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Cogeneration & Trigeneration – How to Produce Energy Efficiently

A practical Guide for Experts in Emerging and Developing Economies

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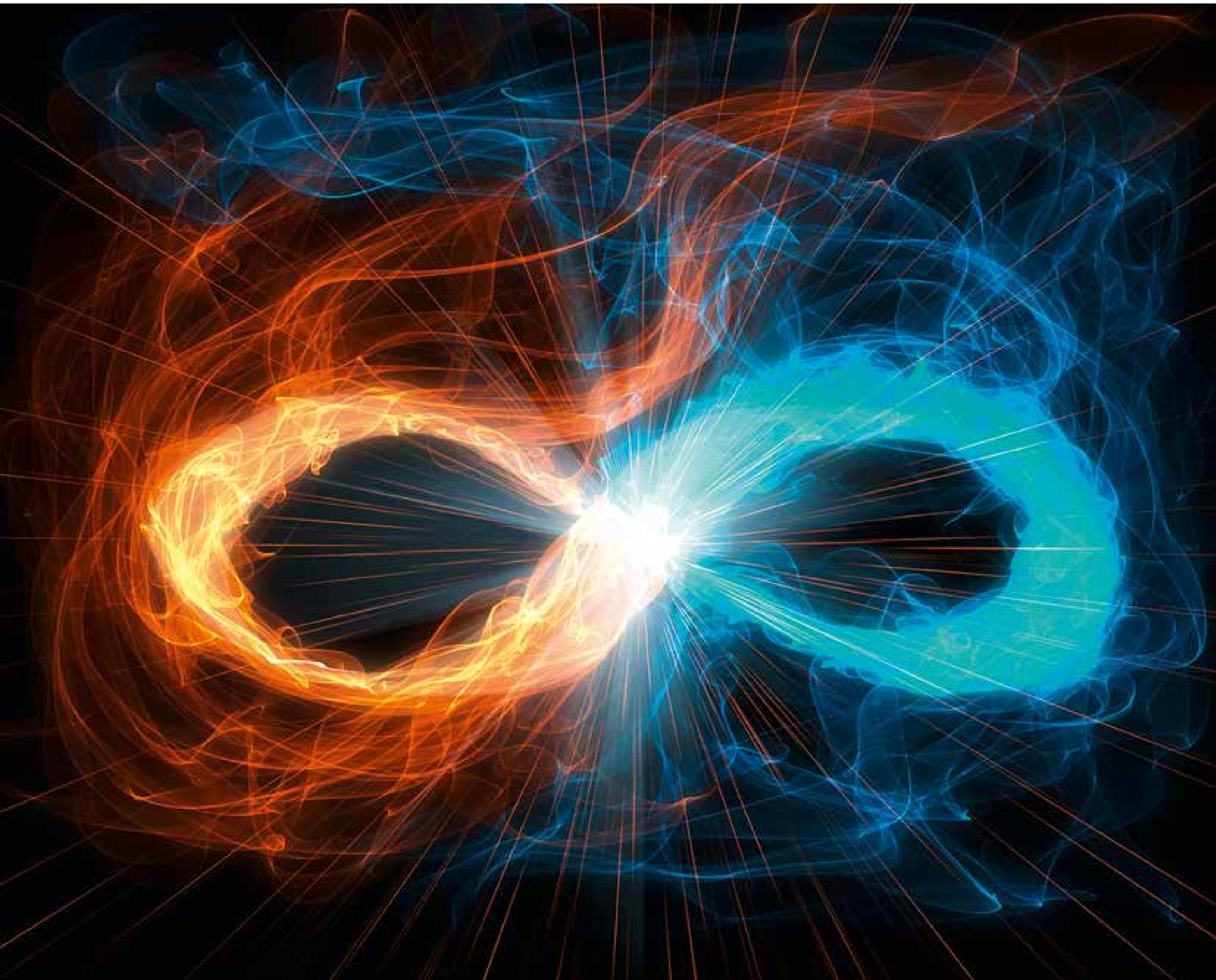

Abbreviations and Acronyms

AChEE	Eficiencia Energética
ANEEL	National Electric Energy Agency
ANME	National Agency for Energy Management
ANP	National Agency of Petroleum, Natural Gas and Biodiesel
ATES	Auqifer Thermal Energy Storage
BEE	Bureau of Energy Efficiency
BMUB	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BMWi	Federal Ministry for Economic Affairs and Energy
BOO	Build Own Operate
C2E2	Copenhagen Centre on Energy Efficiency
CAPEX	Capital expenditures
CCGT	Combined Cycle Gas Turbine
CCHP	Combined Cooling, Heating and Power
CERC	Central Electricity Regulatory Commission
CH4	Methane
CHP	Combined Heat and Power
CHW	Chilling Water
CO_2	Carbon dioxide
Cogen	Cogeneration (Combined heat and power production)
CSP	Concentrated Solar Power
DC	District cooling
DKTI	German Climate Technology Initiative
EBA	European Biogas Association
EE	Energy Efficiency
EEG	Erneuerbare-Energien-Gesetz
EEWärmeG	Act on the Promotion of Renewable Energies in the Heat Sector (Erneuerbare-Energien-Wärmegesetz)
EEX	European Energy Exchange
EnEV	Energy Saving Decree (Energieeinsparverordnung)
EPC	Energy Performance Contracting
EPC	Engineering, Procurement and Construction
ESC	Energy Supply Contracting
ESCo	Energy Services Company
EU	European Union
G20	Group of Twenty (major economies)
G20-EEAP	G20 Energy Efficiency Action Plan
G8	Group of Eight
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GJ	Gigajoule
GSEP	Global Superior Energy Performance Partnership
GW	Gigawatt
h	hour
H_2S	Hydrogen sulfide
HCD	Human Capacity Development
hfu	hours of full utilisation
HVAC	Heating, Ventilation and Air Conditioning
HVDC	High Voltage Direct Curent
IEA	International Energy Agency
IGEF	Indo-German Energy Forum
INR	Indian Rupee
IPEEC	International Partnership for Energy Efficiency Cooperation
IPP	Independent Power Producer
ISO	International Organization for Standardization
JPNATC	Jai Prakash Narayan Apex Trauma Center

kV	Kilovolt
kW	Kilowatt
kWe	Kilowatt electric
kWh	Kilowatt hour
l	liter
LiBr	Lithium bromide
LNG	Liquified Natural Gas
LPG	Liquefied Petroleum Gas
M	million
MDG	Millennium Development Goal
MJ	Megajoule
MME	Ministry of Mines and Energy
MoP	Ministry of Power
MTN	Mobile Telephone Networks
MW_{el}	Megawatt electric
MW_{th}	MW thermal
NAMA	Nationally Appropriate Mitigation Actions
NAPE	National Action Plan on Energy Efficiency
NEEAPs	National Energy Efficiency Action Plans
Nm^3	Cubic nanometer
NRW	North-Rhine Westphalia
O&M	Operation and Maintenance
ODA	Official Development Assistance
OECD	Organisation for Economic Cooperation and Development
ORC	Organic Rankine Cycle
OWG-SDG	Open Working Group on Sustainable Development Goals
PCM	Phase Change Materials
PEM	Polymer Electrolyte Membrane
PPAs	Power Purchase Agreements
ppm	Parts per million
PPP	Private Public Partnership
PPP	Purchasing-Power-Party
RE	Renewable Energy

RPO	Renewable Purchase obligation
SDGs	Sustainable Development Goals
SE4All	United Nations (UN) Sustainable Energy for All
SERCs	State Electricity Regulatory Commissions
SME	Small and Medium Sized Enterprises
t	ton
T&D	Transmission & Distribution
TES	Thermal Energy Storage, Thermal Energy Storage
TMIE	The Ministry of Industry and Energy
TND	Tunisian Dinar
toe	ton of oil equivalent
Trigen	Trigeneration (Combined production of cold, heat and power)
TWh	Terawatt hour
UN	United Nations
US$	Unites States Dollar
WBERC	The west Bengal Electricity Regulatory Commission
WHP	Waste Heat to Power
WMO	World Meteorological Organisation

