Cogeneration (combined heat and power production) in Europe

Sigrid Kusch
ScEnSers Independent Expertise
Ulm, Germany
sigrid.kusch@scensers.org

Abstract—**Implementation of cogeneration, which is also termed as combined heat and power production (CHP), achieves high energy efficiency degrees due to the simultaneous supply of electricity and heat. This paper explores the current situation of cogeneration throughout Europe and beyond. The technology today is state of the art. Despite clear environmental benefits, adoption of cogeneration remains significantly behind existing potentials (70 to 80% of the potential not used). In Europe, the share of electricity produced in cogeneration mode is higher than in other regions, and cogeneration has a rather long tradition. Nevertheless, the share of electricity produced in cogeneration mode in the European Union remains below 12%, and no significant increase of that share has occurred throughout the last decade. In absolute figures, cogeneration in the EU declined by more than 10% in the last 10 years. This work includes a discussion of factors that merit more attention, both with view to interpretation of cogeneration data and with view to more widespread adoption of the technology.**

Keywords- electricity; heat; cogeneration; combined heat and power production (CHP); energy efficiency; decarbonisation

I. Introduction

Cogeneration, or combined heat and power production (CHP), delivers both power (usually electricity) and heat simultaneously. In contrast to power-only schemes, integration of heat valorises energy that would otherwise be considered waste heat of power generation. This make better use of the energy carrier and consequently contributes to a decarbonisation (reduction of carbon dioxide emissions) of the energy sector. Decarbonisation of the energy sector has highest priority on the pathway to limit global warming to below 2°C: around two thirds of global anthropogenic greenhouse gas emissions are energy-related [1]. Increasing energy efficiency is one of the most effective means to reduce emission of the greenhouse gas carbon dioxide (CO2) [2].

In conventional power supply, which is predominantly based on thermal energy processes, the largest share of the energy content of energy carriers is lost in the form of waste heat, and only around one third of the energy content is delivered as electricity to the consumer [3][4]. In thermal energy processes, which consist of a multistep energy conversion chain (release of chemical energy contained in the energy carrier through combustion to reach thermal energy, generation of mechanical energy via heat engines and finally conversion into electricity), occurrence of waste heat as a by-product is unavoidable due to the underlying thermodynamic principles. Advanced technologies today can achieve up to 45% electrical efficiency [3]. If waste heat is valorised to generate additional electricity, the electrical efficiency might be higher than 50%, but in any case, a significant discrepancy exists between energy indeed made available as electricity and the energy content of used energy carriers.

At the same time, a high demand for energy in the form of heat exists worldwide. Heat is often given less attention then electricity or transport fuels, however, globally and in Europe, demand for heat exceeds the demand for electricity or for energy in the form of fuels for transport [3][4]. Heat demand, both worldwide and in Europe, is currently met primarily through the conversion of fossil fuels via specific heat supply equipment such as boilers [5].

A key characteristics of cogeneration schemes is that heat is valorised in addition to the recuperation of the main target product electricity. Heat valorisation can contribute to ensuring comfortable temperatures in buildings, to supply hot water, or to cover industrial heat demands. This replaces other sources of heat supply, and therefore, achieves net savings of energy resources and a decline in corresponding CO2 emissions [6].

Cogeneration can reach up to 90% energy conversion efficiency, and most common are schemes that convert 75 to 80% of fuel input into useful energy [3]. Since not all heat is indeed valorised in practice, the realised average efficiency of cogeneration units operated worldwide was assessed with 58% [7]. This is below the theoretical potential, but still significantly higher than efficiency degrees in electricity-only schemes. This translates into significant environmental benefits of cogeneration schemes, along with economic benefits, although precise quantification of the benefits is not a simple task and remains challenging [8][9].

II. Current Status of Implementation of Cogeneration

Globally, around 10% of electricity is produced in cogeneration mode [7]. This share has not changed significantly over the past decade, even if absolute cogeneration has increased moderately (absolute consumption of electricity has also increased) [7]. Cogeneration has a tradition of more than 130 years: the first central power plant in the USA (New York City) started operation in 1882 in cogeneration mode (heat was supplied to nearby buildings).

