in the period till 2030 as can be seen in the figure below.

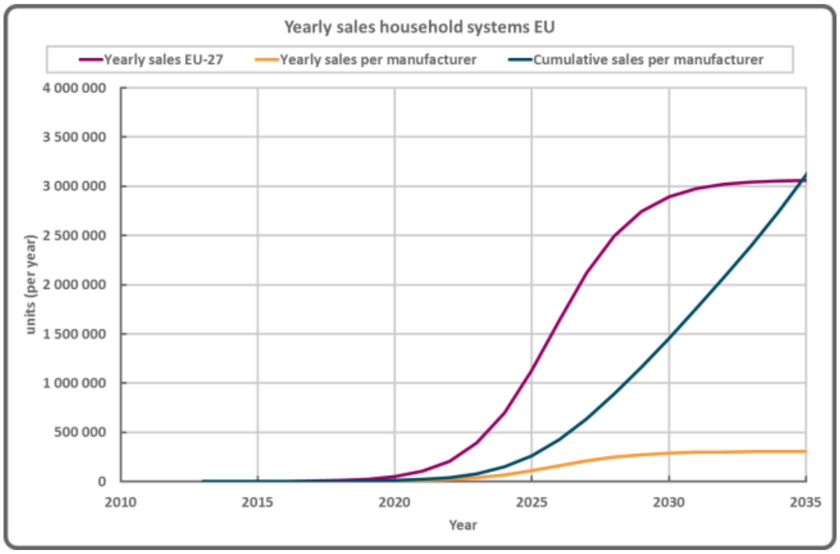

Figure 12: EU-27 sales of micro-CHP systems in the household sector.

The cumulative sales are then translated into a cost price development curve starting at €25,000,- per kW$_e$ in 2013 (sales approximately 50 per manufacturer) with a cost price reduction of 15% for each doubling of production (or doubling of cumulative sale). The results are shown in the figure below.

[9] From various studies; a.o. "The cost of domestic fuel cell micro-CHP systems", I. Staffell & R. Green, Imperial College London, july 2012; "Learning curves for solid oxide fuel cells", R. Rivera-Tinoco, K. Schoots & B.C.C. van der Zwaan, Energy research Centre of the Netherlands, 2010.

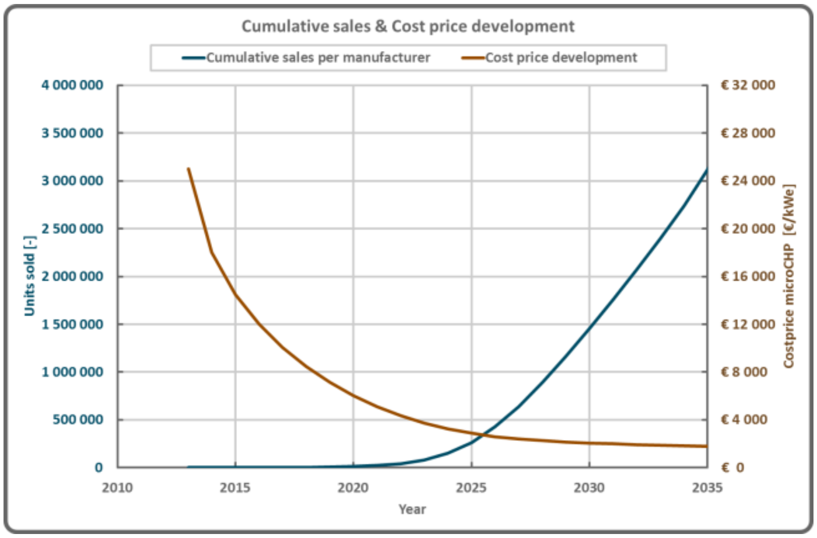

Figure 13: Cumulative sales per manufacturer versus cost price development at 15% learning rate and €25,000 per kW_e at low volumes (10s units per year).

From the graph ,it can be seen that following our micro-CHP potential and market analysis a cost price of €10,000,- can be expected in 2017 at low volumes (a couple of thousands produced per manufacturer). A price level of around €3,000,- per kW_e (retail price €4,000 per kW_e) can be expected in 2025 at relative low volumes (150,000 units produced per manufacturer).

5.1.2 The price of a supportive commercialisation program

To reach this cost price, an EU wide coordinated commercialisation program should be set up. In the commercialisation program a long-term investment subsidy is needed so that the difference between the 'actual' cost price and the cost competitive cost price per technology group is covered. Following the assumptions made in this study, a commercial program is needed till 2025 starting in 2013/2014. In figure 13 it is shown how much units will be sold annually and how much subsidy is needed.