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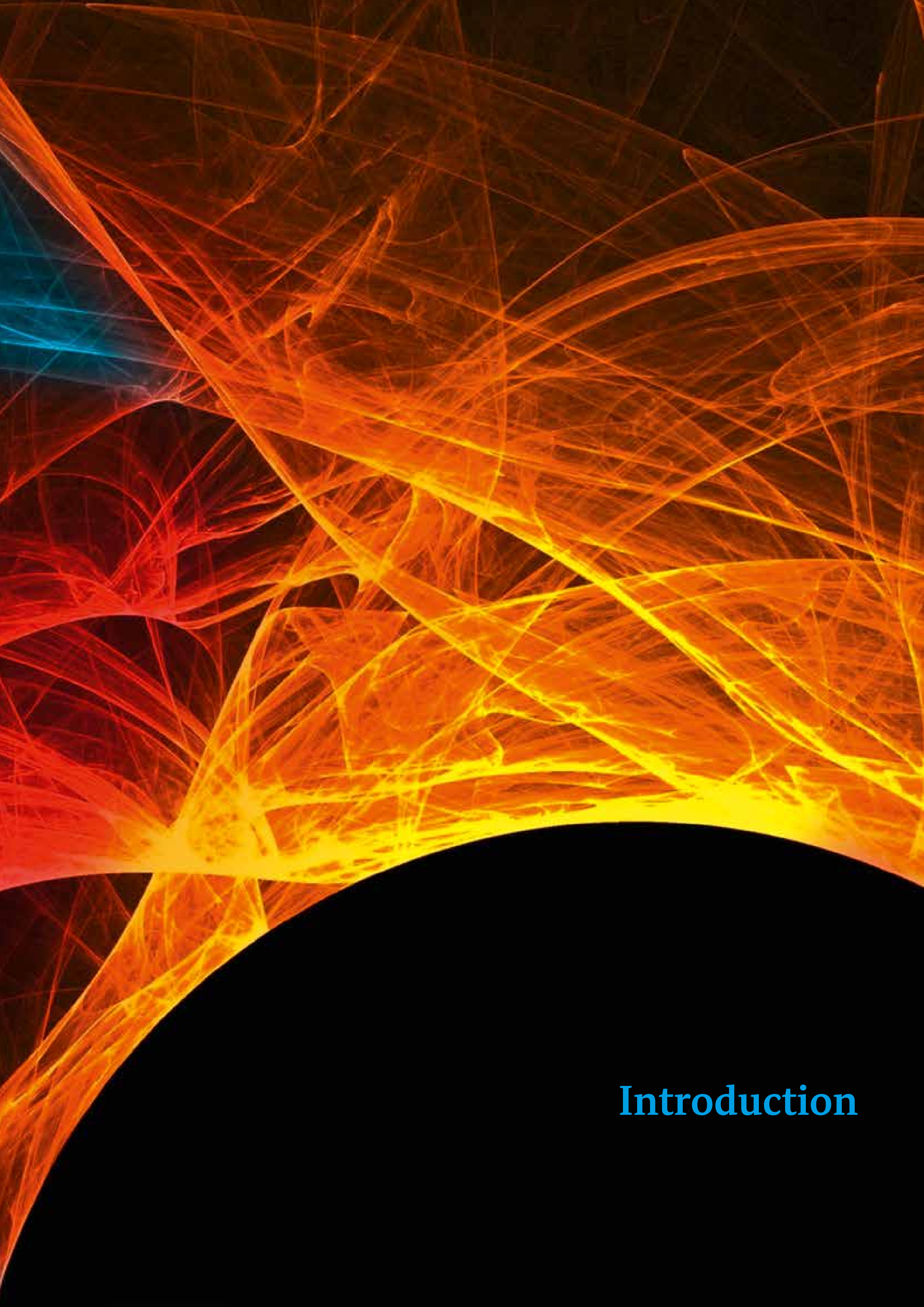


Introduction

1.0 INTRODUCTION

Energy efficiency is an increasingly important contributor to climate change mitigation while at the same time reducing the cost of energy as well as presenting an opportunity for technological innovation. Cogeneration (or 'cogen' for short) is in many cases one of the low hanging fruits of energy efficiency, and also has benefits on the electricity supply side. Cogeneration – the combined production of heat and power (also known as CHP) – encompasses all concepts and technologies by which heat and power are jointly generated in one unit and used by the same consumer, with the option of excess energy being fed into the public grid. The high levels of efficiency achieved in this process result from using waste heat as a co-product of electricity generation. Taking this one step further to include the generation of cooling energy from waste heat is called trigeneration (or 'trigen' for short) or combined cooling, heating and power (CCHP).

What makes the Concept of Cogeneration attractive?

'Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The worsening misalignment between energy demand and supply – with major consequences on energy prices, the threat of disruptive climate change and the erosion of energy security – all pose major challenges for energy and environmental decision makers. More efficient use of primary energy sources can help to mitigate the impact of these negative trends. Cogeneration represents a proven technology to achieve that goal,' states the IEA[1]. Many industrialised countries have taken this to heart and have developed explicit objectives and policies to promote cogeneration.

In February 2004 the EU adopted the CHP Directive to promote cogeneration in the EU by addressing several problems, including lack of awareness, unclear provisions related to electricity network access, inadequate support from local and regional authorities and disparate rules determining how CHP qualifies as highly efficient. The reason why this technological concept attracts so much attention is that the efficiency gain of cogenerated heat and power as opposed to the traditional separate provision of heat by local plants and power from the grid is more than 30% – in many developing countries close to 40%. This relates to savings of primary energy. The climate change mitigation impact is even greater, as cogeneration often also implies a fuel switch for electricity generation, for example from coal-fired power stations to gas-fired engines.

Cogeneration is much more efficient than separate generation of heat and electricity:
> 30% efficiency gain*
(close to 40% in the case of inefficient generation and transmission infrastructure)
> 50% fuel savings*.

* compared to separate generation
[→ see Figure 3]

More specifically the IEA report, which resulted from the 2007 Group of Eight (G8) summit in Heiligendamm, Germany, stated that 'CHP can reduce CO_2 emissions arising from new generation in 2015 by more than 4% (170 Mt/year), while in 2030 this saving will increase to more than 10% (950 Mt/year) – equivalent to one and a half times India's total annual emissions of CO_2 from power generation'.[2] The emission reduction is even larger in those countries where electricity generation, transmission and distribution systems are old and inefficient.

1) International Energy Agency (IEA), 2011

2) OECD/IEA, 2008

'Through reduced need for transmission and distribution network investment, and through displacement of higher-cost generation plants, increased use of CHP can reduce power sector investments worldwide by US$ 795 billion over the next 20 years, which corresponds to around 7% of total projected power sector investment over the period 2005–2030.' [3]

Cogeneration is mainly used in industry where solid/gas-fuelled or electric boilers can be replaced by cogen units, with waste heat and electricity being used for the plant's own consumption; ideally the excess is fed back into the grid. Any remaining electricity demand is provided from the grid, thereby improving the security of supply for the energy user.

Cogeneration technologies also incorporate renewable energy sources. If renewable energies are used, it makes sense to utilise the waste heat from generation processes for heating and/or cooling.

Cogen thus contributes to energy efficiency at the enduser level, but at the same time it can be considered part of the electricity supply system. If biogas or biomass is used as the fuel, cogen becomes part of the country's renewable energy activities.

Is the push towards cogen in many industrialised countries – where the aim is that 25% of electricity generated should come from cogeneration – also relevant to developing countries? Indeed it is, as greater primary energy efficiency and savings in CO_2 emissions are crucial for developing countries. This will apply even more as demand for thermal comfort increases, prompting the need for additional heating and cooling capacity: this could and should be provided by co-/trigeneration in order to limit growth in electricity demand.

Role of this Guide and Target Group

This guideline on co- and trigeneration in developing and emerging countries ('Cogen Guide') addresses all parties concerned with the planning and implementation of international and development cooperation projects and programmes relating to energy efficiency, especially those which promote energy efficiency solutions and technologies.

Other target groups are policy-makers, donors and related experts involved in the elaboration of such cooperation projects as well as their local partners. Both should benefit from the guide, or at least some of its modules.