Although the untapped potential is still huge (see section IV), many thousand CHP schemes are already in operation worldwide. Installations span a wide range of sizes (electrical capacities), and they cover a diversity of fields of applications. They also include different technologies (types of engines, heat recuperation equipment) [8][10].

Installations range from large-scale CHP schemes (more than one megawatt power output, usually using gas turbines or steam turbines, generally custom-build according to the individual needs of the one specific site) to packaged small-scale units (few kilowatts power output up to 1 MW) that are available on the market with predefined specification and sizes. Large-scale CHP units are operated at central power stations or at sites with high energy requirement such as large industrial sites in the chemical industry or the oil-refining sector, while small-scale CHP units are common at smaller industrial sites or smaller commercial applications, in community settings, at hotels, hospitals, or in domestic settings [10].

Most CHP units are operated with fossil fuel, but operation on solid biomass or biogas is increasingly common. At biogas plants, installation of a CHP unit is standard, since part of the heat is usually used to maintain a favourable temperature in the anaerobic digester. In Europe, biogas plants without temperature control are very rare exceptions limited to specific single installations [11][12], therefore, the many thousand biogas plants in Europe (more than 10,000 in Germany alone [13]) are examples of manifold CHP installations in practice. Nevertheless, the best-known example of a cogeneration scheme remains the setting where a large, centralised power plant (usually operated on coal or natural gas, but wood biomass is also relatively common) is equipped with heat valorisation via a district heating network.

Implementation of cogeneration shows high variations among different countries and regions. Although the first cogeneration plant in the 19th century was located in the USA (see above), adoption of the technology remained at rather low level in the USA throughout the 20th century and until today. Rising electricity demand was answered by building very large power plants, predominantly operated on coal; therefore, plants could not suitably be placed in city areas [14]. Considering that heat cannot be transported over long distances, the large distance to potential heat consumers is one explanation why cogeneration is not widespread in the USA [14]. Another reason is a regularly framework that did not incentivise energy efficiency and/or cogeneration throughout most of the 20th century. The US Public Utilities Regulatory Policies Act of 1978 (public utilities were obliged to use electricity from renewable sources and from cogeneration) boosted cogeneration implementation, and the share of cogeneration in electricity supply rose to around 8% [15][16]. Nevertheless, cogeneration has remained less common compared to Europe.

In particular, Scandinavian and continental European countries were (and remain) highly active in implementing cogeneration schemes, which can partially be explained by higher fuel costs compared to other regions such as North America [16]. Another element is the dense population in European cities, with many people living in apartments rather than single houses, which facilitates heat distribution [14]. With the CHP Directive, the European Union (EU) formally incorporated cogeneration in 2004 into its energy policy and has established a framework to foster implementation of cogeneration schemes.

In the EU, the average share of electricity produced in cogeneration mode is slightly higher than worldwide, amounting to around 11% in 2015 (Figure 1) according to official Eurostat data [17][18]. However, the data reveal some fluctuation rather than a constant increase, and overall an increase did not occur when comparing the last available data (year 2015) to the situation 10 years earlier (2005). In this period (2005 to 2015), Eurostat data [20] indicate that EU electricity consumption fell from 1,131,937 GWh to 996,363 GWh (decline of around 12%). This means that in absolute figures, cogeneration in the EU also declined by more than 10%. This is in contrast to the global situation, where electricity consumption is rising, and with the rise in electricity consumption cogeneration in absolute terms also rises, even if the share of cogeneration shows a plateauing performance at some 10% worldwide [7].

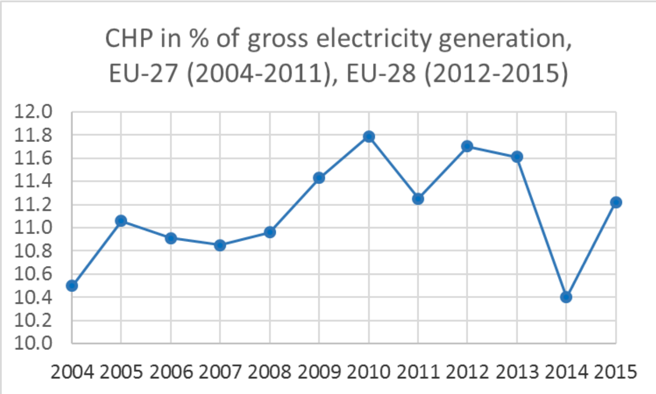

Figure 1. Share of electricity produced in cogeneration mode in the European Union (data source: Eurostat [17][18])