From these figures it can be seen that in the beginning, till approximately 2017, a large subsidy per kW_e is needed. However in these years sales volumes are relatively low, thereby limiting the total necessary subsidy. At the end of this 'commercial starting' phase, cost price should dropped to € 10,000 per kW_e for fuel cells. In the next 'pre-commercial' phase sales volumes start to grow substantially and total necessary subsidy also increases to a maximum of 300 M€ in 2023. In 2023 cost price should have dropped to approximately € 4,000 per kW_e. In the next 'early commercial' phase only a limited subsidy per kW_e is needed and in 2025 the cost price target of € 3,000 per kW_e should have been reached, making micro-CHP a cost-competitive product compared to 'conventional' boilers.

This program can be split up in phases to keep track of the achieved cost price reductions and to decide the necessity and layout of a follow up program.

Figure 14: The costs of a commercial program to support micro-CHP cost price reduction.

With the proposed commercial program, a cost-competitive cost price of €3,000 per kW_e (retail price €4,000 per kW_e) of micro-CHP systems for households could be reached in 2025. At the end of this period around 1,7 million systems will have been sold, thereby making the average subsidy € 700 per unit. The commercial program as a whole would cost approximately 1,200 M€ in total, leading to annual primary energy savings of approximately 240 PJ and annual CO2 reduction of 14 Mton around 2030.

Appendix A Approach of estimating the micro-CHP potential

This appendix goes into more detail on the estimation of the micro-CHP potential.

A.1 Scenario's; Maximum For every aspects a country gets a number of points, these points are defined and divided as follows:

Weighting aspects	**Maximum points**		**Weighting factors**	**Points**
	Household sector	**SME & Collective sector**		
Market alternatives	3	3	No competition Few competition Some competition A lot of competition	3 2 1 0
Economic analysis	4	4	SPOT: < 4 year SPOT: 4 – 7 years SPOT: 7 – 10 years SPOT: 10 - 13 years SPOT: > 13 years	4 3 2 1 0
Legislative environment	3	3	High support Medium support Low support No support	3 2 1 0
Awareness	2	2	High Medium Low	2 1 0
Purchasing power	3		GDP: > 30k€/yr GDP: 25 – 30 k€/yr GDP: 15 – 25 k€/yr GDP: < 15 k€/yr	3 2 1 0
Total points	**12**	**9**		

Table 7: Score card used to estimate country specific penetration rate.

A.2 Boiler market 2030

Extensive boiler market data is available for most EU countries for 1990 and 2004. The first step is to adapt the available boiler market data to data which is representable for 2013. This is done in the following order:

- For 1990 and 2004 the market penetration rates of boilers (in all sectors) are derived by dividing the number of installed boilers (stock) by the number of households in 1990 and 2004 respectively.

- The market penetration rate of boilers for 2013 is then assumed to be linearly extrapolated from the 1990 and 2004 rates.
- The number of installed boilers in 2013 (stock) is the projected market penetration rate for 2013 multiplied by the number of households in 2013.
- The yearly sales of boilers in 2013 is assessed by dividing the stock with the ratio of "stock"/"yearly sales" for 2004.
- The market share of each sector of 2004 is assumed to be the same for 2013.
- The 2013 boiler market is taken for as input for 2030 projections.

A.2.1 Countries without boiler market data

For the countries without boiler market data an estimation is made of the boiler market in another way. Since the household systems are the majority (in absolute numbers) of the boilers systems the share of central heating in households is taken as the basis. This data is available for all EU countries[10].

- For the countries for which market data is available the average penetration rate of boilers in households with central heating is derived.
- For the countries without market data this average penetration rate is taken and multiplied by the number of households with central heating in that country.
- The yearly boiler sales are obtained my dividing the number of boilers by the average EU replacement period of boilers.
- To make the differentiation between individual and collective boiler market, the average market share per boiler type for the EU countries with boiler data is taken as reference.

In these ways an expected boiler market for each member state in 2013 is derived.

A.3 Primary energy savings and GHG emission reductions

A.3.1 Primary energy savings

The primary energy savings are calculated by taking into account the extra gas input that is needed, in comparison to a condensing boiler, with a micro-CHP for delivering the same heat. The electricity production of the micro-CHP is compared to central electricity production with an efficiency of 44%.

PES = gas input micro-CHP – gas input condensing boiler – electricity generation micro-CHP/44%.

