An overview concerning combined heat and power production: a smart way to improve energy efficiency

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Abstract

Cogeneration power plants simultaneously generate power and usable heat in a single, integrated system, which achieves a degree of overall efficiency that is much greater compared to electricity production alone. This makes better use of energy conversion and reduces greenhouse gas emissions. Combined heat and power production is already relatively common in Europe while it is less common, for example, in the USA. There is great potential for further implementation throughout Europe and worldwide, including in the industrial sector. Major challenges are the short potential distances for the transport of heat and the fact that consumers' heat demands vary in quantity, mainly due to seasonal effects, and in quality as different applications require different temperature levels. Cleaner production schemes offer suitable frameworks to foster uptake of combined heat and power production by industry, in particular by small and medium sized enterprises.

Introduction

Energy conversion and use account for around two thirds of global greenhouse gas emissions (IEA, 2015a). Decarbonisation of the energy sector is a fundamental requirement to limit a long-term global rise in temperature as a consequence of anthropogenic climate change and can be, therefore, understood as a prerequisite to enable all future development. Energy efficiency, the switch of energy sources to a more widespread adoption of renewable energies and CCS (carbon capture and storage) are the three main pillars in strategies to reduce energy-related greenhouse gas emissions in terms of equivalent carbon dioxide (IEA, 2011).

Cogeneration schemes are designed to supply both power and heat simultaneously. By including heat, they valorise energy that would otherwise be considered waste heat (excess heat). Recovered waste heat can be used for heating buildings or other areas, for providing hot water, for covering industrial demands and in some cases for driving a second engine for additional electricity production. Assessment of the actual impact of cogeneration on climate change mitigation remains a difficult task (Bianchi et al., 2014; Heinonen et al., 2015). It is evident that the supply of heat to consumers replaces other heat sources. Today, the vast majority of heat demand, worldwide and in Europe, is covered by fossil fuels (European Commission, 2015). Cogeneration therefore leads to overall energy savings and greenhouse gas reductions in the energy system. This indicates that heat valorisation from cogeneration power plants has huge potential to make a vital contribution to decarbonising the energy system. Cogeneration can, therefore, be considered a powerful scheme to improve energy efficiency (IEA, 2011).

Cogeneration is also known as combined heat and power (CHP). Although no precise differentiation exists, the term 'cogeneration' often refers to central power stations delivering electricity to the general grid, and heat valorisation in this context is often in the form of district heating. The term 'CHP' is more common in decentralised applications, industrial settings, local community energy supply or individual applications such as energy valorisation of a biogas plant.

The power in cogeneration schemes (CHP units) is usually electricity but it can also be mechanical energy for operating technical equipment such as fans, compressors or pumps (Carbon Trust, 2010). To implement cogeneration, three basic processes need to occur: power production, heat recovery and heat use (Carbon Trust, 2010). Cogeneration is neither a new idea nor an application that is limited to large power plants. A common example of applied cogeneration is the automobile heater, which makes use of heat from the engine to enable comfortable temperatures in the interior of the automobile (Bridgeman, 2011).

The concept of cogeneration is smart and very appealing but in practice, a range of challenges need to be met and carefully assessed in order to ensure successful implementation. Electricity can be moved over long distances without significant losses, however, this is not the case for heat for which transport is limited to short distances. Another major challenge lies in the fact that consumers' heat demands vary both in quantity (heat amounts) and in quality (temperature levels). District heating, which is closely linked to urban planning and can be fostered and promoted directly by the public sector, is often a focus in assessments on how to increase uptake of cogeneration while potential implementation in industrial settings is less well addressed. The industrial sector has more complex and more diversified conditions, and the potential uptake of CHP by small and medium sized enterprises (SMEs) is particularly challenging.

This study elaborates an overview of benefits, applications and challenges related to implementation of combined heat and power production. The aim of this publication, therefore, is to contribute to more widespread and successful implementation of cogeneration and, in particular, to explore combined heat and power production as a cleaner production measure in industrial settings.

The dominant role of heat in the energy sector

The topic of energy in the climate change debate is often focused on electricity and transport while less attention is given to heat. However, heat demand is actually higher than demands for other key energy forms (IEA, 2014; 2011). Data on heat demand are difficult to obtain, especially as heat produced on site by single consumers is not systematically recorded, therefore assessments need to be based on estimations. Globally, the share of heat in total final energy consumption today exceeds 50 % (IEA, 2014) which puts heat at the level of the sum of electricity and transport shares together. In highly industrialised countries, the share of heat in total final energy consumption is somewhat lower, but on average still exceeds the individual shares of transport and of electricity (IEA, 2011). Figure 1 illustrates the shares of electricity and heat in final energy consumption of industry in the European Union (EU) and reveals that on average, heat accounts for around 40 %. This dominant share of heat in energy demand indicates that transition towards more energy efficient heat supply has a huge potential to reduce energy-related greenhouse gas emissions.