The fluctuations observed in Figure 1 can be assumed to be the result of highly different situations in the individual Member States of the EU. As an example, in Slovakia nearly 80% of electricity was produced in cogeneration mode in 2015, while in other countries, including Greece and France, the share was below 5% [17]. The situation in the EU Member States is shown with Figure 2 (countries with a cogeneration share below 10% in 2015 are not shown in Figure 2, which includes Romania: 8.45%, Sweden: 8.43%, and Spain: 8.08%, all other countries: below 8%). The five EU countries with the highest shares of cogeneration electricity, all with a share of more than 30% in 2015, are Slovakia (78.49%), Latvia (44.75%), Denmark (39.96), Finland (31.69%) and Lithuania (31.26%).

It is worth keeping in mind that the EU is a region with a particularly high diversity of countries, including size of countries and number of inhabitants, and consequently energy demands. Although Germany generates only 12% of its electricity in cogeneration mode, in absolute figures, it has the highest installed cogeneration capacity in the EU.

eISSN: 2453-6571, cdISSN: 1339-5076
ISBN: 978-80-554-1375-4

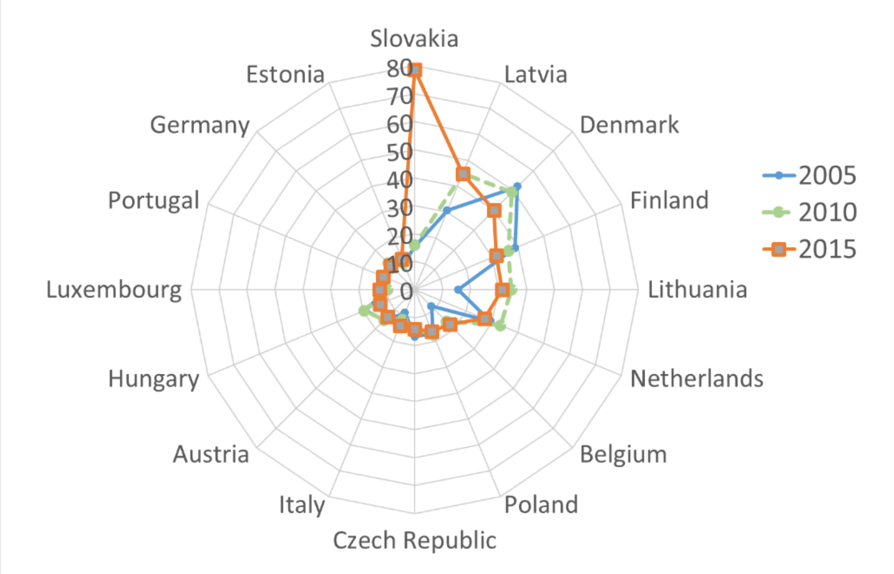

Figure 2. Share of electricity produced in cogeneration mode in EU countries in 2005, 2010 and 2015, in per cent of gross electricity generation (only countries with a share of more than 10 per cent cogeneration shown) (data source: Eurostat [17])

III. Interpretation of Cogeneration Data: Key Factors to be Considered

When interpreting cogeneration data, some factors need to be taken into consideration. Low shares of electricity produced in cogeneration mode can be the result of a generally low adoption of the technology in a country or region, however, such low shares might also primarily reflect specific elements of the prevailing power system. In France, for example, more than 75% of electricity comes from exploitation of nuclear energy [5]. Nuclear power plants are usually not equipped with heat valorisation schemes, therefore, the overall share of electricity produced in cogeneration mode is very low in the country, even if most thermal power plants are operated as cogeneration facilities. Similarly, an increasing share of electricity produced from renewables, which is given for example in Denmark, Italy and Austria, can drastically reduce the share of electricity produced in cogeneration mode: technologies such as solar energy or wind energy do not typically result in waste heat to be valorised (note that this is not the case for bioenergy: increased usage of biomass usually does generate waste heat, since energetic biomass valorisation is based on thermal energy conversion processes).