A.3.2 GHG emission reductions

GHG emission reductions are calculated by taking into account that a by burning a cubic meter of natural gas 1,78kg of CO_2 is produced. The produced electricity of the micro-CHP is multiplied by the GHG emissions of the present national electricity mix.

[10] Housing statistics in the European Union 2010, K. Dol & M. Haffner , Ministry of the Interior and Kingdom Relations, September 2010, The Hague.

A.4 Data used

To this end, the following information sources have been used to arrive at country specific potentials:

1. Boiler market data 1990 and 2004 (based on EHI data)
    a. The available data is split up by sector:
        1. Household sector (gas and oil) (<35kWth)
        2. SME & collective sector (gas and oil) (30-500kWth)
2. EU member state statistics (based on Eurostat), among others
    a. Number of households
    b. Number of household with central heating
    c. Energy prices
    d. GDP
3. MS regulatory framework
4. Primes
5. CODE I - results
6. Cost price development assessments for micro-CHP
7. Technological development assessments for micro-CHP

Appendix B Implementation of approach

B.1 S-curve diffusion

The maximum market share in an EU-member state depends on the score for the aspect market alternatives and is as follows:

Weighting aspects	**Points & maximum market share**		**Weighting factors**
	Household sector	**SME & Collective sector**	
Market alternatives	3 – 90% 2 – 77% 1 – 63% 0 – 50%	3 – 50% 2 – 43% 1 – 35% 0 – 28%	No competition Few competition Some competition A lot of competition

This market share will be reached if a maximum number of points is gained at the other score card aspects. Less points will result in a lower expected potential.

For the household sector, a maximum boiler market share of 90% is defined in 2030, since it can theoretically replace almost all existing boilers. For the SME & collective sector a maximum boiler market share of 50% in 2030 (in boiler sales) is chosen, due to the diversity of users in terms of heating and cooling demand there are more technological alternatives in this sector.

B.2 Assessment of score card

B.2.1 Market alternatives (such as bioenergy, heat pumps, district heating, solar)

If in market alternatives exist that are in competition with micro-CHP, it can be expected that micro-CHP will not develop as much as in member states with little or no competition. Points are assessed based on data from among others Primes and Heat roadmap Europe.

B.2.2 Cost Benefit Analysis (CBA)

The cost benefit analysis is performed under the assumption that micro-CHP has reached an acceptable (mass market) price. The CBA will be expressed in terms of Simple Pay-out time.

Cost price development

Many micro-CHP technologies are still in their early phases of market entry (Stirling engines, small gas engines, fuel cells). Through learning and upscaling, cost reductions can be achieved. We expect a learning rate of 15%, based on different sources[11]. This learning rate implies that for every doubling of production the cost price will reduce with 15%. Thus, for a multi-million mass market application the costs will be brought down significantly for these new technologies.

[11] In a study on the costs development of fuel cells a price development have been seen of 16% per doubling of capacity in recent years (The cost of domestic fuel cell micro-CHP systems, I. Staffell & R. Green, july 2012, Imperial College London).

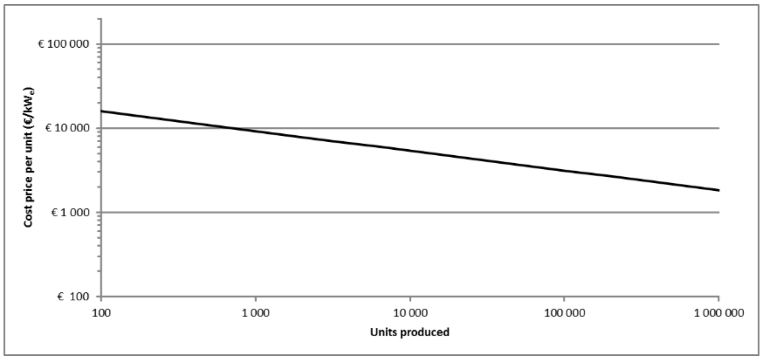

Figure 17: Cost price development of micro-CHP units at a learning rate of 15% and a starting cost price of €15,000 per kW_e at 100 units produced per year.

From an end-user point of view, we consider a cost price of € 3,000 a $1kW_e$ or a retail price of around € 4,000 a $1kW_e$ to be cost competitive. With such a price, the system can be paid back in approximately 10 years. It must be noted that this is a cost price pure from the direct benefits to the end-user. It doesn't take additional benefits into account that can arise, for example increase in the value of the building, abated grid costs etc. etc.