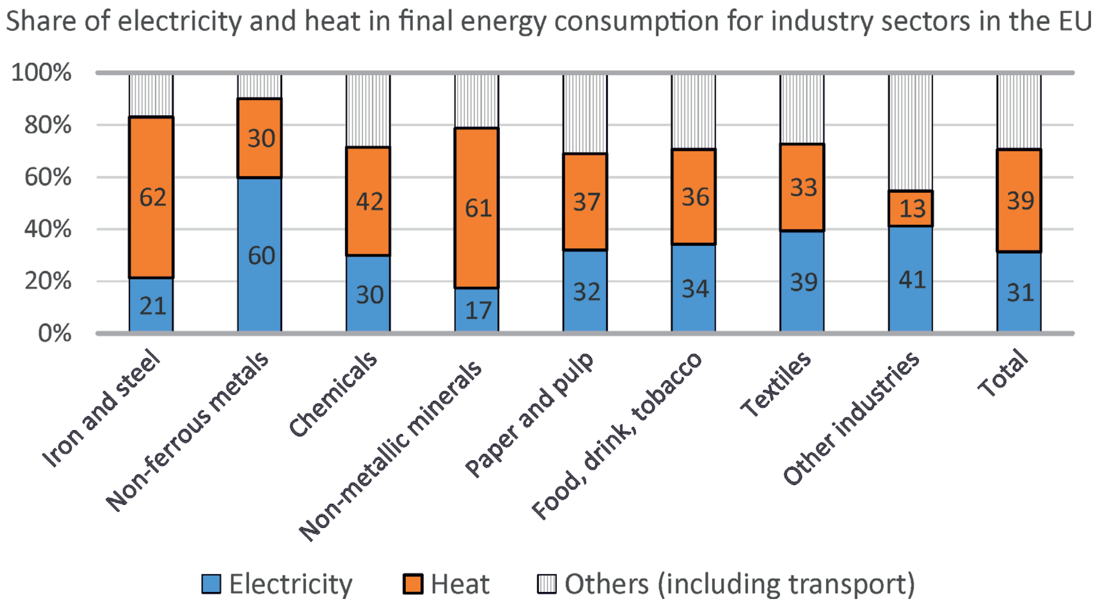

Figure 1 – Relative demand for electricity and heat in industrial sectors of the EU economy (data source: Pardo et al., 2012, there based on estimations using industry energy data of the year 2009).

Globally, most heat is needed by the industrial sector (more than 40 %), while the residential sector is the second largest consumer (if residential sector and commercial and public services are combined into a common category of 'buildings sector', this aggregated sector would be the main heat consumer, accounting for around half of final energy use for heat) (IEA, 2011). This highlights the fact that both the building and the industrial sectors need to be addressed as a priority when aiming for more efficient heat supply systems.

Key benefits of cogeneration

Around two-thirds of input energy is lost in traditional electricity generation (IEA, 2014; 2011) which means that only one third of energy contained in the exploited energy carriers is actually made available to the final consumer. The lost share of the energy content implies huge emissions of carbon dioxide and represents high opportunity costs. The vast majority of losses occur at the power plant during electricity generation, and the high losses are critically linked to thermodynamic limitations and basic conditions of the predominant energy conversion processes. Heat is an unavoidable by-product of power plants based on thermal processes. The conversion chain from chemical energy (contained in the energy carrier) through thermal energy (released through combustion) to mechanical energy using heat engines and finally into electricity results in a scheme that converts less than half of the energy content of the energy carrier into electricity.

The average global efficiency of fossil-fuelled electricity generation remained stagnant for decades at 35 to 37 % whereas advanced technologies today can approach 45 % efficiency (IEA, 2011). Historically, heat was dispersed with cooling towers, gas flues or by other means. Cogeneration allows conversion of 75 to 80 % of fuel inputs into useful energy, and up to 90 % in the most efficient plants (IEA, 2011). The full benefit, however, can rarely be captured and in 2012, cogeneration of heat and power had a global average efficiency of 58 % (IEA, 2015b), which is considerably lower than the theoretically possible benefit but still significantly higher than the efficiency of conventional thermal power generation.

