CODE2

Cogeneration Observatory and Dissemination Europe

D5.1 - Final Cogeneration Roadmap

Member State: **Denmark**

October 2014

Leading CODE 2 Partner: KWK kommt U.G.

Denmark is part of the non-pilot Member States of the Northern Europe CODE2 Region.

The CODE2 Region 'Northern Europe' comprises the following Member States: Austria, Denmark, Finland, Germany, Sweden

Co-funded by the Intelligent Energy Europe Programme of the European Union

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Introduction and Summary

The CODE2 project[1]

This roadmap 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. These roadmaps are built on the experience of the previous CODE project (www.code-project.eu) and in close interaction with the policy-makers, industry and civil society through research and workshops.

The project aims to provide a better understanding of key markets, policy interactions around cogeneration and acceleration of cogeneration penetration into industry. By adding a bio-energy CHP and micro-CHP analysis to the Member State projections for cogeneration to 2020, the project consortium is proposing a concrete route to realise Europe's cogeneration potential.

Draft roadmap methodology

This roadmap has been written by CODE2 partner KWK kommt U.G. based on a range of studies and consultations. It has been developed through a process of discussion and exchanges with experts over the period from 2013 to mid-2014. The national policy framework around CHP continues to evolve in Denmark and at the time of publication of this roadmap (December 2014) some items are under discussion. This should be taken into account when using the material in the roadmap.[2]

Acknowledgement

KWK kommt U.G. and the CODE2 team would like to thank all experts involved for their contributions to develop this roadmap, which has been valuable regardless of whether critical or affirmative. It has to be stressed that the statements and proposals in this paper do not necessarily reflect those of the consulted experts.

Summary

With a share of CHP in total power production of about 50 % Denmark has the most developed CHP system in the EU. With changing the focus to the expansion of renewable energy, support for CHP has shifted to bioenergy which has been designated to take the role of coal while natural gas CHP is not promoted any more. There exist, however, still relevant potentials to switch from boiler firing to CHP in industry, housing, commercial companies and public institutes situated in areas without district heat supply.

In developing this CHP roadmap some barriers and measures to boost CHP in Denmark have been identified. Key proposal to the Danish Government is to take the implementation of the EU-Energy Efficiency Directive as an inducement to reinforce an active CHP expansion policy and to remove existing barriers. By implementing seven proposed measures it is estimated that the CHP electricity produced could be increased by 10 % up to 2030. Together with the fuel shifting from coal to bio energy anyway projected, CO_2 emissions are estimated to decrease between 3 and 4 million tonnes per year and primary energy, depending on the calculation method, could be reduced by 4 to 5 or 6 to 7 TWh/a.

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[1] For more details and other outcomes of the CODE2 project see: http://www.code2-project.eu/.

[2] Seven CHP experts from Denmark have been consulted in 2013 and 2014. A meeting with two experts took place in May 2013 at the University of Aalborg.

1. Where are we now? Background and situation of cogeneration in Denmark

1.1 Current status: Summary of currently installed cogeneration

Denmark has the most extensive co-generated heat and electricity system in the EU. About half of Danish electricity is co-generated with heat. Approximately 60% of heat consumers receive their heat from public district heat supply. In comparison CHP weight in industry, commercial and buildings outside district heat networks is rather low.

With the development of CHP and District heating in the 1980s and 1990s as a reaction to the first oil crisis, Denmark became less dependent on coal and oil supply. Based on intense CHP and other energy efficiency efforts and increasing access to north Sea oil and gas supplies, Denmark became energy self-sufficient in 1997. As a result Denmark today has the most extensive co-generated heat and electricity system in the EU, with a CHP share in total electricity production of about 50 %. This is mainly due to a very far developed district heating network, supplying approximately 60% of room heat consumers.

Table 1 shows the absolute CHP power production capacity and generation in Denmark since 2005 and its share in total power production. The share of autoproduced CHP electricity in industry , commercial and other buildings is relatively low compared to the CHP electricity produced in district heat production.

Table 1 CHP electricity development in Denmark[3]

	Installed CHP electrical capacity (GW)	Total CHP electricity gen. (TWh)	CHP electricity from autoproducers (TWh)	Total electricity generated (TWh)	Total CHP share on electricity	CHP Heat Production (TWh)
2005	5.7	18.9	2.9	36.3	52.1 %	30.5
2010	5.8	19.1	2.3	38.8	49.2 %	34.6

Danish local authorities are the central players in the public heat supply; they develop heating plans and have responsibility for expanding district heating and for implementing any changes due to amendments to the regulations in the Law on Heat Supply.

Typically, CHP facilities are either centralised or decentralised; the existing 16 centralised CHP plants are primarily electricity plants with much larger capacities than the 285 decentralised CHP.

[3] Sources: European Union (2013): „EU energy in Figures – Statistical Pocketbook 2013“; Energy statistics Denmark 2012. The electricity numbers are differing significantly from those presented in the 2nd progress report, which obviously include the condensing electricity from CHP extraction steam turbine plants. (see [7])

The district heating sector is owned and operated in various ways. There are co-operatives, joint-stock companies and local authority companies (often interest group companies and local authority supply bodies). In the district heating market, both production and network companies are monopolies and regulated as non-profit undertakings.

Prices from district heating plants are regulated in accordance with the "non-profit" principle. In contrast to enterprises operating under ordinary market conditions, where the market sets prices, district heating plants' prices may only reflect necessary production and administration costs. [4]

Table 2 shows that the share of CHP in thermal electricity production has increased since 2005 but the CHP share in district heat production has fallen.

Table 2 Development of CHP key parameters[5]

Denmark	2005	2010	2011	2012
Share of CHP total thermal electricity production	64 %	61 %	63 %	75 %
Share of CHP in total district heating production	82 %	77 %	77 %	73 %

Figure 1 shows the development of the different types of heat production plants. The share of heat only plants ("district heating units") has increased substantially in the last years whilst the heat from decentralised small scale CHP has decreased.

Figure 2 shows the heat supply allocated to fuels. The huge amount of coal is used in centralised CHP.

Figure 1 District heating production by type of plant, PJ/a

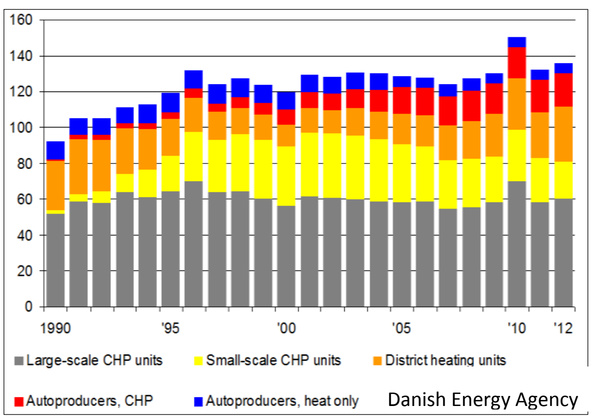
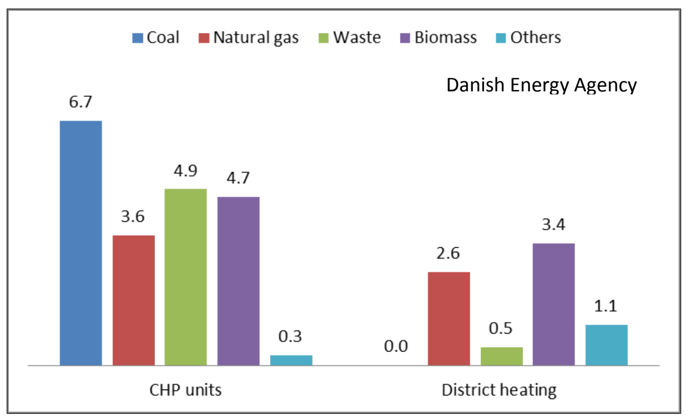


Figure 2 Heat supply by type of fuel, 2012, TWh



[4] Source: International Energy Agency (2012): Energy Policies of IEA Countries - Denmark 2011, p. 62f

[5] Energy Statistics Denmark 2012

1.2. Energy and Climate Strategy of Denmark

Based on an energy agreement in the Danish Parliament in 2012, Denmark has set the target to reach an energy supply system based on 100 % renewable energy up to 2030. CHP with bio energy has an important role to play. CHP in industries and greenhouses shall be promoted.