Therefore, it is important to be aware that cogeneration data usually refer to the total electricity produced in a country and not only to electricity generated in thermal power plants. Countries with high shares of electricity from renewable sources and/ or nuclear plants will usually score low in cogeneration statistics, even if they perform well in implementing cogeneration. One example is Finland, where hydropower is available at large scale and has been exploited since many decades: a major share of electricity generated in Finland comes from hydropower. At the same time, more than 80% of existing thermal power plants in Finland make use of cogeneration [3][8].

IV. Unused Cogeneration Potential

When considering that not all electricity supply solutions result into occurrence of excess heat, it becomes evident that the share of electricity produced in cogeneration mode is not usually a comprehensive indicator for the remaining cogeneration potential [8]. A lack of official statistical data on cogeneration implemented at thermal power plants, i.e. a lack of cogeneration statistics based on electricity generated in thermal processes only, hinders a precise assessment to what extent the cogeneration potential is indeed being used throughout different countries and regions.

Nevertheless, when considering that more than 60% of all electricity worldwide comes from fossil energy via thermal conversion processes [2][5], and still more than 40% in the EU [5], the currently low shares of energy generated in cogeneration schemes reveal a huge unused potential for more widespread adoption of the cogeneration technology, worldwide and in Europe. Therefore, it can be assessed that below 30% of the cogeneration potential in the EU is indeed being used, and below 20% of the potential worldwide, while the remaining 70 to 80% of the potential remains untapped.

Pathways to decarbonise the energy system give high priority to more widespread implementation of renewable energy schemes. As outlined above, such a transition results into less potential to integrate cogeneration. The goals to increase renewable energy and the goal to increase cogeneration unlock little synergy, but they do not exclude each other. On longer perspectives, cogeneration might be a technology of transition [19], and clearly the prioritised promotion of renewable energy schemes is highly justified. Nevertheless, fostering implementation of cogeneration is equally justified as long as the energy systems remain strongly based on thermal processes.

V. A Focus on Cogeneration in a Business Environment

Assessments how to increase uptake of cogeneration often focus on large, centralised power plants in combination with district heating [3]. Such settings are closely interlinked with urban planning and fall into the sphere that can be designed or at least significantly influenced by the public sector. While this area is relatively well studied, less attention is usually given to implementation in an industrial setting or in other decentralised schemes [8].

Implementation of combined heat and power production in an industrial setting clearly requires a different approach compared to cogeneration as a task for urban planning [8]. Elements to ensure successful implementation of CHP projects in a business environment include technical issues, efficient heat valorisation strategies, and successful management of economic challenges [8][21]. A CHP project in a business environment can be approached as part of an integrated environmental strategy of a company [8]. One obstacle is that funding programmes or other promotional programmes are often designed to address district heating or similar initiatives, while the industrial setting is usually less in focus, resulting in a situation where industrial initiatives or other decentralised projects fall between the regulations and might not meet eligibility criteria.

The central driver for CHP implantation in the industrial sector will be the generation of economic benefits. Therefore, programmes that aim at fostering cogeneration uptake should ensure that applications of all sizes (electrical capacities) in the industrial sector are included among the eligible projects. Another key element to encourage uptake of cogeneration by companies is access to knowledge and guidance (both on financial and technical issues), which is particularly beneficial for small and medium-sized enterprises (SME) who often lack human and financial resources to engage in cleaner production measures [8][22][23].

VI. Summary and Conclusions

Cogeneration is a powerful means to increase energy efficiency. However, around 70% of the potential to implement cogeneration in the EU remains untapped, and worldwide around 80% of the potential is not used. Most countries worldwide, and many countries in the EU, generate below 10% of their electricity in cogeneration mode. However, there are huge variations among countries. Five EU countries have shares of cogeneration electricity above 30%, with a maximum value reaching nearly 80%. Programmes fostering uptake of cogeneration often focus on district heating to valorise excess heat from centralised power plants. While that is one suitable application of cogeneration, its potential implementation in industrial settings or other decentralised schemes merits increased attention.