Cogeneration in itself does not increase the power supply for a given plant but by supplying useful heat alongside useful electricity, it increases overall energy efficiency and allows the same level of end-use energy demand to be met with fewer energy inputs (IEA, 2011). Conventional heat supply is substituted by cogeneration heat. This results in decoupling fuel consumption from energy demand. As this reduces greenhouse gas emission, cogeneration can be considered a low-carbon energy solution.

At the same time, valorisation of waste heat can generate significant economic benefits, which is the central driver for implementation of cogeneration in the industrial sector, in particular in industries with high heat requirements. Cost savings are more difficult to quantify than energy savings as prices for energy vary between sites and can fluctuate (Carbon Trust, 2010). Economic benefits might vary significantly for sites within one country and will certainly vary between countries, depending on the relevant frameworks and policies. Nevertheless, combined heat and power production is a highly promising element in cleaner production schemes, with a view to both environmental benefits and economic advantages.

Implementation of cogeneration in different countries

Many thousands of CHP systems are in operation worldwide but the untapped potential is still huge. Challenges are not limited to engineering aspects; they include setting the right incentives by policy makers (Colmenar-Santos et al., 2015). Cogeneration is varyingly common in different countries. Scandinavian and continental European countries have a longer tradition in using cogeneration, which can partially be explained by higher fuel costs compared to other regions such as North America (Waskey, 2007). Another factor is that European cities are quite densely populated with many people living in apartments rather than single houses, which facilitates heat supply and distribution (Bridgeman, 2011). With the CHP Directive, the EU formally incorporated cogeneration into its energy policy a few years ago. Implementation of cogeneration is often fostered by different programmes and in some cases by specific regulations. This can include investment subsidies but also regulations whereby buildings near a cogeneration plant are required to use the waste heat of the plant to cover their heating demands (Bridgeman, 2011).

In the EU, slightly less than 12 % of all electricity is produced in cogeneration mode (Figure 2). The share has increased by 1.5 percentage points during the last ten years, although more recent years show a stagnation.

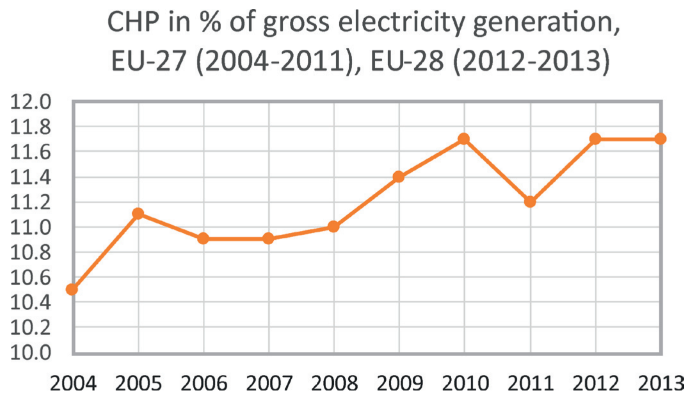

Figure 2 – Share of electricity produced in cogeneration mode in the European Union (data source: Eurostat, 2015).

There are significant differences among European countries: some countries have hardly any cogeneration facilities while for others, application of cogeneration is very common (Figure 3). According to Eurostat (2015), in 2013, 77 % of all electricity in Slovakia and 51 % in Denmark was produced in cogeneration mode. Other countries with particularly high implementation of cogeneration are Latvia (38 % of electricity generated in cogeneration mode in 2013), the Netherlands and Lithuania (35 %) and Finland (34 %). It must be considered that these figures refer to all electricity produced in a country, not only electricity from thermal power plants; therefore, they do not allow direct conclusions towards how well the potential of cogeneration is being exploited. In Finland for example, a major share of electricity comes from hydropower and actually more than 80 % of thermal power plants in the country use cogeneration. The EU country with the highest installed cogeneration capacity is Germany, although in 2013 only around 12.5 % of the country's electricity was generated in cogeneration schemes (Eurostat, 2015).