In March 2012 a new Energy Agreement was decided in Denmark, which has been carried by a large majority in the Danish Parliament (171 seats out of 179). The Agreement contains a wide range of ambitious initiatives, aiming to boost development towards the target of 100% renewable energy in the Danish energy and transport sectors by 2050.

By measures based on the 2012 Agreement large investments up to 2020 in energy efficiency and renewable energy development shall be strengthened. Target for 2020 include 50% of electricity consumption supplied by wind power, more than 35% of final energy consumption supplied from renewable energy sources and over all a 34% reduction in greenhouse gas emissions in relation to 1990.

Heating consumption in Denmark is to be gradually converted to renewable energy. The clear intention is converting from coal to biomass CHP at large-scale utility and heat plants shall be made more attractive. Financial support has been decided on to maintain and promote CHP in industries and greenhouses.

In May 2014 the Danish Energy Agency published an energy scenario report on the energy system of the future including transport and the challenges that need to be managed up to 2050 as fossil fuels are phased out and replaced with renewable energy.[6] In a cost comparison of 4 scenarios (wind, biomass, bio+, hydrogen) and a fossil scenario for comparison) the biomass scenario was found to be the most cost efficient up to 2050 under the assumptions made. This scenario is designed to an annual bioenergy consumption of around 450 PJ, thereof 200 TJ imports, covering 75 % of Denmarks total gross energy consumption in 2050.

1.3. Policy development

Support for CHP has a long tradition in Denmark. In the past it has been mainly focused on the development of district heating based on large centralised or smaller decentralised plants. Bioenergy CHP is supported by operating subsidies and by energy tax exemption. New installation on natural gas based CHP is no longer promoted and has to face a highly complex energy taxation system.

In its 2nd progress report according to the CHP directive submitted to the Commission 2011[7], the Danish Government has stated that in Denmark electricity produced together with heat is given priority grid access and that the production and expansion of cogeneration are given the financial support required to cover the necessary investment costs without unduly increasing the district heating costs borne by consumers. Operating support would also be provided for high-efficiency cogeneration:

- production-independent subsidies granted to electricity producers, financed as a PSO (Public Service Obligations) contribution through the electricity price charged to consumers;

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[6] Danish Energy Agency, Energy Scenarios for 2020, 2035 and 2050

[7] Second progress report DK to DG Energy, see http://ec.europa.eu/energy/efficiency/cogeneration/cogeneration_en.htm

- production-dependent subsidies (price supplements) granted to electricity producers, financed by the budget.

Additional operating subsidies for cogeneration are also granted on the basis of solid biomass and biogas and financed by electricity consumers. These subsidies are awarded as price supplements for biomass or as a fixed total price (market price + operating subsidy) for biogas.

In the case of biomass-based cogeneration, heat production is exempt from taxation. Subsidies are granted both for cogeneration geared towards the heat market and for industrial cogeneration.

Regarding natural gas CHP the extremely high taxation level and a highly complex taxation system for energy, which has developed over time, must be considered:

- Taxation rates on electricity and natural gas are approximately 11 cent/kWh and 4 cent/kWh respectively, which reflects the difference in primary energy values.
- Households, schools, institutions etc. and all kinds of space heating and domestic hot water production are subject to “full rate taxation”.
- Commercial and industry get varying levels of refunds. Natural gas use for process heat production is completely freed from energy tax.
- For CHP, two ways of taxation are possible:
  (1) Fuel tax refund according to an electrical efficiency of 67%, i.e. 10 kWh fuel tax is refunded per 6.7 kWh electricity produced;
  (2) Full refund on fuel, tax paid on heat production according to heat efficiency of 120%, i.e. 12kWh heat is taxed as 10kWh fuel.

In both cases, electricity used by the CHP operator is taxed according to the rules sketched above.

Additionally, CHP systems of less than 150 kW_{el} have the option of operating “unregistered”, i.e. pay full fuel tax and no electricity tax. In this case no tax refund is possible.

Fuel input of condensing power plants is not taxed. Only the electricity is taxed on the user site.

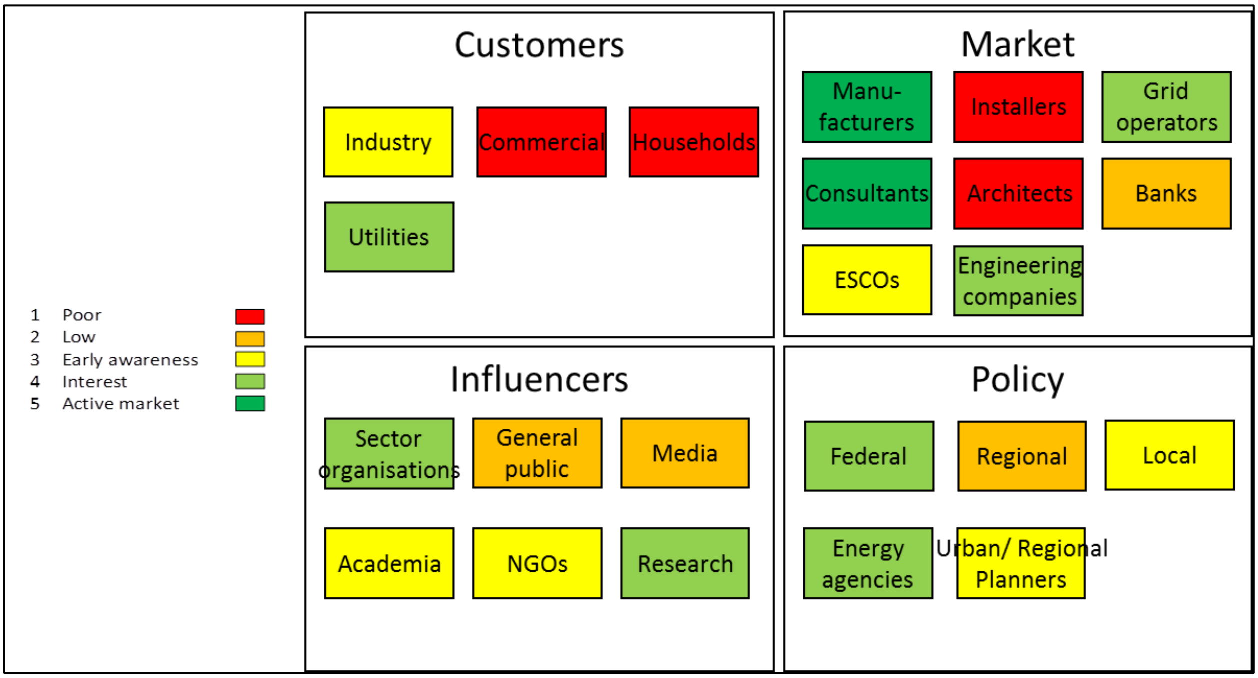
In 2012 a subvention for industrial CHP was introduced as a cost compensation for an increased NOx-tax. The objective is not to increase the level of installation of industrial CHP but to prevent decommissioning of the existing plants, most of which had been installed before 2000 and will need replacement or at least major overhaul before 2020.