The purpose of this guide is to provide:

- → a basic understanding of the technologies and fuels used for co-/trigeneration
- → information on why co-/trigeneration is a key technology for emerging economies and developing countries
- → information on potential cost savings and environmental benefits
- → a guideline for developing ideas and analysing potential to foster the technology as part of the energy efficiency market within a specific country
- → requirements and parameters for the successful implementation of co-/trigeneration projects.

3) OECD/IEA, 2008

Scope of the Guide

The cogeneration guide covers a wide range of technologies, fuels and applications. The emphasis is on application in industry and buildings in the small to medium size range (roughly 100 kW to 20 MW).

In order to be as helpful as possible in the planning and execution phase of development cooperation projects in the energy sector, the guide focusses on practical tools such as:

→ case studies

→ overview on determinants for co-/trigeneration application

→ checklist and decision map.

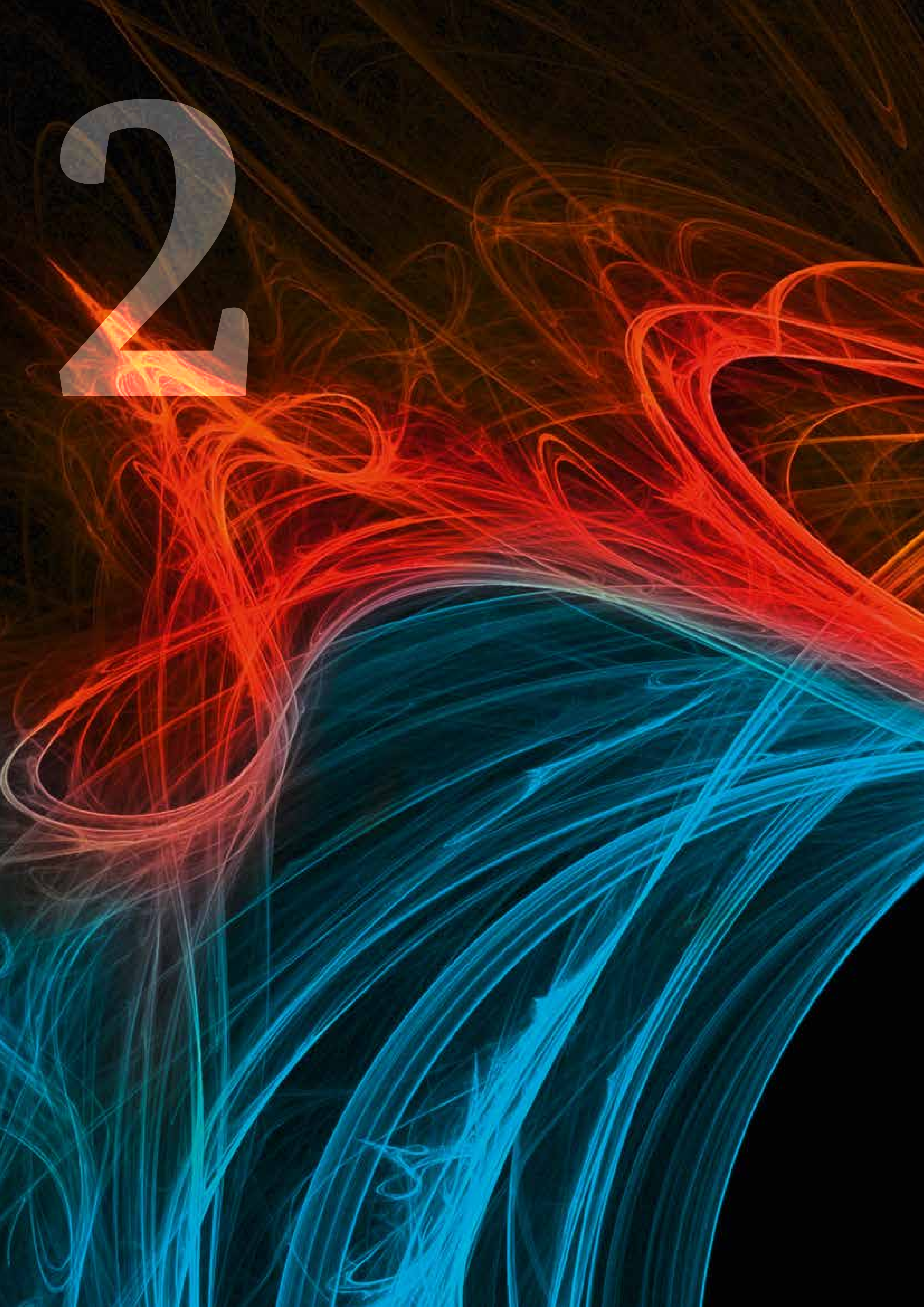
Structure of the Guide

The guide is structured in a modular way, based on the idea that readers can focus on selected aspects according to their needs and interests. Each chapter is self-explanatory.

Table 1 **Structure of the Co- and Trigeneration Guide**

Module/Chapter	Title/Content	Objective	Target Group
Chapter 2	Co-/trigeneration technologies and their application	Overview and basic understanding of technologies and range on applications	Advisors, experts and engineers from local agencies, consulting engineering firms, etc.
Chapter 3	Relevance of co-/trigeneration for development cooperation	Understanding the benefits of co-/trigeneration	Policy-makers and decision-makers
Chapter 4	Determinants for the application of co-/trigeneration including checklist	Detailed understanding and guidance regarding the application of various co-/trigeneration technologies in various sectors	Advisors, national and international experts
Chapter 5	Recommendations to enable co-/trigeneration + decision matrix/map	Guide to the conception, planning and execution of co-/trigeneration in energy sector projects	Development cooperation advisors Local partners and decision-makers

The determinants discussed in *Chapter 4* represent the key issues for successful implementation of co-/trigen technology and make it a focus section of this guide. As one of those determinants is the availability of skills at various levels, these are also discussed in *Chapter 4*. Prerequisites , success factors as well as typical applications for cogen and trigen plants are also presented in *Chapters 3* to *5*.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Co- and Trigeneration Technologies and their Application

2 CO- AND TRIGENERATION TECHNOLOGIES AND THEIR APPLICATION

This technology chapter focuses on cogeneration and trigeneration technologies as defined below and refers to an application capacity range from a few kilowatts electric (kW_{el}) up to 20 megawatts electric (MW_{el}). This is assumed to represent the most relevant application range for the targeted project background within the international development cooperation context. At the beginning of each sub-chapter a table briefly illustrates the key cogen/trigen characteristics for each technology. Selected case study boxes refer to the detailed project description in *ANNEX 1*, which illustrates some reference applications for the corresponding technology.

All case study examples as presented in *Chapters 2* and *4* are differentiated by technology, country and fuel, as illustrated in *Table 2* below and in further detail in *ANNEX 1*.

Table 2 Case Studies Overview

Technology	Country	Plant Capacity	Fuel	Case Study	Relevant Chapter
Trigen (absorption chiller)	South Africa	2,000 kW_{el}	Natural gas	MTN	2
Trigen (absorption chiller)	India	1,000 kW_{el}	Natural gas	JPNATC Hospital	2
Gas engine	Mexico	400 kW_{el}	Natural gas	Lagunero Alimentos	2
Gas engine	Chile	140 kW_{el}	Natural gas	Hospital HUAP	2
Bio-source	Germany	1,000 kW_{el}	Biogas	Im Brahm	2
Bio-source	Honduras	1,200 kW_{el}	Biogas	HonduPalma	2
Network and storages	Netherlands	> 6,000 kW_{el}	Various	UTES - Oostelijke Handelskade	2
Trigen (absorption chiller)	Germany	1,100 kW_{el}	Natural gas	Heideblume Elsdorfer	4
Trigen (absorption chiller)	Germany	694 kW_{el}	Natural gas	LVR Clinic	4
Trigen (absorption chiller)	Germany	2,827 kW_{el}	Natural gas	Phoenix contact	4