The first central power plant in the USA started operation in 1882 in New York City and was operated as a cogeneration plant, delivering heat to nearby buildings. During the course of the 20th century, however, rising electrical demand drove utilities to build ever-larger power plants that could not be located in cities because many of them were fuelled by coal (Bridgeman, 2011). The large distance to potential heat con-

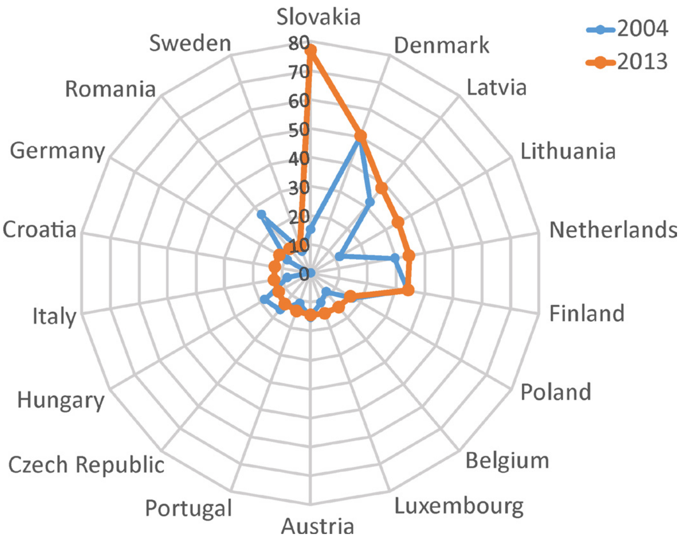

Figure 3 – Share of electricity produced in cogeneration mode in EU countries in 2004 and 2013, in percentage of gross electricity generation (only countries with more than 10 % of electricity produced in cogeneration mode shown) (data source: Eurostat, 2015).

sumers is one explanation of why cogeneration is not widespread in the USA. Another reason is the absence of incentives to improve energy efficiency throughout most of the 20th century. The Public Utilities Regulatory Policies Act of 1978 created a major boost to cogeneration implementation in the US, resulting in cogeneration rising to approximately 8 % (Ehrhardt-Martinez & McKinney, 2011). The Act allowed competition in the generation of electricity and required public utilities to purchase electricity from alternative sources, which included solar power, wind power and cogeneration (Waskey, 2007). Nevertheless, cogeneration has remained less common compared to Europe, in particular compared to those European countries with high shares of cogeneration.

Globally, absolute cogeneration has increased moderately but its share of electricity generation has not changed significantly over the past decade, plateauing at 9 to 10 % of global electricity (IEA, 2015b). District heating represented 10.8 % of global heating energy use in 2012 (IEA, 2015b). The vast potential to create more sustainable energy systems by implementation of cogeneration has not yet been extensively deployed.

Technologies

At the heart of a CHP unit, there is the so-called prime mover or heat engine. Heat from a hot fluid is used to do mechanical work, providing the power to drive the electrical generator. Heat that remains in the fluid will either be dissipated or can be recovered and used. Cogeneration plants are not all based on one single technology, therefore there is not one standard technology (Ehrhardt-Martinez & McKinney, 2011). The majority of plants in operation use a gas turbine with heat recovery, but diverse configurations of technologies exist and have evolved over time (Carbon Trust, 2010). Steam turbines and internal combustion engines are also in widespread use. Recently emerging technologies include fuel cells, sterling engines and ORC (Organic Rankine Cycle) (Carbon Trust, 2010).

The great variety of technical solutions enables high flexibility, which means that cogeneration can meet very different requirements. Fossil-fuel based operation of facilities is most common, but cogeneration processes can also be based on biomass such as wood pellets, biomass-derived energy carriers such as biogas, and waste materials. Waste-to-energy plants, with electricity production via incineration of municipal waste, are typically operated as cogeneration plants. CHP units are standard at biogas plants, as the digester itself requires heat for the process (Köttner et al., 2008). Coupling cogeneration and renewable energy sources creates particularly strong low-carbon benefits (strongly reduced emissions of carbon dioxide: carbon-neutral energy source coupled with high overall energy efficiency) (IEA, 2011; Karschin & Geldermann, 2015).

CHP schemes can be categorised into three groups according to the installed electrical capacity (Carbon Trust, 2010):

- large-scale (power output of more than one megawatt, ranging up to hundreds of megawatts), mainly operated in large industrial sectors with high energy demand, such as chemicals, oil-refining, paper, food and drink, and in large community heating schemes;
- small-scale (around fifty kilowatts up to one megawatt), usually installed at smaller industrial sites, buildings and community heating;
- micro-scale (less than fifty kilowatts), used in very small businesses or commercial applications and in domestic settings; the term 'mini-CHP' is used for systems that generate the equivalent of more than five kilowatts.

Up to a range of one megawatt (small-scale CHP and micro-CHP), installation is often as a packaged CHP which is supplied as a complete unit ready for installation. Packaged CHP systems are designed in a modular fashion and are manufactured on a large scale, thus benefitting from economies of scale. The prime mover in packaged CHP units is usually an internal combustion engine. Internal combustion engines operating on petrol, diesel or gas are favoured because they are reliable, require relatively little maintenance and are flexible in their operation; that is, they can respond well to load changes (McKenna, 2011). In such applications, a heat exchanger commonly recuperates heat from both the engine cooling system and the engine exhaust gas, typically in comparable amounts. This achieves high efficiency but the provided heat in practice is often below 100°C. The engine cooling system usually operates at around 80°C, and up to 120°C in adapted units, while the exhaust gas delivers higher temperature.