In our analysis, we expect that cost price of € 3,000 a $1kW_e$ micro-CHP could be achieved in 2030. This can be reached by scaling up from 100 units per manufacturer at €15,000 per kW_e to 100,000 units per manufacturer using a learning rate of 15%. This potential cost price of €3,000 per kW_e is seen as minimum in Staffel and Green study[12].
The table below shows the individual components of fuel cell CHP system and their cost price at 100.000 units. From these figures it is expected that micro-CHP systems for collective and SME usage can reach price levels of around 1,800 €/kW_e.

		Potential minimum		
		$1kW_e$ FC	$1kW_e$ FC	$40kW_e$ FC
Fuel cell stack	per kW_e	$ 200	€ 160	€ 160
Major sub-systems	per kW_e	$ 600	€ 470	€ 470
Balance of plant	per kW_e	$ 1 500	€ 1 170	€ 1 170
Auxiliary boiler	per kW_e	$ 1 000	€ 780	€ -
Hot water tank	per kW_e	$ 500	€ 390	€ -
Total cost price	**per kW_e**	**$ 3 800**	**€ 2 970**	**€ 1 800**
Selling price	**per kW_e**		**€ 4 000**	**€ 2 500**

Table 8: Potential minimum costs for manufacturing each component of a fuel cell micro-CHP system at high volumes.[13]

On top of the cost price, the manufacturer needs a profit as do the retailers. Therefore we use 4,000 €/kW_e and 2,500 €/kW_e as ultimate selling price for a household system respectively SME & collective system for the cost benefit analysis in this study later on.

[12] In a study on the costs development of fuel cells a price development have been seen of 16% per doubling of capacity in recent years (The cost of domestic fuel cell micro-CHP systems, I. Staffell & R. Green, july 2012, Imperial College London).
[13] The costs estimation for a 1kWe fuel cell is adopted from "The cost of domestic fuel cell micro-CHP systems" (I. Staffell & R. Green, july 2012, Imperial College London). It is converted to euro's at a rate of $1 = €0,77. The estimation of the 40kWe system is based on the assumption that an auxiliary boiler and hot water tank are not necessary in that situation, since it will be a "add-on" on the existing heating infrastructure.

Technological development

In Figure 18 the results are shown of a technical assessment of the existing microCHP technologies (0,5 – 5kW$_e$). In this figure, the electrical and thermal efficiencies are plotted against each other. Stirling engines produce little electricity and lots of heat, while SOFC fuel cells produce mainly electricity. From these figures we expect an average electrical efficiency of micro-CHPs of 40% and an overall efficiency of 90% (LHV) (yellow star in figure).

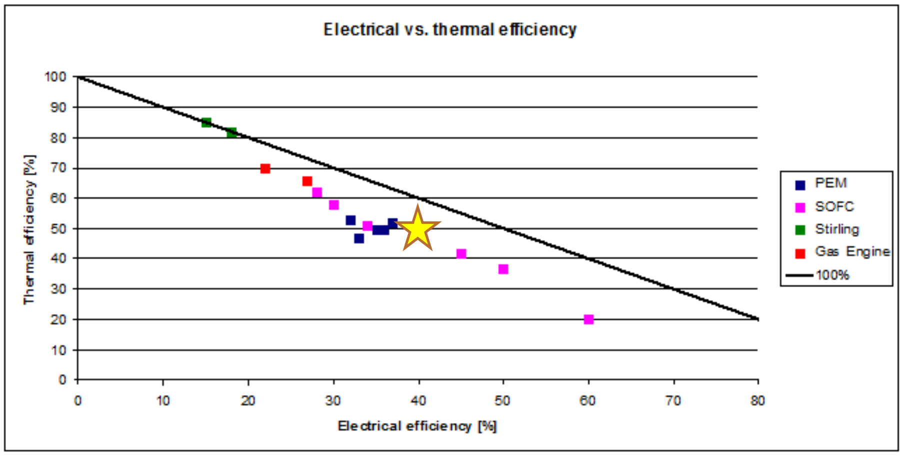

Figure 18: Electrical & thermal efficiencies of (existing) micro-CHP technologies.