1.4 Exchange of information and awareness

For utilities cogeneration is a common technology in Denmark. In the general public, compared to a high priority of environment and energy issues, knowledge and awareness on the role of CHP are rather low. Also in the industry knowledge on CHP is limited.

Table 3 gives an overview, based on interviews of experts concerning the awareness of CHP and its benefits in the main economic groups (more details see annex 1). Despite the high share of households supplied by district heat, which is mainly produced in cogeneration (> 70 %), general awareness on CHP is estimated to be low. It has been noted that for utilities cogeneration is a common technology, in the capacity range greater than 10 MWel and not regarding smaller CHP plants. In the industry knowledge of CHP and its application would be limited to process oriented industry.

Table 3 Ratings of the awareness of CHP in the different groups



1.5. The economics of CHP

CHP investments in both district heating and industry are currently not attractive in Denmark. For micro CHP good economic prospects exist in some applications, particularly in combination with heat pumps, but there is currently only a very small beginning market.

Table 3 gives a snap shot of the current 2014 economic situation of CHP in the main use areas.

Investments in cogeneration plants in district heating and industry have been considered to be unattractive for some years. The background to this poor economic analysis is low electricity prices, expectation of further decreasing Nord Pool exchange power prices and persistently low ETS carbon prices. Even in industry with its favorable steady heat use pattern attractive economic conditions for new CHP do not exist, though here the dependency of CHP profitability on power exchange prices is lower than in the district heating area, where produced CHP electricity is competing immediately against the low power exchange prices whereas autoproduced CHP power in industry competes against power sales prices including grid cost and business margins. In industry CHP profitability is additionally worsened due to the existing tax exemption for natural gas used for process heat production.

Also the economic situation of existing cogeneration has worsened with the effect that cogenerated district heat production has been reduced in the last years.

For micro CHP there is currently only a very small starting market in Denmark. It has been shown in a recent study[8] made by the Dansk Gasteknisk Center that with few exceptions micro CHP systems

[8] Dansk Gasteknisk Center a/s: Innovative mini-KV-installationsmuligheder I Danmark med kort tilbagebetalingstid, Projektrapport, Maj 2014.

installed in Denmark always operate as “unregistered” installations[9], as the operators would have to pay full taxes also if they register. That is the case e.g. in institutions, schools, sport centers, municipal / governmental buildings and hotels. Profitability of micro CHP is only due to the replacement of electricity from the public grid with its high price including grid cost.

In these micro CHP plants electricity production is always used 100% on-site. According to the study and confirmed by a Danish micro CHP manufacturer the associated economy is generally quite acceptable.

Table 3: Economic situation of CHP in major user groups

CHP Economics Matrix							
	Micro		**Small & Medium**		**Large**		
	up to 50kW		***up to 10 MW***		***more than 10 MW***		
	NG	**RES**	**NG**	**RES**	**NG**	**Coal**	**RES**
Industry	[grey]	[grey]	[red]	[red]	[red]	[red]	[red]
District heating	[grey]	[grey]	[red]	[yellow]	[red]	[yellow]	[yellow]
Services & Commercial	[green]	[grey]	[grey]	[grey]	[grey]	[grey]	[grey]
Households	[grey]	[grey]	[grey]	[grey]	[grey]	[grey]	[grey]

Legend:

[green]	**“normal”**	CHP Investment has **good economic benefits**, return on investment acceptable for the investors, **interest for new investment exists**; there are no significant economic barriers for the implementation.
[yellow]	**“modest”**	CHP Investment has **modest/limited economic benefits** and return on investment, **limited interest for new investments**.
[red]	**“poor”**	CHP Investment has **poor or negative return on investment or is not possible due to other limitations, no interest/possibilities for new investments**.
[grey]		**Not applicable** for the sector

[9] CHP systems of less than 150 kWel have the option of operating “unregistered”, i.e. pay full fuel tax and no electricity tax. In this case no tax refund is possible (see also chapter 1.3).

1.6. Barriers to CHP

Despite the active promotion of cogeneration in the past and its high presence in the DH sector some barriers to be removed have been identified. This is partly in contradiction to the Danish Governments opinion, that the overall regulatory framework presents no barriers to the expansion of cogeneration.

In its 2nd progress report according to the CHP directive the Danish government in 2011 has explained, that the overall regulatory framework presents no barriers to the expansion of cogeneration and that, on the contrary, the active promotion of cogeneration has been a matter of policy.

However in the discussions with Danish CHP experts the following barriers have been suggested:

Barrier 1: Decreasing electricity market prices impede investments in new larger natural gas fired CHP plants and even threaten the continued operation of existing gas CHP plants, and the energy savings that result.

Due to the fast rising share of fluctuating RES in the power exchange prices with their low marginal cost prices[10] in combination with the extremely low ETS carbon prices in recent years, the economic situation of existing and new natural gas fired CHP plants has become worse. These power market and fuel price developments have also added considerable uncertainty for investments in new cogeneration plants. Investments in new gas fired plants are considered to be more and more unattractive against the background of expectations of further decreasing average power exchange prices and persistently low ETS carbon prices – see chapter 1.5.

Low electricity prices are estimated by Danish experts to be mainly due to growth in wind energy in Germany and Denmark distorting the power exchange prices with their low marginal cost prices. Consequently, production from CHP plants has dropped. At the same time appropriate investment in “dispatchable” high efficiency power such as gas CHP is recognised as an important requirement for future grid stability.

Barrier 2: Uncertainty on economics of CHP investments because of capacity payments expiring 2017 is creating reluctance to invest

It has been stressed by Danish experts that without capacity payments being regulated by the Energy Agency depending on the power prices, investments in new medium and larger scale CHP are not economic. Pending a legal decision on future capacity payments after 2017 investors are adopting a “wait-and-see” position regarding new CHP investments.

Regarding Danish energy policy, there have also been complaints from CHP experts, that in the potentials of flexible natural gas CHP for balancing the power supply system regarding growing contributions of fluctuating renewable energies would not be taken into account enough and that generally the focus would be unbalanced on the fast extension of renewable energy while neglecting the options and benefits of natural gas CHP.

Barrier 3: Uncertainty on biomass availability and future fuel cost lead to a wait-and-see position regarding investments in new bioenergy CHP or conversion from coal CHP

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[10] At the Nord Pool power exchange the spot prices fell from a peak of 80 €/MWh in December 2010 to 26 €/MWh in June 2014. – see http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/ALL1/Hourly/

This uncertainty is connected to a current political discussion (2014) on bio energy sustainability and the criteria for differentiating between “good and bad” bio energy.