2.1 Introduction and Definitions

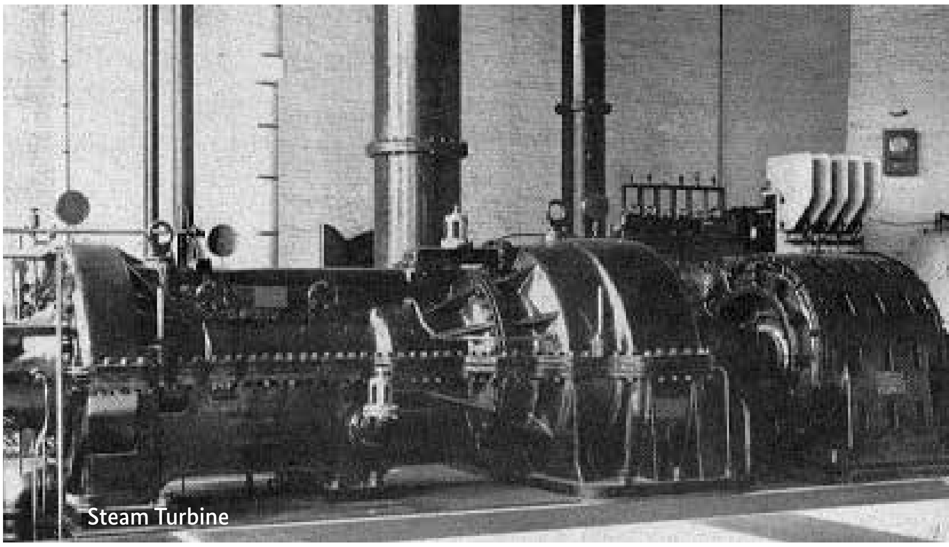
Conventionally, power and heat are supplied from separate generation cycles. Electricity is produced in large-scale centralised power plants and supplied to the customer via the grid. Heat is mainly produced in decentralised heating boilers and utilised on-site. During the electricity generation process, thermal power plants emit large quantities of waste heat, which frequently remains unused. This waste heat from central power plants can be used to cover nearby heating or cooling demands by means of district heating or cooling networks. Alternatively – and as used in most countries – cogeneration produces power and heat at the consumer's premises. The decentralised on-site process thereby serves the client's heat and, at the same time, electricity demand.

'Cogeneration or Combined Heat and Power (CHP) is the simultaneous generation of both electricity and heat from the same fuel, for useful purposes.'
[(OECD/IEA, 2011)]

The cogen principle is not new at all, but has been proven over many decades as state of the art technology. The advantages of a cogen plant were first utilised by Thomas Edison's Edison Illuminating Company, which supplied both electricity for street lighting and steam for industrial use in New York City in 1882.

Cogen and trigen are proven technologies.

Figure 1 Pearl Street Power Station, New York City, U.S., in 1882 [4, 5]



'Trigeneration' (trigen) is often used in this context and describes the combination of cogeneration with chilling technology to produce cooling energy. It is the sequential or simultaneous generation of electricity and heating as well as cooling energy in a single integrated system. Trigen is also referred to as Combined Cooling, Heating and Power (CCHP) *[→ see also 2.3 Trigeneration Technologies].*

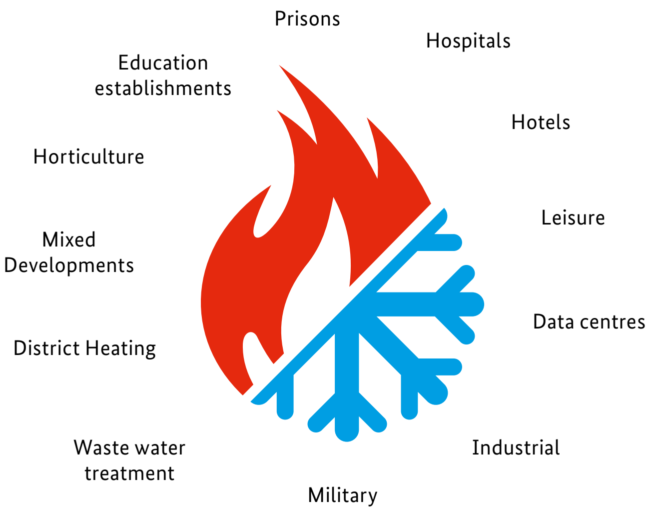
4) © Americanhistory.si.edu, 2014

5) © Connecticut Light & Power, Northeast Utilities Service Company, 2014

Cogen/trigen applications are ideally suited for constant load profiles of heating and/or cooling energy and electricity *[→see Chapter 4 for further details of cogen system design and the framework/prerequisites for economically advantageous operation of cogen plants]*. Cogen technology is therefore especially applicable for the sector segments shown in *Figure 2*. The cogen technology available to implement these applications is presented in the technology sections of this chapter.

Figure 2 **Typical Applications for Cogen Technology** [6]

'CHP encompasses a range of technologies, but will always be based upon an efficient, integrated system that combines electricity production and a heat recovery system.'
(OECD/IEA, 2009)



Cogen reaches aggregate efficiencies as high as 80–95%, compared to efficiencies of about 50% for separate generation.
[→ see Figure 3]

Since the simultaneous generation process on-site minimises energy losses compared to the separate generation and transmission of electricity and heat (and/or cold), cogen reaches aggregate efficiencies as high as 80–95% compared to the efficiency of separate generation processes of about 50%, providing efficiency gains of more than 30% and thus primary energy savings of more than 50%. Thus cogen technologies show significant ecological and also economic advantages (less fuel input and thus reduced greenhouse gas emissions, as well as decreased energy costs for the operator, etc.) compared to the separate production of electric and thermal energy *[→ see also 3.2 Effects of Cogeneration]*.

6) Adapted illustration by © ENER-G Group, 2014

Figure 3 Separate Heat and Power Production vs. Cogeneration [7]