Large-scale applications are custom-built, generally consisting of complex systems installed on-site. Due to their high overall efficiencies and reliabilities, the prime mover of large-scale applications is generally a gas or steam turbine or at high power outputs, combined cycle (gas and steam) turbines (McKenna, 2011). Units larger than fifty megawatts power output often use a combined cycle gas turbine (Carbon Trust, 2010). Although a wide range of sizes exist, cogeneration plants are usually designed to be smaller than conventional power plants, since the waste heat from electrical power production in a cogeneration plant must be used locally (Bridgeman, 2011). Heat recuperation mode depends on the selected prime mover type and can include partial steam recovery or steam generation from exhaust gas.

Heat utilisation

Heat can be valorised if the demand for heat exists. Heat demand, in particular from the buildings sector, is highly seasonal and moreover shows variations linked to weather conditions and throughout the day as well, which is a key challenge in heat valorisation. Another challenge is transport. Unlike electricity, heat - even with good insulation - cannot be transported without significant losses over large distances. Transport of heat requires its own infrastructure, which means additional investment costs, and is economically only viable for relatively short distances of a few kilometres (Köttner et al., 2008). Heat, therefore, needs to be generated in physical proximity to the consumer. Large operations such as health care centres, hospitals, hotels, universities, industrial plants or other facilities that consume large quantities of both power and heat are the most suitable locations for cogeneration on site (decentralised schemes). Centralised, large power (electricity) production facilities with continuous generation of high amounts of heat are often the starting point to implement district heating in nearby city quarters or villages via heat pipes. Such facilities are often public facilities and might encompass various partnerships. The pipes supply heated water, and heat exchangers transfer the heat to the building's utilities.

Meeting heat demand is not only a question of quantity but also of quality (heat temperature level). It is not sufficient to focus on required heat quantities; it is necessary to ensure that there is no mismatch between the quality of heat supplied and that actually needed by the customer. Heat demands span a wide range of temperatures. Buildings require temperature regulation to around 20°C to provide comfort to users, while at the upper end of temperature requirements are industrial processes, of which some need heat of 400°C or higher (IEA, 2011). Heat demand can be classified into three segments (Euroheat & Power, 2006; IEA, 2011; Pardo et al., 2012):

- low temperature heat demand (below 100°C), primarily for space heating and for hot water;
- medium temperature heat demand (100 to 400°C), which corresponds to processes of drying and evaporation, and is normally produced by steam;
- high temperature heat (over 400°C), for transformation processes that take place in industry, such as reduction of ores, calcination, electric induction.

With a view to the quantitative heat requirements of buildings, wide variations exist due to not only geographic location as well as season and time of day but also due to age, architectural characteristics and design, and materials of the building. Industrial heat demand varies hugely both in quantity and quality. There is a lack of data on industrial heat demand and shares of temperature levels in many countries (IEA, 2011). No official statistics are available to reveal the heat demand fully and continuously, but elaborated estimations allow an assessment. In Europe, the estimations indicate that around 40 (IEA, 2011) to 55 % (Pardo et al., 2012) of industrial heat demand is in the high temperature segment. Sectors with significant demands for high temperature heat are the iron and steel industry, the chemical industry, non-metallic mineral production and the basic metal industries (Figure 4). Quantitative heat requirements in the medium and low temperature segments are at a comparable level and together the two segments account for around 45 (Pardo et al., 2012) to 60 % (IEA, 2011) of total industrial heat demand.

The data reveal that in the industrial demand, high temperature heat overall has the highest share but clearly the demand is not always for high temperatures and many different types of process result in a wide diversity of needs with regard to temperature levels. This indicates that industry specific peculiarities need to be taken into account in CHP projects. The data further indicate that the following industrial sectors in particular have favourable heat requirement patterns (medium and low temperature heat) with a view to implementation of combined heat and power production: the chemical industry, food sectors and the paper and printing sector.

At large-scale power plants, significant heat quantities occur at higher temperature levels and in such cases heat can further be used in a second engine to produce smaller amounts of electricity, thus increasing the overall electricity production from the input fuel. This reduces the amount of waste heat occurring but does not eliminate it, and therefore still offers potential for the valorisation of heat.