References

[1] International Energy Agency (IEA), Energy and climate change – world energy outlook special briefing for COP21, IEA publication, Paris, 2015.

[2] International Energy Agency (IEA), World Energy Outlook 2015, IEA publication, Paris, 2015.

[3] International Energy Agency (IEA), Co-generation and renewables, IEA publication, Paris, 2011.

[4] International Energy Agency (IEA), Heating without global warming, IEA publication, Paris, 2014.

[5] European Commission (EC), EU energy in figures – statistical pocketbook 2016, Brussels, 2016.

[6] U. Çakir, K. Çomakli, and F. Yüksel, "The role of cogeneration systems in sustainability of energy," Energy Conversion and Management 63, 2012, pp. 196-202.

[7] International Energy Agency (IEA), Tracking clean energy progress 2015 – Energy technology perspectives 2015 (excerpt IEA input to the Clean Energy Ministerial), IEA publication, Paris, 2015.

[8] S. Kusch, "An overview concerning combined heat and power production: a smart way to improve energy efficiency," CSE City Safety Energy 2-2015, 2016, pp. 132-141.

[9] M. Bianchi, L. Branchini, A. De Pascale, and A. Peretto, "Application of environmental performance assessment of CHP systems with local and global approaches," Applied Energy 130, 2014, pp. 774-782.

[10] Carbon Trust, Introducing combined heat and power (Technology guide), Carbon Trust, London, 2010.

[11] S. Kusch, and H. Oechsner, "Vergärung landwirtschaftlicher Substrate in Feststofffermentern," in Fachagentur Nachwachsende Rohstoffe (FNR) (Ed.), Trockenfermentation - Evaluierung des Forschungs- und Entwicklungsbedarfs. Gülzower Fachgespräche, vol. 23, 2004, pp. 105-113. (in German)

[12] S. Kusch, Methanisierung stapelbarer Biomassen in diskontinuierlich betriebenen Feststofffermentationsanlagen, PhD thesis, University of Hohenheim, Herbert Utz Verlag, Munich, 2007. (in German)

[13] Agentur für Erneuerbare Energien, website https://www.unendlich-viel-energie.de/, accessed 26 September 2017.

[14] B. Bridgeman, Combined heat and power (cogeneration). In: N. Cohen, and P. Robbins (Eds.), Green Cities: An A-to-Z Guide, Thousand Oaks, SAGE Publications, 2011, pp. 96-100.

[15] K. Ehrhardt-Martinez, and V. McKinney, Combined heat and power. In D. Mulvaney and P. Robbins (Eds.), Green Energy: An A-to-Z Guide. Thousand Oaks, SAGE Publications, 2011, pp.88-90.

[16] A.J. Waskey, Cogenerators. In P. Robbins (Ed.), SAGE Encyclopedia of Environment and Society. Thousand Oaks, SAGE Publications, 2007, pp. 298-299.

[17] Eurostat (2017a), Combined heat and power generation (official statistical dataset of the European Union), retrieved via http://ec.europa.eu/eurostat on 26 September 2017.

[18] Eurostat (2015), Combined heat and power generation (official statistical dataset of the European Union), retrieved via http://ec.europa.eu/eurostat on 27 October 2015.

[19] K.A. Kelly, M.C. McManus, and G.P. Hammond, "An energy and carbon life cycle assessment of industrial CHP (combined heat and power) in the context of a low carbon UK," Energy 77, 2014, pp. 812-821.

[20] Eurostat (2017b), Electricity consumption by industry, transport activities and households/services (GWH) (official statistical dataset of the European Union), retrieved via http://ec.europa.eu/eurostat on 26 September 2017.

[21] M. Köttner, S. Kusch, A. Kaiser, D. Dörrie, and D. Collins, Economic modelling of anaerobic digestion/ biogas installations in a range of rural scenarios in Cornwall. Cornwall Agri-Food Council, 2008.

[22] Umweltbundesamt (UBA) (German Federal Environment Agency), Cleaner production Germany (website), http://www.cleaner-production.de/, last accessed on 26 September 2017.

[23] United Nations Environment Programme (UNEP), Resource efficient & cleaner production (website), http://www.unep.org/recp/, last accessed on 26 September 2017.