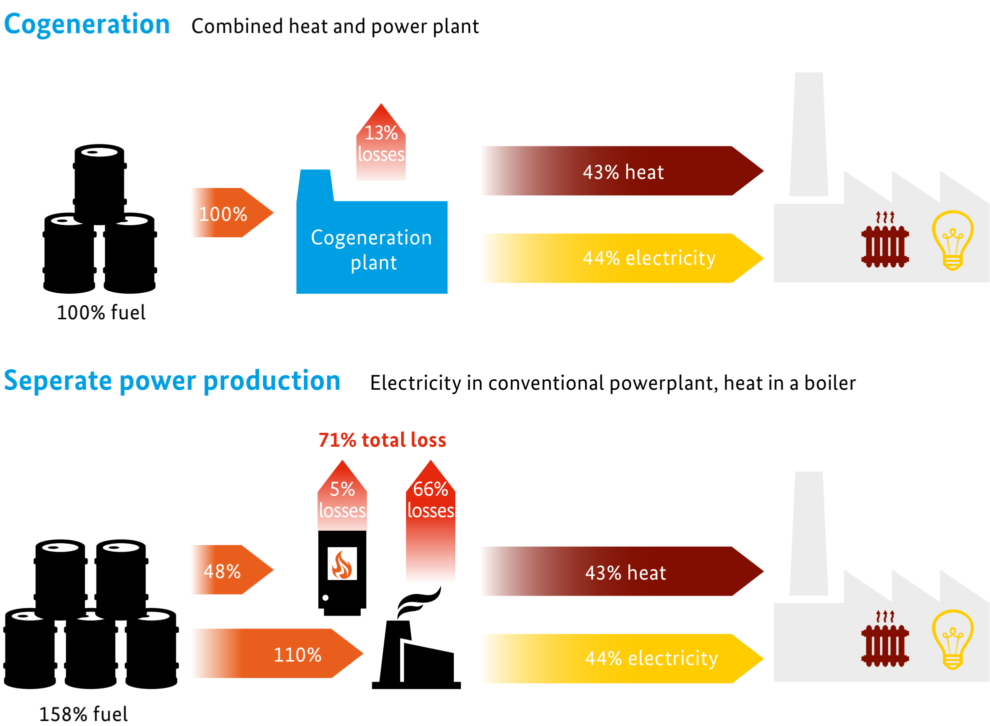


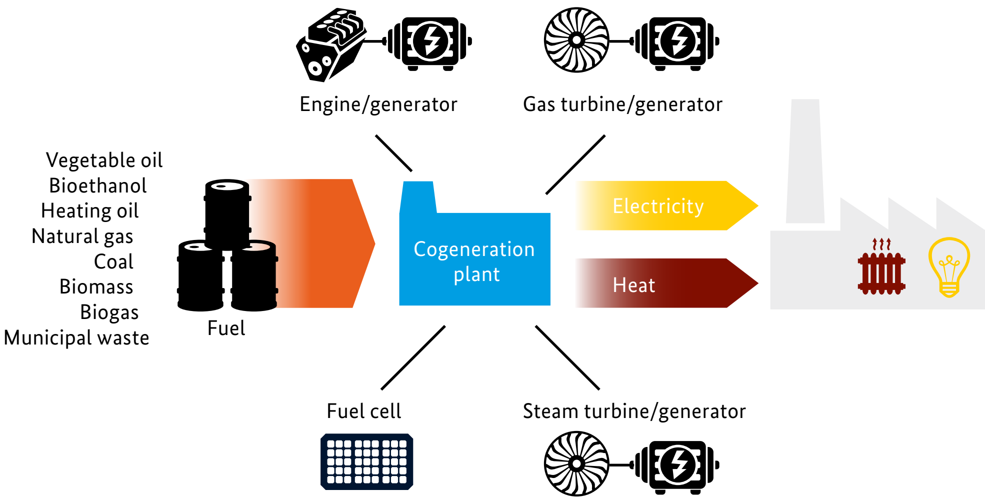
Figure 3 illustrates the aggregate efficiency gain through cogeneration. In this example, highly efficient generation technology (power plant efficiency: 44%) is assumed, which leads to fuel savings of 58 units compared to separate production of electricity and heat. The aggregate efficiency gain through cogen is 37%.

The prerequisite for the appropriate utilisation of cogen (or trigen) plants is demand for both (or all three) forms of energy, electric power and heat (and cold as applicable). Wherever this demand for both (all) types of energy is given, co-/trigen technology seems to be a promising approach to increase energy efficiency and reduce energy costs. However, certain additional framework conditions are still required if co-/trigen application is to be successful. This cogen guide focuses on the most promising cogen applications from 100 kW_{el} up to 20 MW_{el} for both the residential and the industrial sector.

As possible plant sizes vary depending on the technology, so does the choice of fuel. Waste heat recovery and thus cogeneration can be operated in all types of combustion processes and fuels, as *Figure 4* indicates. The choice of fuel is subject to fuel availability and costs *[→ see also Chapter 4 Determinants for the Application of Co- and Trigeneration]* as well as technological and economic optimisation.

7) © MWM, 2014, own remarks

Figure 4 Types of Fuel, Technology and Energy Conversion Process for Cogen [8]



Coal is the dominant fuel for large-scale cogen (> 50 MW_{el}) in the power sector, whereas natural gas and biomass are common in smaller-scale applications.

The choice of the appropriate cogen technology depends on various factors. However, suitable fuel types for cogen processes, corresponding technology and plant sizes may be characterised as presented below. This also includes certain types of biofuels, which are shown in italics (fuel type).

Table 3 Types of Fuel per Cogeneration Technology, Application and Sector[9]

Sector	Power demand	Fuel type				
		Coal/lignite	**Natural gas**	**Heavy fuel oil**	**Diesel or heating oil**	**Biomass**
		Bio-coal/char	**Bio-methane/gas**		**Bio-diesel/ethanol**	**(Thermal use)**
Domestic	< 15 kW_{el}		GE		GE	
Commercial	15–100 kW_{el}		GE		GE	ST/ORC
	0.1 – 1 MW_{el}		GE		GE	ST/ORC
	1 – 5 MW_{el}	ST	GT/GE	ST	GT/GE	ST/ORC
Industrial	1 – 5 MW_{el}	ST	GT/GE	ST	GT/GE	ST
	5 – 50 MW_{el}	ST	GT	ST	GT	ST
	> 50 MW_{el}	ST	CC	ST	CC	ST

ST: Steam Turbine, GT: Gas Turbine, GE: Gas Engine, CC: Combined Cycle, ORC: Organic Rankine Cycle

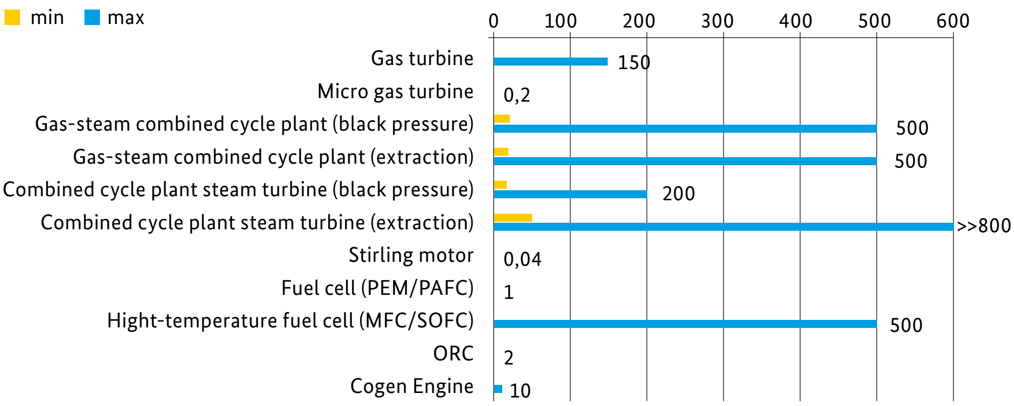
8) © Cogen Europe, 2014
9) DFIC, 2013

In addition, concentrated solar power (CSP), not listed above, is mainly used for electricity generation in large-scale power plants > 50 MW_{el} due to the economies of scale and cost of operation and maintenance (O&M). The principal logic of the technology is based on the generation of steam, using thermo-oils that are heated in parabolic mirrors. Steam can then be used in conventional steam turbines, with the same options to utilise the waste heat to cover heating and/or cooling demand.

2.2 Cogeneration Technologies

Cogen encompasses a wide range of proven technologies. Combined heat and power technologies can be divided into small scale applications, starting from some 1 kW_{el} engines that are usually focused on thermal energy supply, up to large-scale power plants mainly focused on electric power production. These types of cogen plants can be differentiated by technology and feasible capacity, as illustrated in *Figure 5*.

Figure 5 Cogen Capacity Range per Technology (MW_{el}) [10]



2.3 Trigeneration Technologies

As the name suggests, trigeneration provides a third form of energy: cooling energy in addition to heat and power. Trigeneration systems – also called Combined Cooling, Heating and Power (CCHP) systems – are typically a combination of cogeneration plants and chillers to produce electricity, heat and cooling energy in one process. Waste heat is thereby converted to chilled water, either by absorption *[→ see 2.3.1]* or adsorption *[→ see 2.3.2]* chiller technology.

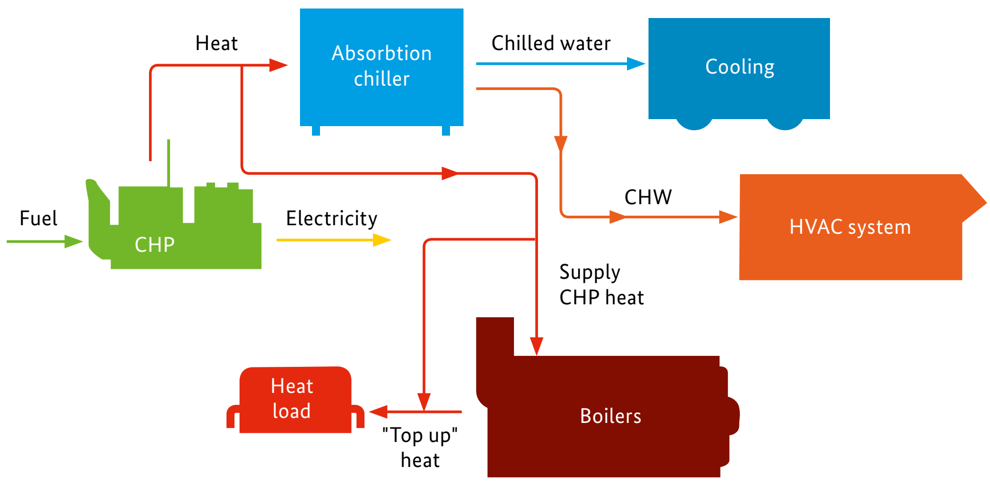
Cooling energy from (waste) heat?