Further assumptions CBA

- Continuous operation (6000 hours/year)
  - 100% use of produced electricity
  - 90% use of produced heat
    - Heat for room heating and hot water preparation.
- Thermal output microCHP replaces thermal output boiler.
- Gas & Electricity prices households and industrial consumers.[14]
  - For household sector; household price data is used.[15]
  - For SME & collective sector; industrial price data is used.[16]
- Purchase price micro-CHP:
  - For household sector; € 4,000/kW$_e$.
  - For SME & Collective sector; € 2,500/kW$_e$.
- Maintenance costs:
  - For household sector: €0,03 / kWh produced electricity.
  - For SME & collective sector: €0,01 / kWh produced electricity.
- Costs savings = Costs for gas input boiler + Saved electricity costs CHP – Costs for gas input CHP – Maintenance Costs CHP
- SPOT = Additional investment costs / Cost savings

[14] Source: Eurostat energy prices May 2012. No natural gas price data available for Greece, Finland, Cyprus and Malta.
[15] Household energy consumption profile: 15,000 kWh/year natural gas and 3,500 kWh/year electricity.
[16] SME energy consumption profile: 0.25 GWh/year natural gas and 2 GWh/year electricity.

B.2.3 Legislative environment & support schemes
For assessing points to the aspect of legislative environment & support schemes the results of the CODE-project are used.[17] Though these schemes are only valid at this moment and can be changed, in both a positive and negative way, in a short period it gives an indication of the current regulative position of micro-CHP in a country.

B.2.4 Awareness
Awareness in a country is used as an indicator to show to what level stakeholders/influencers in a country know what the technological, financial and/or market consequences are of micro-CHP. Awareness scores are based on results from the awareness study carried out in CODE2.

B.2.5 Purchasing power (only for the household sector)
At the end the customer will have to invest in a more expensive product then a 'conventional' boiler. However the ability to do so is not the same in each country. For this we use the GDP to indicate the purchasing power of the customers.

B.2.6 Score card result
Each MS gains a total number of points through the score card assessment. The more points a MS gets, the more share micro-CHP will get in the boiler market in 2030.

B.3 2030 boiler market expectation
The performed market data adaption results in the expectation of the 2013 boiler market are shown in Table 9. Total sales outlook for 2013 is 9.2 million boilers per year and this is taken as potential market for micro-CHP in the EU-27 MS up to 2030. This number is close to a reported sales outlook of 8.9 million boilers per year in the European Union in 2025.[18]

[17] http://www.code-project.eu/wp-content/uploads/2011/02/231210-European-Summary-Report-on-CHP-support-schemes.pdf

[18] Eco-design of boilers; Market Analysis, VHK, September 2007, Delft.

Boiler market EU-27 (household & SME & collective sector)				
	2004[19]		2030	
	Stock	Sales	Stock	Sales
	000 units	000 units/year	000 units	000 units/year
Total EU-27	**91 740**	**6 991**	**115 457**	**9 199**
Member state				
Austria	1 134	84	1 377	102
Belgium	2 236	175	2 707	212
Bulgaria			169	13
Cyprus			40	3
Czech Republic	1 158	148	1 896	242
Denmark	690	34	688	34
Estonia	40	5	58	7
Finland	501	19	571	22
France	13 354	834	17 517	1 094
Germany	17 542	810	14 586	674
Greece	1 709	80	2 056	96
Hungary	1 266	111	1 747	153
Ireland	967	113	1 386	162
Italy	15 166	1360	21 428	1 922
Latvia	34	13	51	20
Lithuania	89	22	167	41
Luxembourg			71	5
Malta			1	0
Netherlands	5 048	420	5 614	467
Poland	1 343	237	2 051	362
Portugal	223	50	388	87
Romania			1 884	144
Slovakia	401	60	578	86
Slovenia	284	27	372	35
Spain	5 720	546	9 876	943
Sweden	1 443	81	1 830	103
United Kingdom	21 392	1762	26 348	2 170

Table 9: Expectations of the 2013 boiler market, used as input for the potential market in 2030.[20]

[19] Sources: http://www.ecoboiler.org/public/ecoboiler_task2_final.pdf and http://susproc.jrc.ec.europa.eu/heating/docs/ProductDefinition-Market-TechAnalysis.pdf.

[20] For Bulgaria, Cyprus, Luxembourg, Malta and Romania no historical market data is available. Cyprus, Luxembourg and Malta are as expected only small potential markets. Romania and Bulgaria show potential interesting markets for micro-CHP. For Romania the number of sales are in line by a reported sales of 135,000 units in 2011, also since growth is expected in this country. For Bulgaria the number of sales are perhaps still a little low, since the Bulgarian Government has the aim to increase the share of gas connected households to 30% in 2020, in contrast, it was 1,5% in 2011. This gasification project is carried out to replace electrical heating by natural gas heating. 30% gas connected households would mean that approximately 1 million households will be connected to gas.