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COMMON CHALLENGES IN THE IMPLEMENTATION OF DECENTRALIZED COMBINED HEAT AND POWER PRODUCTION (CHP)

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ABSTRACT

Cogeneration, or combined heat and power production (CHP), delivers both electricity and heat simultaneously, which achieves high overall energy efficiency. Although CHP technologies are state of the art, and advantages of their adoption are well known, 70% (European Union) to 80% (worldwide) of the existing potential remains untapped. Initiatives fostering more widespread uptake of cogeneration so far often focus on large scale electricity supply schemes combined with the operation of district heating, while the situation at single industrial sites or other decentralized energy supply schemes is less in focus, although this area of potential application clearly merits high attention.

A range of challenges can be identified in practice when it comes to implementation of CHP schemes at industrial sites or other decentralized locations. However, problems commonly occurring in such a context in practice are currently not well documented in literature. Using a lens located at the science-practice interface allows to explore typical contexts and to propose solutions for commonly occurring problems when it comes to implementation of decentralized CHP schemes, in particular in a business environment.

Identified challenges can be structured into three clusters or dimensions. The challenges include (1) elements linked to meeting heat requirements in quantity but also in quality (heat valorisation dimension); (2) elements linked to the operation of the unit on site (technology dimension); and (3) specific management issues (management dimension). Each dimension is analysed and solutions to successfully meet challenges are indicated.

Keywords: cogeneration, CHP, energy efficiency, decentralized energy supply, science-practice interface

INTRODUCTION

Implementation of cogeneration, or combined heat and power production (CHP), aims at valorising excess heat in addition to the main target product power (usually electricity), which increases overall efficiency of thermal energy conversion processes from typically well below 50% to significantly higher levels of up to 90% [1]. Valorisation of excess heat replaces other forms of heat supply. Many thousand CHP units of very different types and capacities are operated worldwide [2]. However, implementation of cogeneration remains well behind existing potentials: in the European Union (EU) just around 30% of the potential is currently being used (and the share of electricity generated in cogeneration mode has remained at around 11% throughout the last decade), and globally on average just around 20% of the cogeneration potential is being used [3].

Studies and initiatives to foster more widespread uptake of cogeneration often focus on large, centralized power plants in combination with district heating [1, 4], which is closely interlinked with urban planning and can be significantly influenced directly by the public sector. Despite the huge potential, less attention is given to CHP implementation in industrial settings or other decentralized schemes, where a successful implementation clearly requires a different approach [5].

The publication explores common challenges in CHP implementation in a decentralized setting, and in particular in a business environment. The manuscript integrates experience from practice in combination with knowledge documented in literature. By considering both scientific knowledge and practice-based experiences, the work is located at the science-practice interface, which is assumed suitable both to analyse the context and to bring the knowledge to the attention of a wider audience. Challenges explored here are common in practice, nevertheless, they are rarely documented and not usually available in literature. This might partially reflect the fact that failed projects are rarely presented in literature, which applies to both scientific and practice-oriented publications. One main aim of this publication therefore is to make knowledge widely available. Another aim is to structure the challenges, so that they can be better addressed. Furthermore, approaches to address challenges are proposed, which aims at being instrumental towards minimizing the risk of failure of projects in practice.

THREE DIMENSIONS OF CHP CHALLENGES: HEAT VALORISATION, TECHNOLOGY, MANAGEMENT

A variety of challenges towards implementation and successful operation of a CHP unit in a business environment can occur, and such contexts are usually equally relevant for other decentralized energy supply projects. Challenges encountered in practice can be classified to belong to three dimensions (Figure 1), namely (1) the heat valorisation dimension, (2) the technology dimension, and (3) the management dimension.