At sites without significant heat requirements, requirements

	High temperature heat [PJ]	Medium temperature heat [PJ]	Low temperature heat [PJ]
Iron and steel	1044	53	50
Non-ferrous metal	98	5	10
Chemical	346	180	351
Non-metallic mineral products	826	53	57
Ore extraction (except fuels)		5	7
Food, drink, tobacco		162	256
Textile, leather, clothing	13	36	23
Paper and printing	92	246	175
Transport equipment	4	10	29
Machinery	10	22	67
Other industries	29	58	119
Total	2462	829	1142

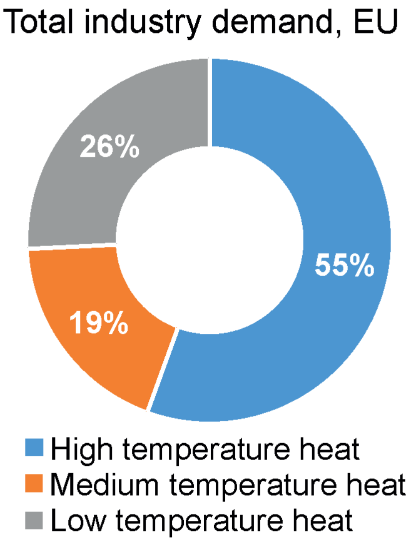

Figure 4 – Breakdown of heat demand in the industrial sectors of the European Union (EU27) according to heat levels, as estimated for the year 2009 (Pardo et al., 2012).

for cooling should be assessed as a priority since waste heat can be valorised to cover cooling demands. Such an option might turn an economically unviable CHP project into a project with business profit. Tri-generation is presented in the next section of this study.

Tri-generation

Combined heat and power production that produces heat, electricity and also cooling is termed 'tri-generation' or CHCP (combined heat, cooling and power production). Tri-generation can be highly effective in improving overall energy conversion efficiency by satisfying a variety of energy requests (Ascione et al., 2014). It can replace conventional electrical cooling systems, thus reducing electricity consumption and carbon dioxide emissions. In this concept, heat energy is transformed into energy for cooling/chilling. Heat can be used to achieve air-conditioning in buildings through absorption chilling technology. While conventional air conditioning infrastructures are used for distribution, specific equipment is installed to produce chilled water by using heat energy. Implementation is still marginal but commercial use exists. Tri-generation is particularly suitable at sites with limited heat demand but high heat availability (IEA, 2011). It can improve economic viability of energy projects at sites with limited demand for heat but high demand for cooling, thus turning unviable projects into viable ones.

One challenge is the achievable temperature level. Chilling to around 8°C can be considered state-of-the-art and is sufficient to regulate temperature in buildings. However, other applications require lower temperatures (such as freezing or cold storage of food) but the energy level contained in excess heat is often too low to achieve such temperatures with common technologies, and therefore such applications require further research and development (Köttner et al., 2008; Lira-Barragan et al., 2014). Other challenges are comparable to those associated with distribution of heat; the main problems are that only short distances are feasible and that often the overall demand for such energy within reachable distance is limited. One very positive factor is that heat and chilling demands have different seasonal patterns. Excess heat from CHP installations is particularly high during the warm season, which is when chilling is most required.

Modern district cooling networks can achieve efficiencies five to ten times higher than traditional electricity-driven cooling systems (IEA, 2015b). District cooling might account for about 2 % of cooling demand in Europe, and it is more common than in other regions worldwide, but availability of data is limited (IEA, 2015b; DHC+, 2012). District cooling, similarly to district heating, can be influenced directly by the public sector and is often a focus in assessments of how to increase uptake of tri-generation and cogeneration, while the potential implementation in industrial settings is less well focused. The industrial sector has more complex and more varying conditions, and industrial projects require adapted approaches.

Basic requirement for successful implementation of CHP (CHCP): precise assessment of electricity and heat (and cooling) demands and of technical and economic feasibility

Cogeneration power plants (CHP units) only generate environmental and economic benefits if they are running, and are only viable if there is a high and constant demand for heat.

This is similarly the case for tri-generation (CHCP units) and in the following therefore, tri-generation is not discussed explicitly, since the elaborated information is directly transferable.

Electricity output per unit of fuel (electrical efficiency) is generally lower in CHP units compared to electricity-alone installations. Only if significant amounts of heat can indeed be valorised is a CHP a suitable choice for an industrial site, a community energy scheme or a private setting. As a general rule, a significant and constant demand for heat should exist for at least 4,500 hours per year (more than half of the year) (Carbon Trust, 2010).