Barrier 4: The energy taxation system discriminates against natural gas CHP

As described in chapter 1.3., the electrical efficiency reference used for electricity taxation from CHP is very high; in reality no available technology can deliver fuel-to-electricity conversion at 67% efficiency[11]. This is devastating for the basic economics of CHP, as it means that an amount of fuel consumed by CHP brings much higher tax revenue than the same amount consumed by a condensing power plant – see the calculation example in the box. As a result CHP is significantly overtaxed.

Simplified example showing the fuel taxation disadvantage of CHP compared to power plants

1: Condensing power plant: electrical efficiency 40%; no useful heat production.

2: District heating CHP: electrical efficiency 40%; heat efficiency 50%.

Electricity production in both cases 1 MWh; fuel consumption in both cases 2.5MWh (=1/0.4)

Electricity taxation (at consumers) is the same in both cases.

Fuel taxation (Fuel tax on fossil fuel: 39 €/MWh fuel input):

1. Condensing power plant: **fuel tax paid = 0 €/MWh el**

2. CHP: fuel tax paid optionally according to one of the following formulas as described in chapter 1.3:

   a. “120%”: Taxed fuel = 1.25 MWh/1.2 = 1.04MWh → **fuel tax paid = 40.6 €/MWh el**

   b. “67”: Taxed fuel = 2.5MWh – (1MWh/0.67) = 1.01MWh el → **fuel tax paid = 39.3 €/MWh el**.

Effect: CHP electricity is burdened by the fuel taxation rules with about 40 € per MWh, because heat use is taxed and waste heat is not taxed.

Barrier 5: Tax exemption for natural gas used for process heat production reduces incentive for industrial CHP

As reported from CHP experts and also mentioned already in chapter 1.5. the economy of cogenerated process heat production is affected by the tax exemption for natural gas used in steam boilers for that purpose. Without this tax exemption switching to CHP would be more profitable.

2. What is possible? Cogeneration potential and market opportunities

Regarding the high share of CHP already reached in Denmark there are only limited additional potentials. But considering some new aspects accrued since the potential analysis reported to the EU commission in 2007 opportunities for further growing CHP electricity exist.

[11] For comparison: the standard EED reference value reflecting the “best available technology” is about 52,5%.

In its 1st report from 2007 according to the European CHP directive 2004[12] the Danish government presented a CHP potential analysis the results of which are summarised in Table 4 below:

Table 4 CHP potentials in Denmark according to the official Government analysis 2007

Cogeneration segment	Installed output [MWe]	Theoretical potential [MWe]	Economic potential [MWe]	Comments
Central district heating	Ca. 7600	Ca. 7600	Ca. 7000	The potential is dependent on the operating time and the electrical efficiency of the plants. From the economic point of view, there is currently over-capacity in electricity production in the Nordic countries. This may indicate that capacity should be reduced over time, whereas operating time should be increased.
Local district heating	Ca. 1600	Ca. 2400	Max 2400	In 2004 local cogeneration was produced in the proportion of 1½ units of heat per unit of electricity. In the long term it will be technically possible to improve the electrical efficiency to alter the ratio to approx. 1:1.
Industrial cogeneration	480	1750	<600	Structural changes in the sector may alter the picture in the longer term.
Micro-cogeneration	~ 0	2200	<100	Technological development may increase the economic potential in the long term as well as the theoretical potential (increased electrical efficiency)
District cooling	~ 0	TBD	TBD	Analytical work in progress. With regard to efficiency, there will ideally be a complete merging with cogeneration units producing district heating, so that only the exploitation of capacity is improved.

The report concluded that “at present it is judged that Danish potential for installing cogeneration output is largely being exploited. However, new technologies and a change to the rest of the energy system may alter the picture in respect of both theoretical and economic potential.”

In the 2nd progress report submitted to the Commission 2011[13] the Danish Energy Agency mandated by the Government explained that measures were not taken to increase the share of high-efficiency cogeneration, arguing that the socioeconomic potential of cogeneration was found to be limited.

However, referring to the remark in the conclusion of 2007, that “new technologies and a change to the rest of the energy system may alter the picture”, the following aspects should be considered according to the opinion of the roadmap author:

- The planned increase of wind power to 50 % share in total power production up to 2020[14] needs a further development of flexible backup capacities of fuel based power production. Contrary to the analysis made nine years ago for the 2007 report this means growing CHP electric capacities in all use areas. Regarding the aim of increasing overall energy efficiency the additional amounts

[12] Danish Energy Authority, Ministry of Transport and Energy: Report to the European Commission in connection with the implementation of the Cogeneration Directive 2004/8/EC, 2007

[13] DANISH ENERGY AGENCY: 2nd progress report Denmark to DG Energy, 2011.

[14] Danish Ministry of Climate, Energy and Building, The Danish Climate Policy Plan - Towards a low carbon society, 2012/2013

of wind power should not replace CHP electricity but the remaining production of condensing electricity, which covered still 26 % in 2011[15].

- Regarding Denmark´s political objective of reaching a 100 % share of RES in electricity and heat supply up to 2035, the Danish Energy Agency has carried out a study on possible pathways to this target[16]. The result was that from four scenarios designed to reach 100 % RES target the "biomass" scenario with a relative high share of bio energy was the pathway with the lowest total cost. In this study also the cost of electricity grid construction measures of the different scenarios have been taken into consideration.
- With a growing share of bio energy in heat production, either in district heating or decentralised with biomethane over the gas grid or by on-site conversion, new technologies of solid biomass and waste gasification offer the opportunity to replace the conventional steam turbine CHP plants with their relative low electric efficiency by high efficient CHP based on engines, gas turbines or combined cycle gas turbines (CCGT). Suitable systems are meanwhile nearing market launch or already entering the market, other technologies need further development efforts.
- The replacement of old low-efficiency coal fired CHP by modern technologies with biogas, biomethane and gasified solid bioenergy and waste could increase the electricity capacity and supply from CHP by an estimated 20% to 30 %.
- For micro CHP in the meantime systems are available in the markets which offer good economic results for the users and, combined with heat pumps, they additionally can contribute to a flexible smart electricity supply system – see chapter 1.5. and particularly footnote[8] .
- In industry additional CHP potentials, which have been already identified in the 2007 report, should be reconsidered. It is estimated that by a revision of the energy taxation system and possibly some financial incentives to switch from boiler fired process heat production to CHP about half of the estimated theoretical potential of 1,270 MW_{el} hence about 600 MW could be achieved.

Micro CHP[17]

In 2005 the Danish Energy Authority commissioned an analysis of the potential for micro cogeneration. The analysis was carried out by Dansk Gasteknisk Center (DGC). DGC analysed the potential for micro cogeneration units up to 15 kW_{el} in buildings outside the areas supplied with district heating. The result was a technical potential of 1,100 MW_{el} in areas supplied with natural gas (divided between 380,000 units) and a further 1100 MW_{el} in the open country, i.e. where there is no access to either district heating or natural gas (spread over approximately 280,000 units). With regards to economic limits the Energy Agency estimated the economic potential at less than 100 MW_{el}.