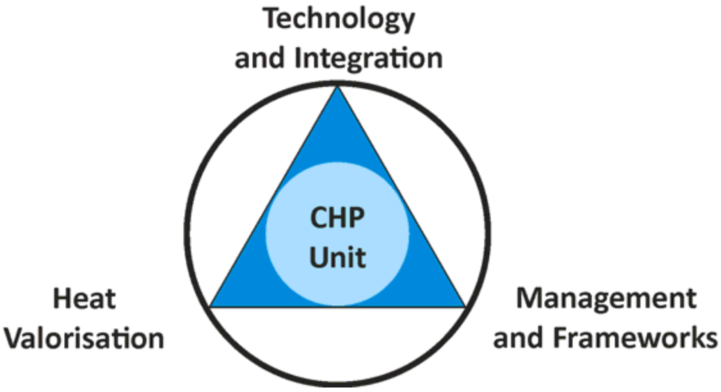


Figure 1: Triangle of challenges in the implementation of combined heat and power production in a business environment

Specific issues that will require extensive attention typically exist in the following areas:

- Distribution and usage of heat *(heat valorisation challenges)*: quantity, quality and continuity of heat required by the site itself and/or that can be delivered to other sites; transport of heat
- The actual CHP technology and its integration *(technology challenges)*: CHP unit; compatibility of CHP unit with the existing production units and control systems; characteristics of existing energy infrastructures (connection to electricity grid, heat network)
- Management issues and wider frameworks affecting economic viability *(management challenges)*: existing contracts for energy supply; time scale for the amortisation of existing and newly to install equipment (e.g. existing boiler); availability of grants; favourable regulatory frameworks

The following explores key challenges and identifies pathways to limit risks associated with each area. While all three dimensions require careful attention, heat valorisation can be considered being the core dimension in this triad.

HEAT VALORISATION CHALLENGES

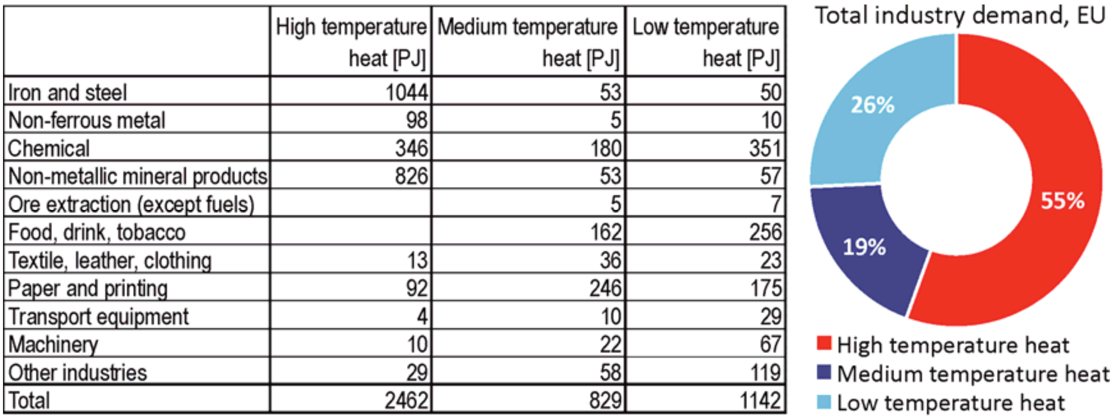
Installation of a CHP unit is only suitable if indeed a high share of generated heat can be valorised. If such valorisation is not possible, electricity-alone installations should be preferred, as they usually have higher electrical efficiency. If not sufficient heat is indeed valorised, implementation of a CHP unit will neither be economically viable nor will it be of environmental benefit [2, 5]. Therefore, in the planning phase, demand for heat should be assessed in detail. As a rule of thumb, a project can be assumed to be potentially viable and should therefore proceed to more detailed planning if a significant heat demand for half of the year exists within a reasonable distance [2, 8].