Trigeneration case study
[→ see ANNEX 1 Case Study Projects]

- Trigeneration for cooling server farms + buildings
- 2 x 1 (MW) gas engines, fuel: natural gas
- 3 x lithium bromide absorption chillers
  - 1.5MW cooling capacity (total)
  - CO_2 savings of more than 60%
- EUR 3.5 million capex, pay-back < 5 years.

10) Own illustration based on B.KWK, Federal Cogen Association of Germany, 2014

Figure 6 **Elements of a Trigeneration System (using Absorption Technology)** [11]



As *Figure 6* illustrates, the trigen system adds cooling technology in the form of absorption (or adsorption as appropriate) chiller components to the cogen process. Heat is thus used to produce cooling energy.

Trigen systems further optimise CHP efficiencies by making use of the (waste) heat that is produced for the purpose of heating and/or cooling. Moreover, CCHP increases the flexibility of waste heat utilisation as the process can be adapted to seasonal variations of heating and cooling energy demands.

2.3.1 Absorption Technology

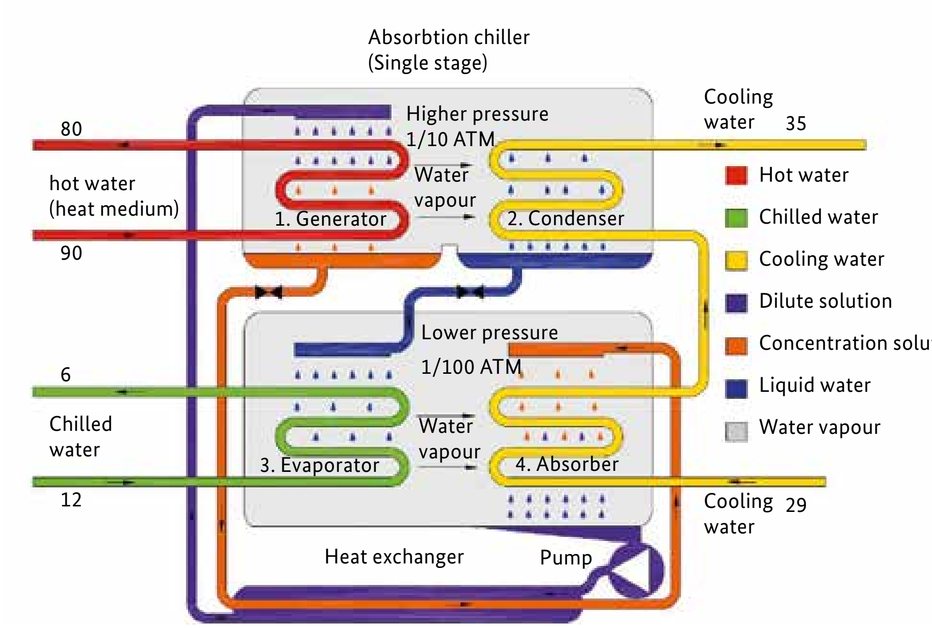
Key Facts: Absorption Technology	
Typical capacity range	100 kW_{el} – 20 MW_{el}
Efficiency, coefficient of performance (COP)	Hot water 0.6 – 0.8 Steam chiller 1.2 – 1.3
Achievable cooling temperatures	+4.5°C lithium bromide, (-60°C with ammonia)
Application focus	Industry; low-quality waste heat utilisation for cooling

Absorption technology is a proven and widespread thermal chiller technology, especially within the trigen market. The technology has been used for many years to utilise low-quality waste heat from power generators, including cogen systems for cooling demand. Due to the fact that absorption chillers often use corrosive lithium bromide (LiBr) salt as a refrigerant, these systems usually have high maintenance costs as a consequence of corrosion effects.

Absorption chiller capacities typically start from several hundred kW, ranging up to multi-MW chillers. Specialised products even start from capacities as low as 5 kW_{el} up to 20 MW_{el} and more for high cooling energy demands. *Figure 7 next page* shows the functional principle of absorption technology on the left and a small- to medium-scale 700 – 2,460 kW_{el} absorption chiller on the right.

11) Illustration by © (Dalkia Alternative Energy, 2014)

Figure 7 **Absorption Process** [12, 13]



Absorption principle

Absorption chiller, 700 – 2,460 kW_{el} capacity

For case studies of trigen projects that use absorption technology, refer to the MTN case study and the Indian trigen project at JPNATC Hospital, New Delhi *[→ see ANNEX 1 Case Study Projects]*.

2.3.2 Adsorption Technology

Key Facts: Adsorption Technology	
Typical capacity range	5 kW_{el} – 2 MW_{el}
Efficiency, coefficient of performance (COP)	Hot water ~ 0.8 Steam/direct-fired ~1.4+
Application focus	Industry, low-quality waste heat utilisation for cooling

Adsorption technology is relatively new, and installations are not yet widely used for trigen applications.

Although there are similarities between absorption and adsorption refrigeration, the latter is based on the interaction between gases and solids.

Cooling energy from (waste) heat?

'When a source of free hot water is available, as it is in cogeneration systems, the electrical consumption saved by using a thermal chiller instead of a mechanical chiller can be very significant. Since there is no compressor, liquid desiccant chillers simply require a circulating pump to move the desiccant through the chiller's internal heat exchangers. The electrical consumption of absorption chillers is thus only about 0.03 kW per ton of refrigeration capacity, while the solid desiccant adsorption chillers consume even less, about 0.004 kW/ton refrigeration capacity provided.'*; **

* (PennWell, 2014)

** one ton of refrigeration capacity can freeze one short ton of water at 0°C (32°F) in 24 hours. A ton of refrigeration is 3.517 kW.

Adsorption chillers operate on the principle of adsorption rather than absorption, namely that molecules adhere to the surface of an adsorbent rather than being dissolved. The adsorption chamber of the chiller is filled with a solid material (for example zeolite, silica gel, alumina, active carbon and certain types of metal salts), which in its neutral state has adsorbed the refrigerant (in most cases water). When heated, the solid desorbs (releases) refrigerant vapour, which subsequently is cooled and liquefied. This liquid refrigerant then provides its cooling effect at the evaporator, by absorbing external heat and turning back into a vapour. In the final stage the refrigerant vapour is (re) adsorbed into the solid. Once the material is saturated, adding heat into the supply will again regenerate it. This process results in intermittent cooling. [14]

12) © Trullos, 2012

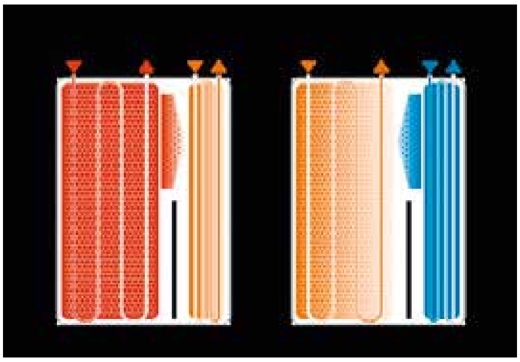
13) © Johnson Controls, 2014

14) SorTech AG, 2015

As an adsorption chiller requires no moving parts, it is relatively quiet.[15] Moreover, adsorption chillers are less energy and maintenance intensive and consequently less costly than absorption processes. Simplicity of operation makes the adsorption chiller technology reliable, safe and attractive for trigen applications. Capacities of adsorption chillers range from 5 kW_{el} to 2 MW_{el}; tailored solutions can have even higher capacities.

Figure 8 illustrates the functional principle of the adsorption process as well as a small-scale adsorption chiller.

Figure 8 Adsorption Process [16, 17]



Adsorption principle

Adsorption chiller, 50 kW_{el} capacity

The chiller works without hazardous substances such as ammonia or lithium bromide, and can be operated in a wide range of temperatures between 50° and 90°C and without corrosion. The adsorption process allows stable operation and chilled water output of about 3°C to 9°C, even with fluctuating hot water temperatures and flow rates that are common for waste heat recovery applications.

In the following sections the different cogen technologies are presented in further detail.

2.4 Gas Engines

Key Facts: Gas Engines	
Typical capacity range	1 kW_{el} – 10 MW_{el}
Electric efficiency	~ 35 – 45%
Typical costs	From > 1,000 €/kW for small scale to < 500 €/kW for MW size
Application focus	Broad application fields

As has been pointed out, cogeneration is a proven and reliable technology. One of the first widely used engine technologies within the cogen segment was the gasoline-based engine. Based on car engines (and on technology from automotive volume production), these engines were further optimised and equipped with heat recovery components adapted to the client's individual needs.