According to the CODE2 analysis, based on a "score card" analysis of key parameters, in 2030 there is estimated a market potential for residential 1 kW_{el} micro CHP of 5,000 installed units per year (29 % of

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[15] Danish Energy Agency : Energy Statistics 2012.

[16] Danish Energy Agency, Energy Scenarios for 2020, 2035 and 2050; May 2014.

[17] According to the EU CHP directive from 2004, Micro CHP means installations with an electric capacity of up to 50 kW.

relevant boiler market) and 50 installations per year up to 40 kW_{el} at commercial users (9 % of relevant boiler market). For more details see annex 2.

Bio energy

A bio CHP potential analysis carried out in the CODE2 project[18], which is based on a favorable framework assessment ("score card analysis"), shows that CHP and DH heat production from bio fuels is estimated to grow by 83 % from 2009 to 2030. The bio-energy penetration rate is estimated to increase from 16 to 28 %. For more details see annex 3.

3. How do we arrive there? : The Roadmap

3.1. Overcoming existing barriers and creating a framework for action

Key proposal is to take the implementation of the EU-Energy Efficiency Directive as an opportunity to reinforce an active CHP expansion policy and to remove existing barriers.

3.1.1. The European Energy Efficiency Directive 2012 EED should be taken as an impulse to reinforce an active CHP development policy

As mentioned already in chapter 2, in the 2nd progress report submitted to the Commission 2011 the Danish Energy Agency explained that measures were not taken to increase the share of high-efficiency cogeneration, referring to the conclusion of the CHP potential analysis from 2007, that the socioeconomic potential of cogeneration was found to be limited. However in chapter 2 it has been shown, that in the meantime some new aspects and developments should be considered, requiring a revaluation of additional CHP potentials. The transformation of the EED should be used as an opportunity to reconsider the role of cogeneration in the transformation of the energy supply system and to consequently use the energy efficiency potentials linked with CHP. The following proposed measures to intensify CHP support are estimated to fit well to the energy plans of the Danish Government as shown in chapter 3.2.

3.1.2. The Government should consider suitable instruments to encourage investments in new CHP and modernisation or replacement of old CHP and to make the CHP share in DH production independent from power exchange prices.

Referring to barrier 1 (decreasing electricity market prices), a suitable instrument could e.g. be a minimum electricity price attained by a (windfall) tax on the difference between power exchange prices (future and day ahead markets) and politically defined sustainable power prices. It may also be useful to

[18] The national bio-CHP potential analysis is based on figures from the PRIMES database, Eurostat, the National Renewable Energy Action Plan (NREAP), and the project Biomass Futures. The analysis has been discussed and, where necessary, refined in consultations with national energy experts (see Annex for the country bio-CHP potential analysis or http://www.code2-project.eu/wp-content/uploads/130712_Bio_CHP_EU-27.pdf for the complete EU-27 analysis).

consider possibilities to „repair“ the power exchange market. Maybe also a European discussion on an appropriate EU body about the reasons of the obviously wrong market signals from the power exchange with regards to CHP investments could be useful and appropriate.

3.1.3. In natural gas supplied areas small scale and micro CHP should be promoted

It should be considered that flexible production units will be needed in the electricity supply system in the years to come, and that, with regards to decarbonisation, natural gas CHP backup is to be preferred to back up by condensing electricity based on coal.

3.1.4. Electric heat pumps in combination with district heating and small scale CHP should be promoted

Combined systems of district heating and small scale CHP with heat pumps should be encouraged, as such systems are both extremely energy efficient and able to play an important role in future “smart” electricity supply systems, if appropriate signals and incentives are given to run the systems according to the balancing power market needs.[8] Currently only electric boilers are being installed for this purpose at district heating CHP plants, whereby the profitability of much more efficient heat pumps is suffering from the heat taxation regime.

3.1.5. The Government should revise the energy taxation system with the aim to encourage natural gas CHP

The current threshold of 67% (see chapter 1.3.) used for electrical efficiency reference value is not technically achievable and impedes further CHP expansion. The Danish legislation could usefully revisit the relevant primary energy reference values for CHP electricity produced replacing the present 67% electrical efficiency reference value. The energy tax exemption for process heat production with natural gas boilers should be abolished or significantly reduced. Alternatively a special support for CHP in this application field should be introduced to overcompensate the tax exemption.

3.1.6. A subsequent regulation of capacity payments after 2017 should be decided as soon as possible

As described in chapter 1.6 (barrier 2), removing the uncertainty on the economics of CHP investments created by capacity payments expiring 2017 could help to encourage investments in CHP.

In this context also payments to small and micro CHP for system stabilising contributions should be considered.

3.1.7. Implementation and operation of CHP by energy service companies (ESCOs) should be strengthened

Energy service companies (ESCOs) can play a key role in mobilising additional CHP potentials, particularly in industry and the commercial sector but in principle everywhere in the heating market. The ESCOs business model introduces the possibility of longer payback times than individual industrial companies use to accept for capital investments. That´s why in many cases ESCOs are able to bring cogeneration potentials into reality, where otherwise “business as usual” would apply: the inefficiency of separate electricity generation and heat and steam production in boilers.

As specialised experts on efficiency ESCOs have the necessary know-how on technical and legal issues and many of them can offer cogeneration solutions by "contracting" even as a part of an integrated efficiency package including other energy saving measures regarding the supply of power, heat and cold. CHP related energy services may be offered either by existing energy supply companies or by new suppliers.

The implementation of Article 18 EED, requiring that "Member States shall promote the energy services market …" could be a core element for bringing the cogeneration potentials of the industry outside pulp & paper and chemical industry into reality. The same may apply for many other energy users e.g. in the commercial sector who aren´t able, or do not wish to build and operate cogeneration devices. It is important to make sure that cogeneration implementation by external ESCOs is explicitly supported as part of the implementation of the comprehensive assessment, cost benefit analysis and "adequate measures " of Article 14 of the EED.

3.1.8. For use of bio energy enduring and reliable sustainability criteria should be decided as soon as possible

The widespread perception that bioenergy is not sustainable due to a possible competition with the production of food and feed stock for combustion is a barrier to the wider use of bioenergy in the Danish energy system. .

The establishment of reliable sustainability criteria would clarify the issues and create a necessary basis for the wider use of bioenergy. This decision should be developed based on a structured and transparent discussion process with participation of the public.

3.1.9. Government and industry should support the development and market introduction of biomass gasification for use in CHP

New technologies of solid biomass and waste gasification offer the opportunity to replace the conventional steam turbine CHP plants with their relative low electric efficiency by high efficient CHP based on engines, gas turbines or combined cycle gas turbines (CCGT). Suitable systems are meanwhile nearing market launch or already entering the market, other technologies need further development efforts.

With the aim to increase efficiency of solid bio energy and waste use in CHP, appropriate measures should be considered to support the development and market introduction of thermal biomass gasification systems, as gaseous bio energy can be used in engines and CCGT with significant higher electric efficiency than in conventional steam turbines.

3.2. Possible paths to growth

With the proposed roadmap it is estimated, that up to 2030 CHP electricity production could further increase by 10 % to an average level of 21 TWh/a. Without the roadmap measures cogenerated power production is estimated to stagnate.