Transport of heat requires own infrastructures and is only viable for short distances, even if high insulation efforts are made. Heat insulation is a cost factor; therefore, the level of efforts needs to be assessed under overall economic viability of a project. It is not possible to state a general maximum distance for the transport of heat. Viability will depend on several factors, including: (1) temperature level of heat recuperated at the CHP unit, (2) geographical location and general profiles of the ambient temperature, (3) overall quantity of heat to be transported, (4) temperature level required by consumers, (5) costs for pipelines and construction works. While a large-scale cogeneration unit allows recuperation of heat with several hundred degrees Celsius, heat from a small-scale CHP unit will not only be of smaller quantity but also of a lower temperature, because of characteristics of used technologies [5]. With CHP units below 500 kW electrical capacity, recuperated heat will rarely exceed 150°C, and in practice a temperature level around 100°C is common. This reduces potential use for larger district heating (a minor contribution is possible), or other supply over longer distances. Where connection to an existing heat network is feasible, this can nevertheless often represent the best choice to deliver heat to a valorisation pathway. More common for small-scale CHP installations are decentralized micro-grids for heat that connect few entities, e.g. a biogas plant equipped with a CHP unit and a number of rural heat consumers in a nearby village. Transport of heat from small-scale CHP units will usually be economically viable for few kilometres [5, 8]. A CHP unit therefore needs to be placed close to where the actual heat demand is. If the CHP unit is run on biogas, a potentially very advantageous alternative to actually transporting heat is the delivery of biogas via a micro gas grid. Gas transport does not require heat insulation and unlike heat networks only requires one-way pipelines, which drastically reduces costs. Gas transport is viable over longer distances. A micro gas grid allows the transport of biogas to a remote CHP unit that is placed in proximity of a heat consumer (e.g. a school, a commercial site).

Quality of heat that is required by customers is a major element to be considered. Assessing the quantity of heat demand is not enough; even at sites with high demand for heat, the CHP unit might not be able to valorise its heat if the required temperature level is higher than the temperature level of heat recuperated at the CHP unit. Three temperature ranges for heat demand exist [1, 4, 6]:

- *low temperature heat:* below 100°C, primarily for space heating, hot water
- *medium temperature heat:* 100-400°C, e.g. for processes of drying, evaporation
- *high temperature heat:* above 400°C, for industrial transformation processes such as reduction of ores, calcination, electric induction

Heat from a decentralized small-scale CHP will usually be a suitable choice to meet low temperature heat demand, and can supply some medium temperature, but it will not be useful in the high temperature heat segment required in various industrial sectors (Figure 2). Therefore, typical applications are temperature regulation in buildings and provision of hot water (residential sector, public sector, industrial sector). Nevertheless, several applications in industry, such as drying processes in the chemical industry, or applications in the food sector and the paper and printing sector, are further promising [5]. A detailed feasibility study should therefore ensure the best possible match between the quality of heat supplied and the temperature level actually needed by the customer.



	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 2: Breakdown of heat demand according to heat levels in the industrial sectors of the European Union (EU27) (based on data estimated for the year 2009 by [6]) (here reproduced from [5])

Seasonality of heat demand further requires detailed attention. Especially in the building sector (space heating, provision of hot water), the difference between requirements in the summer period and in the winter period can be very high, and in addition, weather conditions and changing profiles throughout the day can contribute to marked fluctuations in the heat demand profile. The industrial sector can have own profiles. Heat cannot be conventionally stored over longer periods; therefore, it is not suitable to simply balance heat demand and availability as averages over the year. More detailed assessments are required that take into account seasonal patterns but also other important elements in the profiles of both heat demand and heat availability. Availability of temperature demand profiles can be a specific challenge [7]. Heat available for use on site or for delivery to customers will also depend on self-consumption of the facility (e.g. a biogas plant has a higher self-consumption of heat in the winter, thus excess heat is lowest in winter when external heat demand is highest).