15) wikipedia, 2015

16) © SorTech AG, 2015

17) © Emissionless Pty Ltd., 2014

18) © Emissionless Pty Ltd., 2014

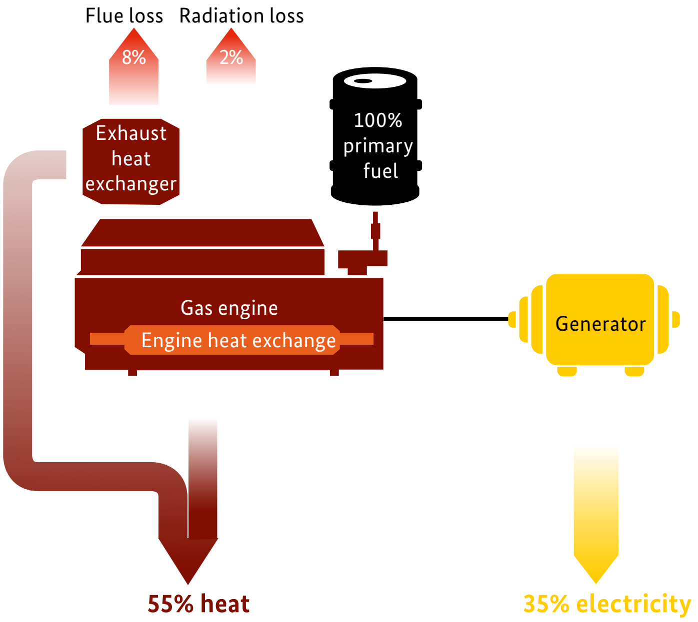
The increased volume production of standard cogen gas engines in combination with greater customisation to meet individual needs as offered by a larger number of specialised companies has led to this cogen technology gaining the highest market share within the cogen market. Case study examples are represented by projects in two emerging economies, Mexico *[→ see markup box gas engine cogen case study]* and Chile, and one developing economy, Honduras *[→ see ANNEX 1 Case Study projects]*. The principle of gas engines and the corresponding energy conversion is illustrated in *Figure 9* below.

Gas engine cogen case study

[→ see ANNEX 1 Case Study Projects]

- Mexican animal food manufacturer
- Gas engine (fuel: natural gas)
  - 400 kW_{el}
  - 484 kW_{th}
- Fully containerised cogen design
- Efficiency: 40% electric, 90% aggregate.

Figure 9 Principle of Cogen with Gas Engines [19]



The combustion of gas releases mechanical energy that a generator converts into power. The heat produced in the engine during the process can be utilised through integrated heat exchangers.

19 CODE2 - Cogeneration Observatory and Dissemination Europe, 2014

Figure 10 **Gas Engines from Small to Large Scale** [20,21,22]

Small scale, starting from about 1 kW_{el} View of a gas engine Large scale, up to 10 MW_{el}

Gas engines are not limited to conventional gas engine technology; other options are (micro) gas turbines or Stirling technology (explanation below). The use of gas turbines allows both higher capacities and higher temperatures. Micro-turbines are typically employed when a high temperature level is required. On the downside, in most cases costs are higher and electric efficiency is lower compared to conventional gas engines.

A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas (the working fluid) at different temperatures, such that there is a net conversion of heat energy to mechanical work. More specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanently gaseous working fluid. Closed-cycle, in this context, means a thermodynamic system in which the working fluid is permanently contained within the system, and regenerative describes the use of a specific type of internal heat exchanger and thermal store, known as the regenerator. The inclusion of a regenerator differentiates the Stirling engine from other closed-cycle hot air engines.

For an overview of feasible efficiencies and capacities for each technology *see [→ Figure 17 at the end of Chapter 2].*

The Stirling engine is noted for overall high efficiency compared to steam engines, quiet operation, and its ability to use almost any heat source. The heat energy source is generated external to the Stirling engine rather than by internal combustion as with the Otto cycle or Diesel cycle engines. Because the Stirling engine is compatible with alternative and renewable energy sources it could become increasingly significant as the price of conventional fuels rises. This engine is currently much used as the core component of micro combined heat and power (CHP) units, in which it is more efficient and safer than a comparable steam engine. [23]

Stirling technology requires less maintenance and is thus less cost intensive, but achieves lower electric efficiency (approximately 15-30%)[24] than gas motors. Since the process is very quiet, in-house applications are practicable. As Stirling engines are not dependent on traditional fossil fuels but only on heat, they can also be operated with alternative heat sources, such as solar thermal energy

[→ Further information on Stirling engines, including technology videos, is available at www.cleanergy.com/technology, for example].

20 © ASUE, 2006

21 © DFIC, 2014 with permission of Phoenix Contact

22 © Rolls-Royce plc , 2012

23 wikipedia, 2015

24 B.KWK, Federal Cogen Association of Germany, 2014

2.5 Steam Turbines

Key Facts: Steam Turbines	
Technology capacity range	45 kW_{el} – 500 MW_{el}
Typical cogen capacity range	300 kW_{el} – 50 MW_{el}
Electric efficiency	~ 20 – 30%
Temperature level required (steam)	> 400°C
Application focus	Industry, power plants (incl. solid biomass)

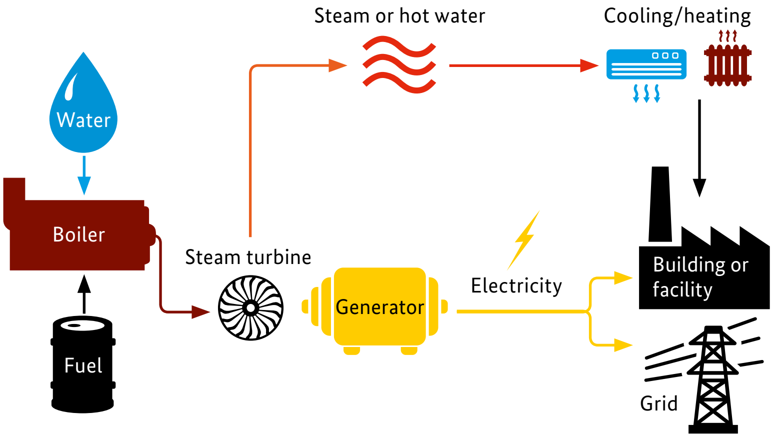
Steam turbines leverage the Rankine cycle[25] and therefore require the implementation of separate high-pressure steam boilers. Depending on the type of steam turbine, in cogen applications steam may be extracted or exhausted from the steam turbine and used directly. Two main types of steam turbine technology for cogen applications can be differentiated:

- → non-condensing (back-pressure) turbine
- → extraction steam turbine.[26]

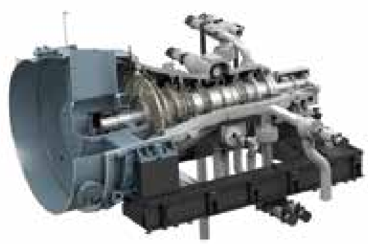
Generally, steam turbine cogen systems are characterised by very low power to heat ratios, typically in the 0.05 to 0.2 range. This is due to the fact that steam turbines usually generate electricity as a byproduct of heat (steam) generation, unlike gas turbine and reciprocating engine cogen systems, where heat is a byproduct of power generation. Steam turbine-based cogen systems are typically used in industrial processes, where solid fuels (biomass or coal) or waste products are readily available to fuel the boiler unit.[27] Steam turbines are frequently used in applications where thermal demands require steam or very high temperatures.

Due to their technical design, steam turbines are efficient for high-capacity systems rated at more than 10 MW_{el}, even though they are available from below 1 MW_{el}. As shown in *Figure 12*, cogen applications maximise the overall efficiency (thermal and electrical efficiency) of steam turbines by utilizing steam for processes.