The following projected development of CHP power production marks rough targets for a CHP roadmap in comparison to an estimated "no- roadmap path". Based on assumptions presented in annex 4, it is estimated that up to 2030 CHP electricity production in Denmark, supported by additional efforts as suggested in the CHP roadmap, could increase by about 2 TWh/a or 10 % from the current level of about 19 TWh/a to 21 TWh/a, distributed to the main use areas as follows: district heating (centralised and decentralised) 1 TWh/a, industry 0.6 TWh/a, commercial and housing (outside of DH areas) 0.4 TWh/a. These targets are considered to be in line with the long term Danish energy policy milestones (see box and Figure 3)

Without intensified efforts to switch from condensing electricity and heat only production towards cogeneration, it is estimated, that CHP power production would stagnate up to 2030, though the Governments energy plans are announcing also measures to boost CHP but without any details or specifications.

Figure 3 Development of fossil fuels and renewable energy consumption according to the Danish Governments energy plans

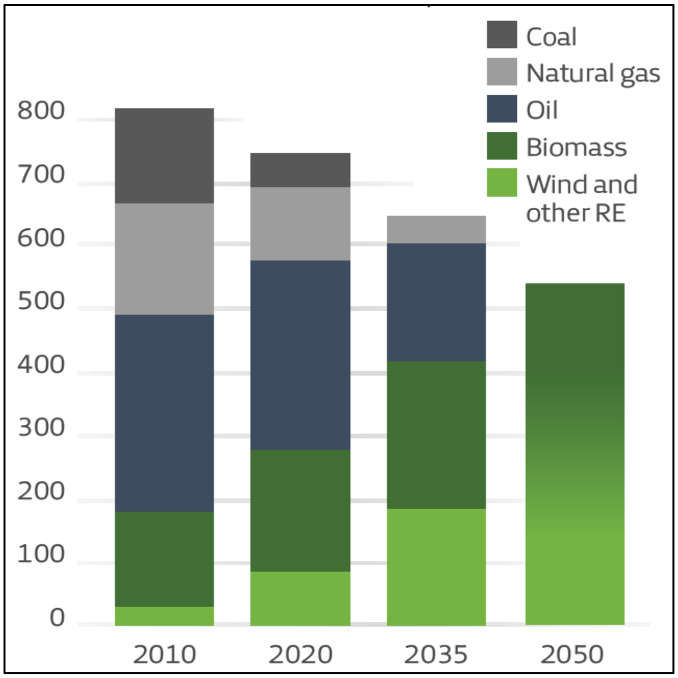
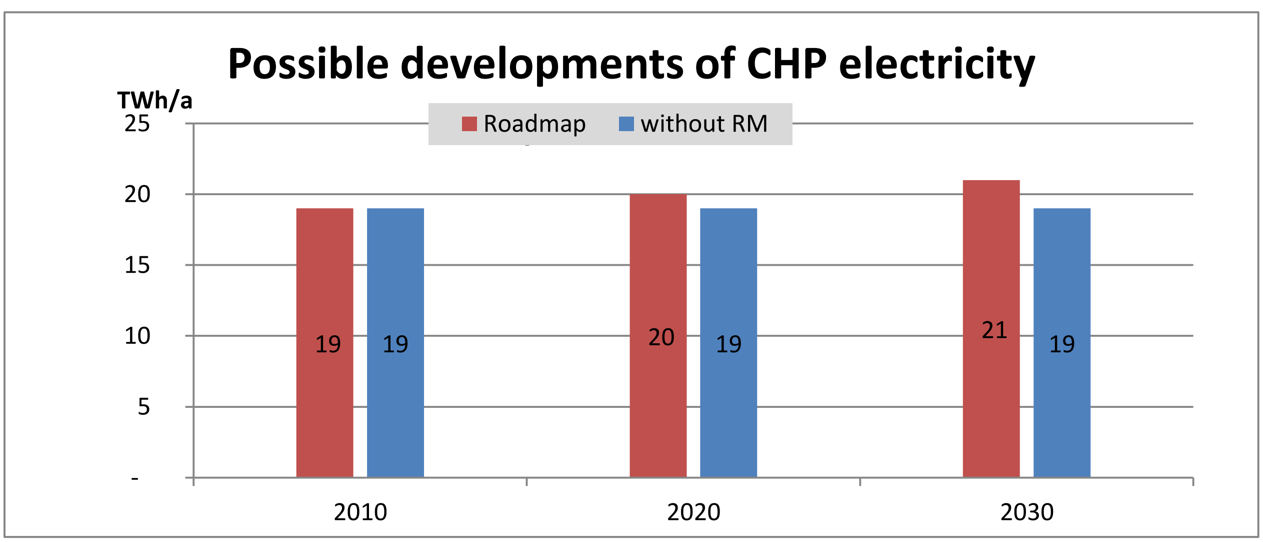


Figure 4 shows that the difference between the two paths is not big, reflecting the high level of CHP already realised in Denmark and the Governments ambitious plans to substantially raise the wind energy contribution. Though it may be true that the additional Danish CHP potentials are limited, they exist and should be made use of to strengthen energy efficiency as an equivalent element of decarbonisation compared to the transition to 100 % renewable energy.

Figure 4 CHP roadmap path compared to the "No-RM path"



3.3. Saving of primary energy and CO_2 emissions by the CHP roadmap

It is estimated that with the projected CHP growth induced by the roadmap between 3 and 4 million tonnes of CO_2 emissions per year could be saved in 2030. The corresponding primary energy saving has been calculated 4 to 5 TWh per year or, using the EED calculation method, 6 to 7 TWh/a.

Primary energy saving (PES) and CO_2 emissions saving projections resulting from increased use of CHP require assumptions about not just what types of fuel and technology are displaced, but also their operation on the market. Within CODE2 two approaches are developed. These represent two different analytic considerations which are summarised here and more fully explored in Annexe 6.

1) **Methodology according to Annexes I and II of the EED**. This method is used at a member state level today for national reporting to the European Commission and at project level for determining if a specific CHP plant is highly efficient. In the methodology, the efficiency of each cogeneration unit is derived by comparing its actual operating performance data with the best available technology for separate production of heat and electricity on the same fuel in the market in the year of construction of the cogeneration unit using harmonized reference values which are determined by fuel type and year of construction.

2) **Substitution method**. This method has been developed within the project and estimates the amounts of electricity, heat and fuel which are actually replaced by additional new CHP based on a projection of the supply base changes in the member state supply over the period are calculated. The situation in 2030 is compared to the current status. With this method PES for Denmark through implementing the roadmap for CHP is estimated between 4 and 5 TWh per year and CO_2 savings are estimated to be between 3 and 4 Million tons per year in 2030. The actual saving is particularly dependent on the efficiency increase through upgrading both current power plant and CHP technology efficiencies. The final share of bio energy in additional CHP has a major impact on the CO_2 savings which can be anticipated. The CO_2 reduction achieved is due to both higher energy efficiency and fuel switching towards low carbon (natural gas) or non-carbon (bio energy) fuel, but CHP development and fuel switching are anticipated to be an integrated process driven by policy objectives.

Table 5 Saving of primary energy and CO_2 per year in 2030 by the Danish CHP roadmap

	Substitution method				**EED method**			
	low case		**high case**		**low case**		**high case**	
PE saving	4	TWh/a	5	TWh/a	6	TWh/a	7	TWh/a
CO2 saving	3	Mio t/a	4	Mio t/a				
- per kWh el*	1,51	kg/kWh el	1,97	kg/kWh el				

* This value represents the CO_2 reduction of the power generation. It includes the avoided CO_2 emissions from fuel savings for separate heat generation in boilers; it must not be confused with the considerably lower CO_2 emissions of the substituted condensation electricity or with even lower emissions of compared power production according to the BAT approach in accordance with the EU CHP directive reference values.