At sites with little overall heat demand or with unfavourable heat requirement profiles, the demand for cooling should be assessed. Excess heat can be transformed into energy for cooling/ chilling in trigeneration schemes. Trigeneration is also called CHCP (combined heat, cold, and power production). One application that can be considered state-of-the-art is the implementation of absorption chilling to achieve air conditioning in buildings, which replaces conventional air conditioning. Absorption chilling uses heat energy to generate chilled water that can be distributed via standard infrastructures. Comparable to cogeneration, trigeneration is typically rather assessed for larger applications under the lens of district solutions, in projects that are advanced by the public sector, while industrial applications or decentralized applications are rarely assessed, and their potential is often overlooked.

Valorisation of heat via CHCP can turn an economically unviable CHP project into one with business profit [2, 8]. Consumers with significant demand for cold include hospitals, public and private buildings, stores and supermarkets, the food sector, agricultural sites. One example of an agricultural unit that benefits from temperature control even in a moderate climate zone is a pig stall [8]. The demand for cooling is expected to significantly rise in future worldwide, including in Europe [9]. Cooling is most required when demand for heat is low, i.e. during summer periods, which contributes to the potential profitability of considering both heat and cold along with electricity generation. Similarly to heat valorisation, challenges to deliver cold to consumers are maximum suitable transport distances, seasonal demands and fluctuating demand profiles, and quality requirements (achievable temperature levels). With decentralized (small-scale) units, the energy level contained in excess heat is suitable to ensure chilling down to a temperature of around 8°C, which is sufficient to regulate temperature in buildings. If a consumer requires lower temperatures, e.g. below 5°C for cold stores to keep agricultural produce such as potatoes at a favourable temperature, a decentralized CHCP unit will not usually be able to ensure such results [8]. More advanced applications require and merit further research and development [5, 8, 10].

CHALLENGES RELATED TO CHP TECHNOLOGY AND ITS INTEGRATION

Thousands of CHP units are in operation worldwide. A country or region that is experienced in operating large-scale cogeneration is not necessarily particularly well positioned for the successful implementation of small-scale CHP units. Romania is an example where district heating traditionally was highly popular during the socialist era until the end of the 1980s. After the revolution, many district heating systems were dismantled due to lack of maintenance, unreliable operation, and unfavourable cost structures [11]. Today, many bigger cities in Romania use district heating based on heat provided from cogeneration at large power plants, while the absence of decentralized small-scale CHP units is staggering [11]. A similar situation seems to exist in other Eastern European countries. Such a situation will require successful pioneer projects to reach a tipping point where technologies and their adoption become more common. In the absence of a domestic market, small-scale CHP units for individual sites can be imported. However, an installed CHP unit requires regular maintenance; furthermore, an operator, especially without prior detailed know-how about such equipment, will usually benefit from availability of routine support by the manufacturer of the CHP unit [8]. Therefore, a future operator needs to carefully and realistically assess the market in the specific region along with individual needs for support. It is advantageous to exchange knowledge with other operators of the same equipment.

One area that requires a detailed assessment on site is whether it is technically feasible to integrate the foreseen CHP unit in the existing site-specific infrastructures, including the existing control systems of production units [2].

Furthermore, challenges frequently occur when it comes to connecting a CHP unit to wider networks, namely the electricity grid, and if available a heat distribution network. Technical network specifications need to be assessed in detail, along with requirements of the grid operator. Depending on the technology, a decentralized small-scale CHP unit might be able to function without connection to the electricity grid, or not [2]. CHP units equipped with an asynchronous (‘grid-controlled’) electrical generator instead of a synchronous (‘self-controlled’) generator cannot actually be operated as stand-alone units by self-generators but require connection to the electricity grid. Especially at lower capacity, such units are significantly cheaper compared to units that do not necessarily require connection to the electricity grid. Since a CHP unit is designed to be a facility that produces electricity (and heat), the CHP site is a potential supplier of electricity to the electricity grid. National regulations or individual regulations of the electricity grid operator define the conditions of connection. A favourable situation is given where regulations are in place that oblige the operator to connect the new facility. Otherwise, extensive negotiations might be necessary, which can induce long periods of time to come to a decision and costly individual assessments to clarify the conditions for connection [8, 12]. Electricity grid reinforcement might be necessary.