Figure 5 illustrates that energy savings associated with implementation of a CHP unit are closely linked to heat utilisation and replacement of a conventional heat supply method. If heat is not sufficiently needed by the consumer, implementation of a CHP unit will neither be economically viable nor will it be of environmental benefit. Therefore, a decision in favour of CHP implementation at a specific site should be based on a detailed individual assessment, including a precise feasibility study and a detailed calculation of economic viability under consideration of current and future electricity and heat (quantity, continuity and quality) requirements.

While meeting the actual heat demand and enabling proximity to the heat consumer are the main challenges in implementation of CHP projects, further challenges exist and can have a decisive influence on the success of a specific project. Typical challenges occurring in practice include the following aspects and should therefore be considered during the planning phase:

- Is the existing grid (electricity grid, heat grid if available) suitable to connect the new facility? Is grid reinforcement necessary? Is the grid generally available for connection, i.e. is a regulation in place that obliges the operator to connect the new facility or are negotiations necessary? What costs are relevant in this context?
- Is it technically and managerially feasible to integrate the CHP unit into the existing infrastructures, including the existing control systems of production units?
- Are there any circumstances which hinder the switch from current energy supply to a CHP scheme, such as long-term binding contracts for electricity and heat supply?

Often, the most advantageous situation is when the existing

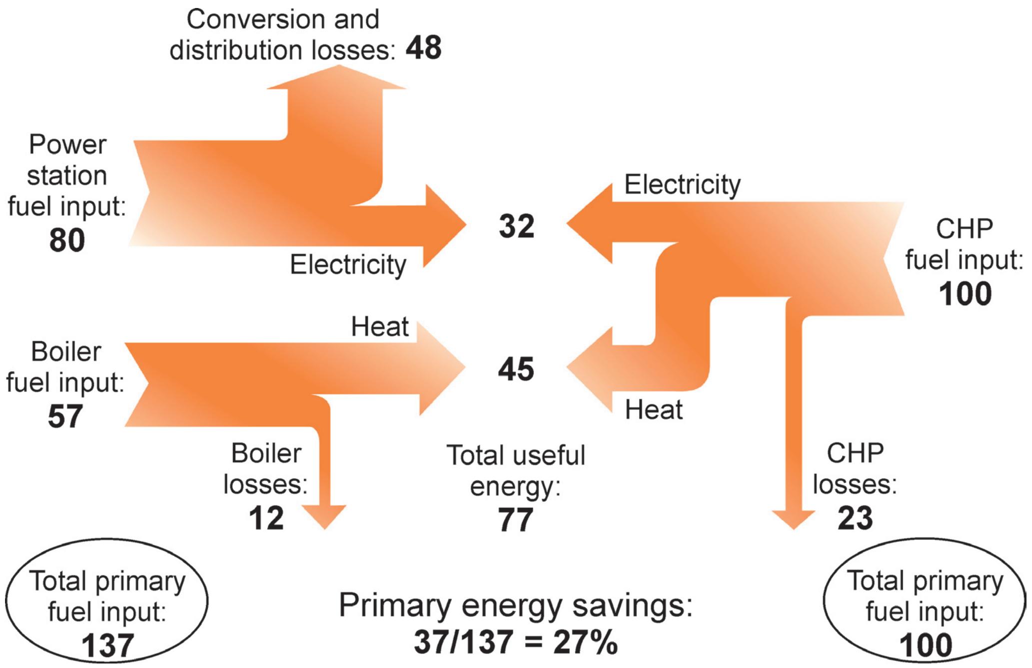

Figure 5 – Energy savings through a small-scale CHP unit installed at the site of the energy consumer compared to conventional energy sources (electricity from grid and on-site heat generation with boiler) (shown in units of energy). The example assumes that the central power station operated on fossil fuel has an efficiency of 40 %, while the remaining 60 % of the energy is lost, mostly as heat via cooling towers and to a smaller degree in electricity transmission. The example further assumes for the CHP unit an overall conversion efficiency of primary fuel to usable energy (power and heat) of 77 %. For 100 units of fuel, the CHP would produce 32 units of electricity and 45 units of heat. To produce an equivalent level of heat and electricity, the conventional power station and boiler would need around 137 units of fuel, so CHP yields primary energy savings of around 37/137 or 27 %. (partially based on: Carbon Trust, 2010).

equipment (such as the boiler for heat generation) needs to be replaced anyway, when investment is to be made for the plant and infrastructures or if an increase in demand for heat is expected (Carbon Trust, 2010).