Annex 1: Stakeholder group awareness assessment

A Questionnaire on awareness of CHP and its benefits in the main groups was filled by 4 CHP experts. They were asked to fill a table with the main user groups and to give back their personal opinion on the grade of awareness. The average results can be seen in table 2.

It should be underlined that these results cannot be regarded as representative in a scientific sense. They just provide a snapshot on the opinion of some Danish CHP experts.

Annex 2: Micro CHP potential assessment

micro-CHP potential summary
Denmark

Country statistics

Population: 5 600 000 (2010)

Number of households: 2 700 000 (2010)

GDP per capita: € 31 500 (2010)

Primary energy use: 15 500 ktoe/year (2010)

GHG-emissions: 61 Mton $CO_{2,eq}$/year (2010)

Household systems (±1 kWe)

Boiler replacement technology

Present market (2013)

Boiler stock: 526 000 units
Boiler sales: 26 000 units/year

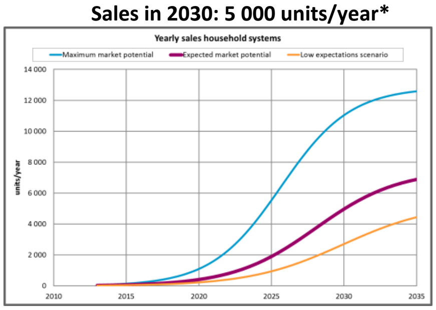
Potential estimation

Indicator	Score
Market alternatives	0
Global CBA	4
Legislation/support	0
Awareness	0
Purchasing power	3
Total	**7 out of 12**

Expected final market share: 29% of boiler sales in Household sector

Yearly sales

Sales in 2020: 400 units/year*
Sales in 2030: 5 000 units/year*



Stock

Stock in 2020: 1 300 units*
Stock in 2030: 25 000 units*
Stock in 2040: 68 000 units*

Potential savings in 2030

Primary energy savings:
0 PJ/year*
10 ktoe/year*
GHG-emissions reduction:
0.0 Mton $CO_{2,eq}$/year*

SME & Collective systems (±40 kWe)

Boiler add-on technology

Present market (2013)

Boiler stock: 26 000 units
Boiler sales: 1 300 units/year

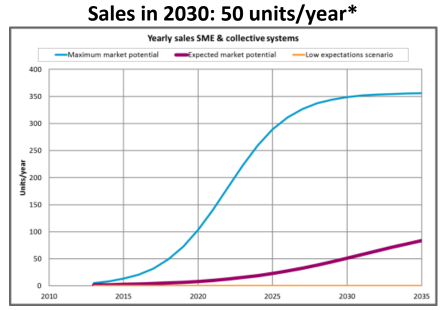
Potential estimation

Indicator	Score
Market alternatives	0
Global CBA	3
Legislation/support	0
Awareness	0
Total	**3 out of 9**

Expected final market share: 9% of boiler sales in SME & Coll. sector

Yearly sales

Sales in 2020: 10 units/year*
Sales in 2030: 50 units/year*



Stock

Stock in 2020: 60 units*
Stock in 2030: 300 units*
Stock in 2040: 860 units*

Potential savings in 2030

Primary energy savings:
0 PJ/year*
5 ktoe/year*
GHG-emissions reduction:
0 Mton $CO_{2,eq}$/year*

*Corresponding to the expected potential scenario.

The score card is used to assess the relative position of an EU country based on current regulations, markets and economics. The score itself functions as input to the implementation model to 2030.

±1 kWe systems (Households) *Boiler replacement technology*	***±40 kWe systems (SME & Collective systems)*** *Boiler add-on technology*
Scorecard	***Scorecard***

Indicator	*Score*
Market alternatives	0
Global CBA	4
Legislation/support	0
Awareness	0
Purchasing power	3
Total	**7 out of 12**

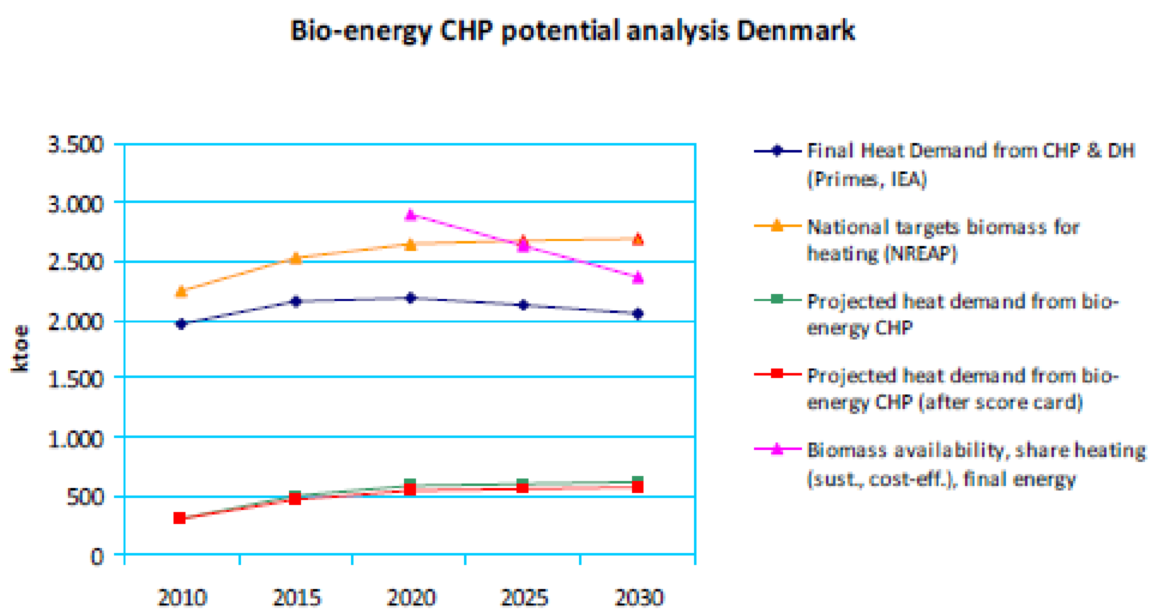
Indicator	*Score*
Market alternatives	0
Global CBA	3
Legislation/support	0
Awareness	0
Total	**0 out of 9**

Market alternatives	***Market alternatives***
Estimates for other 'boiler replacement technologies in current national roadmaps on other technologies, ***DH, Heat pumps*** *Development (local) gas grid* ***low for heating in houses***	*Current national roadmaps on microCH:* ***No*** *Current national roadmaps on other technologies:* ***Yes: HP and district heat***
Global CBA	***Global CBA***
SPOT: ***3.5 years***	*SPOT:* ***7 years***
Legislation/support	***Legislation/support***
Current incentives on micro-chp ***No*** *Current incentives on other technologies as heat pumps and district heat:* ***Strong*** *Current regulation in favour of micro-CHP* ***No*** *Current legislation in favour of other technologies:* ***Strong***	
Awareness	***Awareness***
Are stakeholders aware of the microCHP technologies *Homeowners?* ***No*** *Consultants?* ***No*** *Installers?* ***No*** *Planners?* ***No*** *Government?* ***Yes but no issue in DK*** *Are manufacturers active in the market?* ***Low in DK***	*Are stakeholders aware of the technology* *Homeowners?* ***No*** *Consultants?* ***low*** *Installers?* ***low*** *Planners?* ***low***
Purchasing power	
GDP: ***€ 31 500 per year***	