THE MANAGEMENT DIMENSION OF CHP CHALLENGES

It is essential to also consider circumstances linked to the wider management and operation of the (industrial) site. In this context, any circumstances that hinder a site to switch from the current energy supply schemes to the operation of a CHP scheme, or circumstances that are particularly beneficial in the context, supporting a clear decision in favour of a CHP unit, must be identified. Circumstances that hinder a site to switch away from its current energy supply schemes might be the result of existing long-term binding contracts for electricity and heat supply [2]. An advantageous situation is given when existing equipment such as the boiler for heat generation needs to be replaced anyway [2], or if significant increase of heat demand is to be expected in near future due to modifications of the process units or new areas of operation.

A review of current heat consumption against actually required heat of a site can add value to a CHP project. If required temperature levels can be reduced, potential applicability of heat from CHP is increased. Modifications of process operation, or substitution of auxiliary or other materials are examples of frequent measures that can often significantly reduce the required temperature level without reducing the quality of the product or overall efficiency of the process [13, 14].

In addition to site-specific challenges, the general frameworks require attention. Decentralized CHP often falls under other regulatory frameworks than large centralized installations that are typically connected to district heating systems. CHP in an industrial environment can also fall between policy fields in a problematic way that will reduce potential profitability and more generally the interest of potential investors. Typical examples are promotional programmes that encourage CHP uptake via availability of grants or other financial incentives, but where the schemes are shaped for requirements of large-scale installations, while they are not sufficiently beneficial for small-scale units. The EU has formally incorporated cogeneration into its energy policy in 2004 via the CHP Directive, but the directive targets primarily district heating and large-scale power plants, which is reflected in the measures and programmes introduced by the Member States. Influencing this situation towards better frameworks and more investment subsidies or other financial incentives for small-scale facilities requires putting decentralized CHP with more priority on policy agendas.

In the current industrial practice which is usually characterized by a lack of specific CHP regulation that fosters decentralized applications, one promising solution is to frame a CHP initiative as a Cleaner Production measure [5]. This will often allow to apply for financial assistance and external expertise under general Cleaner Production programmes aimed at encouraging pro-active initiatives to implement environmentally beneficial projects in a business environment [5]. Cleaner Production is a now widely used structured approach, tailored to the specific needs of companies, including small and medium-sized enterprises (SMEs), to pro-actively improve environmental performance of single sites [14, 15]. To identify suitable schemes, especially SMEs, who frequently lack financial and human resources for Cleaner Production initiatives, will often benefit from pro-actively searching for independent expertise offered by Cleaner Production Centres or other institutions. CHP as a Cleaner Production measure is documented in dozens of case studies from Germany, all of which have received state support and have been facilitated via Cleaner Production schemes [13, 14].

CONCLUSIONS

The potential for more widespread implementation of CHP worldwide is huge. Although CHP can be considered state-of-the-art, a range of common challenges and potential pitfalls exist in practice. Challenges were identified to belong to three dimensions: (1) heat valorisation, (2) CHP technology and its integration, and (3) management and wider frameworks. Each dimension should be carefully assessed in a detailed feasibility study. Explicit consideration of the possible problems described in this publication can be expected to contribute to the success of a specific project.

Science, research and development can foster implementation of decentralized CHP units. Progress is required with view to both technical and non-technical elements. Development of more advanced CHCP units can contribute to better valorisation of heat, if the heat energy can be used to provide cooling at low temperatures. Actual usage of heat, including in an industrial setting, generally is a wide area with significant potential for improvement, and one important field is the quality of heat (temperature level) required for specific applications. Furthermore, theory and practice around optimum integration of CHP units in decentralized settings merit increased efforts. At the science-policy interface, initiatives that put decentralized CHP schemes on policy agendas can contribute to more favourable frameworks.

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