Even if environmental benefits can easily be assessed and are clearly given, implementation of a CHP project in a business environment will only be attractive if the two other dimensions of cleaner production are ensured as well: economic viability and no risk of a negative impact on the quality of the company's products. This is closely linked to maintaining or ideally strengthening the market position of the company. The cleaner production triangle in Figure 6 illustrates the company perspective which sets the framework for implementation of projects in practice.

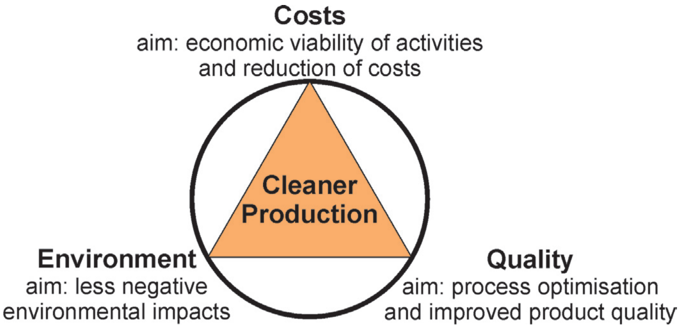

Figure 6 – Cleaner production objectives under company perspective (source: VDI, 2005, adapted).

In industrial settings, know-how and availability of resources can be major factors, in particular for SMEs. Those industrial sectors with favourable heat requirements according to Figure 4 are characterised by presence of a high number of SMEs. This indicates that implementation of combined heat and power production by SMEs has considerable potential. At the same time, implementation of combined heat and power production is among the measures that require significant financial investments and need to be aligned with existing infrastructures and strategies of a company. Therefore, a detailed and professional assessment of the project is highly advisable as well as a structured approach in order to cope successfully and efficiently with the level of complexity of such a project. In this context, cleaner production programmes and schemes can be highly valuable.

The cleaner production concept was developed in the early 1990s by UNEP (United Nations Environmental Programme) and UNIDO (United Nations Industrial Development Organization) to reduce the environmental impact of industry, and was defined as "the continuous application of an integrated environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment" (UNEP, 2015). Today cleaner production represents one central element in the transition to more sustainable consumption and production.

In its application, cleaner production can be seen as a simplified version of an environmental management system pursuant to ISO 14001 or EMAS (UBA, 2015). It is tailored to acceptability in practice and rapid uptake by companies, including SMEs, and focuses on a range of central elements that address preventive environmental protection. Access to knowledge, financial assistance and guidance to a structured implementation of cleaner production measures are among the central benefits. SMEs are major beneficiaries of external expertise, due to the fact that they often do not have the capacity to employ a cleaner production expert themselves.

The cleaner production approach aims at gradually improving environmental performance of companies by subsequently identifying and implementing most promising measures at a given site. The cleaner production framework offers a structured approach to assessment and implementation of measures. Such measures are not limited to the actual production processes, but include infrastructures, supply and management of resources, general procedures, etc.

The cleaner production approach has demonstrated its success in practice, and cleaner production programmes and/or cleaner production centres have been established in several countries, including Germany, Slovakia and France. From Germany alone, around 2,500 case studies are available (UBA, 2015; Webportal about Cleaner Production and Pollution Prevention, 2015), all of which have received state support and have been facilitated by cleaner production schemes. Implementation of CHP as cleaner production measure is documented in some cases and in different industrial sectors, in general in the context of implementation of renewable energy. Under such a framework, a CHP project can be implemented similarly to other cleaner production measures, which ensures an approach tailored to the actual needs of the company.

In cleaner production projects, replacement of conventionally produced heat by heat from a CHP unit should not remain the single focus when looking at improving the heat requirement of a process or a company. Cascaded use of heat energy (from high to low temperature levels) and reduction of the necessary temperature level (for example, through process modifications) are further options that can be successfully implemented in practice.

Conclusions

Cogeneration of heat and power has the potential to save significant amounts of fossil fuel and to reduce energy-related greenhouse gas emissions drastically. Although cogeneration is a sufficiently well proven technology in practice, its potential is still highly underexploited. District heating is a prominent and very suitable scheme to valorise excess heat from central power plants. Despite the similarities of the underlying technologies and processes, industrial application of combined heat and power production should be considered differently and in the specific context of the individual company. A viable approach is to define a CHP project as a cleaner production measure and therefore to assess it as part of the integrated environmental strategy of a company and to make use of the associated framework of well-proven procedures for successful implementation of such measures. A better consideration of CHP in the scope of cleaner production seems a very promising option to foster more widespread implementation in the industrial sector, including better uptake by SMEs.

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