Annex 3: Bio CHP potential assessment

Bio-energy CHP potential analysis Denmark

Figures (projections)	2010	2020	2030
Final heat demand from CHP and DH (PRIMES, IEA), ktoe	1.965	2.182	2.051
(Projected) heat demand from bio-energy CHP and DH (after score card), ktoe	314	545	574
Bio-energy penetration rate in CHP markets (2009: EEA, Eurostat)	16,0% (2009)	25,0%	28,0%
Biomass availability, share heating (sust., cost-eff.), final energy (Biom. Futures), ktoe		2.899	2.356



Framework Assessment (Score card)	Score	Short analysis
Legislative environment	++ 3 (of 3)	Large political support, high priority in the national energy plan
Suitability of heat market for switch to bio-energy CHP	++ 3 (of 3)	High interest of consumers for bio-fuels in all market segments
Share of Citizens served by DH	++ 3 (of 3)	44% share in the room heating market
National supply chain for biomass for energy	+ 2 (of 3)	
Awareness for DH and CHP	++ 3 (of 3)	

Annex 4: Assumptions used in the market extrapolation

Non-roadmap path

Based on the CHP policy related plans of the Danish Government according to the publication “Our future Energy” from 2011, the Danish Climate Policy Plan from 2013 and the Danish Energy Agreement from 2012. The support for CHP is considered to be mainly indirect by phasing out of heating with conventional oil and natural gas boilers. No special support is announced for switching to CHP in the industry and in natural gas supplied housing areas and commercial companies. No attention is given to increase bio electric efficiency of solid biomass and waste CHP by new gasification technologies.

CHP Roadmap path

Measures as proposed in chapter 3.1.

Growing wind power production replaces the remaining production of condensing electricity but not CHP electricity.

Bioenergy grows according to the Governments energy plans, taking into account the results of the Danish Energy Agency study “Energy Scenarios for 2020, 2035 and 2050” from May 2014.

Annex 5: Assumptions used in the economics of CHP

Detailed economic analysis of four standard CHP cases was implemented in all pilot roadmaps and optionally in non-pilot roadmaps.

As requested detailed economic data for economic analysis of four standard CHP cases were not available or are not sufficiently reliable for making objective conclusions about the CHP profitability and comparison of economics with other member states, detailed calculation table is not included in this report.

Annex 6: Methodologies used to calculate the saving of primary energy and CO_2 emissions under the roadmap.

Substitution method

This method has been developed in the CODE2 project. In doing this, two other approaches have been considered: 1) the “replacement mix method[19]” from the Munich FfE institute, which however cannot be used directly for a long term comparison as needed in CODE2; 2) a method used to calculate the CO_2 saving resulting from a voluntary commitment of the German industry for CO_2 reduction[20], however this method has been considered as too simple. Therefor the following more differentiated approach has been developed:

Based on an estimate of the increase in cogeneration electricity the thereby caused decrease of CO_2 emissions and primary energy consumption is estimated. In this approach, an attempt is made to determine the actual quantities saved compared to the base year (e.g. 2010). Hence it refers to the actual saving of fuels for the production of the amounts substituted by modern CHP plants

a) of electricity and heat in the replaced or retrofitted old CHP plants

b) of electricity in power plants

c) of heat in boilers.

The savings result from a combination of three effects:

- CHP effect

- Technology effect (improved CHP technologies)

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[19] 10. FfE Forschungsstelle für Energiewirtschaft e.V., Energiezukunft 2050; http://www.ffe.de/die-themen/erzeugung-und-markt/257

[20] The calculation has been made by the VIK Verband der Industriellen Energie- und Kraftwirtschaft e.V., 2010, Unpublished.

- Fuel switching (e.g. lower carbon content of natural gas compared to coal, CO_2 neutrality of bioenergy)

The results show the savings actually induced by the expansion of CHP compared to the situation in the base year.

This approach differs fundamentally from the methods for checking the high-efficiency according to the CHP Directive or in accordance with ANNEX II of the EED (Directive 2012/27/EU on energy efficiency), in which a comparison between CHP and the best available Technology (BAT) of separate production of electricity and heat produced is carried out strictly on a same-fuel basis.

This procedure is considered to be inappropriate to deliver an estimate of the actual fuel saving quantities by CHP over a longer period, which is considered relevant value, representing meaningful the contribution of CHP to the long-term objectives of the EU to reduce CO_2 emissions and primary energy consumption. The BAT approach of the CHP Directive has been developed to verify the high efficiency of individual plants, but not to determine actual saved CO_2 emissions and primary energy quantities by CHP expansion.

In fact, the CHP expansion is closely associated with a replacement of old by new cogeneration technologies and a change in the structure of fuel away from coal to natural gas and bio-energy. These three developments,

- replacement of separate generation by cogeneration

- replacement of old by new cogeneration technologies

- replacement of carbon-rich by low-carbon fuels,

can be usefully seen only as an integrated process.

To account for the uncertainties in particular with regard to fuel shares and technology development, a window of possible developments with an upper value and a lower value of emission reduction and savings has been determined. The different levels of results are due to assumptions about key parameters such as current share of electricity from cogeneration, which is replaced by electricity from new or retrofitted units, fuel shares in the replaced CHP plants, power plants and boilers as well as in the new CHP plants.

The results have been calculated based on the following input values: growth of CHP power production, share of current old CHP to be replaced by new installations and retrofitting, fuel efficiency and electric efficiency of new CHP and replaced CHP for different fuels, electric efficiency of replaced power from conventional power plants for different fuels, heat efficiency of replaced heat from boilers, corresponding fuel shares.

EED method

The Primary Energy Savings methodology of the EED is used at a country level for national reporting to the Commission, and at project level for determining if CHP is highly efficient. In the methodology, each cogeneration unit is compared with the best technology for separate production of heat and electricity on the same fuel on the market in the year of construction of the cogeneration unit and the harmonized reference values are determined by fuel type and year of construction.

The underlying principle is that, knowing that regularly new investments have to be made in new energy production units, it is necessary to compare CHP with the centralized production installation which could be built using the same fuel rather than assuming a displacement of a different fuel or introduction of a new fuel. It is a logical approach when looking at the decision making process of investors or a member state government. By investing in or supporting CHP, a certain electricity generating capacity will be produced by CHP and NOT by centralized production based on the same fuel (= principle of 'avoided production').

For the timeframe of the roadmap (between 2010 and 2030), and especially in countries where there is no overcapacity, it is relevant to compare installing a certain capacity (at national level) of CHP compared to installing new capacity with another technology (power plant + gas boiler). Older installations being replaced with state-of-the-art technology.is a typical reinvestment decision. New CHP-plant (or combination of smaller installations) would not necessarily lead to less production in older production installations, but would rather preempt investments in e.g. new CCGT investments.

Annex 7: Sources

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