Figure 11 **Cogen with Steam Turbines** [28,29]



Steam turbine principle



Steam turbine, capacity range 5 – 150 MW_{el}, also used for biomass applications

25 'The Rankine cycle is the fundamental operating cycle of all power plants where an operating fluid is continuously evaporated and condensed.' Further information is available at "Thermopedia - Muller-Steinhagen, Hans Michael Gottfried, 2011"

26 Further technology details may be retrieved from "United States Environmental Protection Agency (EPA), 2015"

27 United States Environmental Protection Agency (EPA), 2015

28 © United States Environmental Protection Agency (EPA), 2015

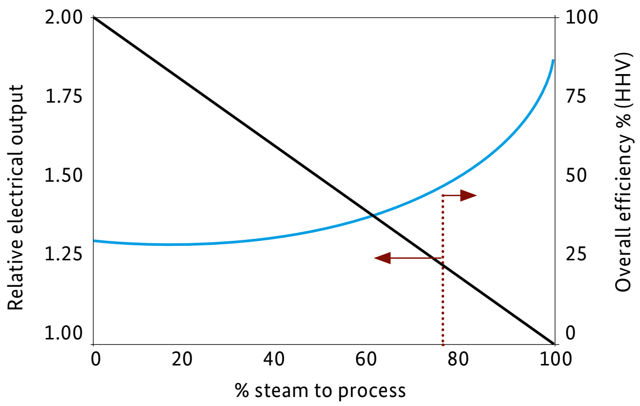
29 © Siemens AG, München/Berlin, 2014

Steam turbines can generally (and usually are required to) be designed to meet specific process heat requirements – unlike gas turbines that are sold in specific sizes or frame sizes steam turbine generators have traditionally been custom-designed machines and seldom have 100% identical components or capabilities.

Often the steam turbine is utilised in a system that already exists and is being modified so that a number of steam system design parameters are already established from previous decisions, which exist as system hardware characteristics, and the turbine must be properly matched to these conditions.

Thus steam turbines are often designed to maximise electric efficiency while providing the required thermal output.

Figure 12 **Steam Turbine Cycle Performance** [31]



Alternatively, instead of producing electric power (e.g. utilised to drive other equipment), steam turbines may also drive equipment directly such as boiler feedwater pumps, process pumps, air compressors and refrigeration chillers.

Steam turbine-based cogen systems enable various industrial (biomass) waste products to be used as fuel, such as wood waste in sawmills or waste from agriculture. Small steam turbines are used for biomass-based cogen applications too, as some agricultural and other biomass process residues can be utilised for combustion only. Waste heat recovery from (industrial) high-temperature processes is another promising field of application for steam turbines.

Capacities of modern industrial steam turbines vary from as low as 45 kW_{el} up to large steam turbines with about 250 MW_{el} (and higher for power stations). Correspondingly, steam parameters vary in a range from 40 to 165 bar and 400°C to 585°C.[32] The higher the spread between the temperature level of the extracted heat at the source and the temperature required at the heat sink, the better the efficiency of utilisation.

31) (General Electric (GE), 2009) Assumptions: 1) Steam conditions 1450 psig, 950°F (101 bars, 510°C), 150 psig (11.4 bars) process, 2 1/2" (63.5mm) HgA condenser pressure; 2) Three stages of feed water heating; 3) Boiler efficiency 85% HHV

32) E.g. Siemens steam turbine product portfolio
www.energy.siemens.com/hq/pool/hq/power-generation/renewables/biomass-power/Biomass_Turbines_EN.pdf

Whether cogen is possible using steam turbines depends on the heat quality (high-value heat > 400°C, e.g. process steam). Alternatively, to allow the utilisation of low-temperature waste heat, Organic Rankine Cycle (ORC) applications (for low heat quality < 300°C) is a technology that is increasingly being used. It is described in detail below.

2.6 Organic Rankine Cycle (ORC)

Key Facts: ORC	
Technology capacity range	3.5 kW_{el} – 130 MW_{el}
Typical cogen capacity range	150 kW_{el} – 10 MW_{el}
Electric efficiency	~ 10 – 20%
Temperature level required	~ 100°C
Application focus	Low-quality heat recovery; geothermal and biomass; industry

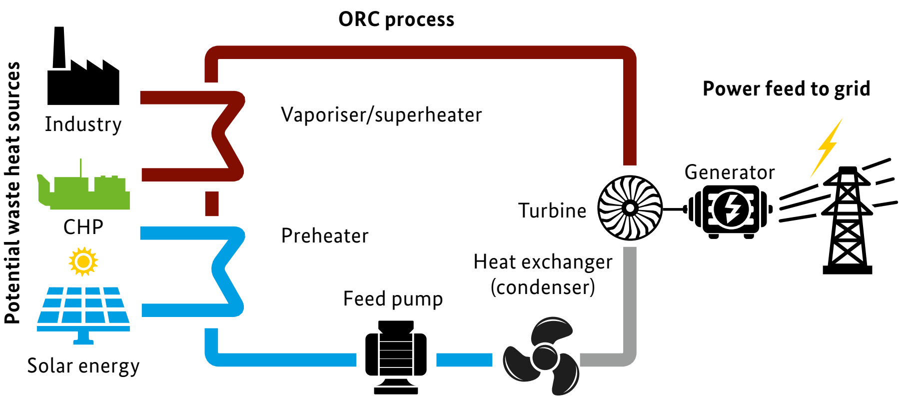
The Organic Rankine Cycle (ORC) produces power through the conversion of (waste) heat into electric energy. This involves waste heat passing through a heat exchanger, transferring its energy in a closed cycle to an organic coolant medium to produce high steam pressures at low temperatures.

The pressure is used to drive a turbine connected to a generator. Afterwards the steam is returned to its fluid state in an air-heat exchanger, cooled down and then fed back into the vaporization cycle as indicated in *Figure 13*.

'The ORC (Organic Rankine Cycle) is a cyclic thermodynamic process. It is based on an organic coolant that enables the generation of electric power at comparatively low temperatures.'
(Bosch KWK Systeme, 2014)

Compared to the Rankine cycle[33] leveraged by steam turbines for higher heat quality *[→ see 2.4 Steam Turbines]*, the ORC approach does not use water but an organic fluid characterised by a boiling point at a lower temperature than the water-steam phase change.

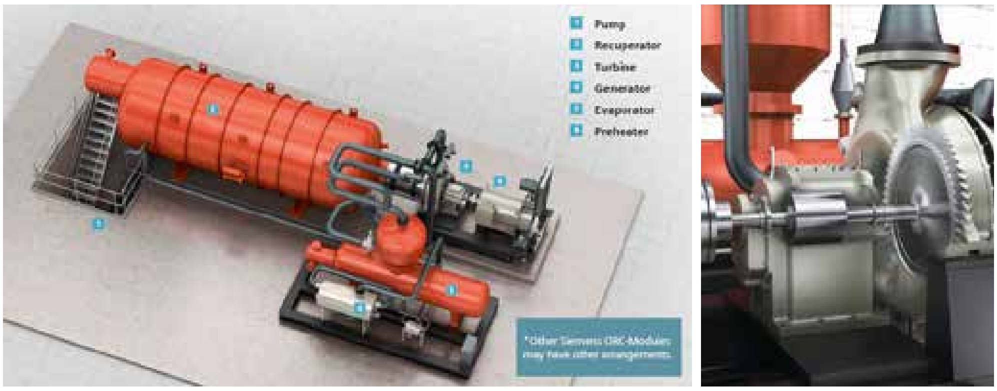
Figure 13 ORC Principle of Power Generation from Waste Heat using Different Sources [34]



33) See also "Thermopedia - Muller-Steinhagen, Hans Michael Gottfried", 2011
34) © Bosch KWK Systeme, 2014

ORC units can be operated with low-quality heat of about 300°C and below, from various sources, such as heat from biomass and biogas, sewage gas, exhaust gas of gas turbines, waste heat from industrial processes and process steam.

Figure 14 **Industrial 2 MW_{el} ORC Unit** [35]



ORC applications are typically found in geothermal or biomass applications and achieve efficiencies of about 10-12%, but can also reach up to 18-20%, depending on the specific application and plant capacity. Although the electric efficiency of ORC technology is comparatively low, it allows power to be generated from the exhaust gas of various industrial processes or biomass/biogas applications which often remains unused. Exhaust gases contain a large amount of energy, but this is usually lost in the form of waste heat as the temperature quality is not sufficient to use it for traditional power production processes, for example with steam turbines.

Waste heat provides a significant energy potential as it is a fuel source that is available on-site almost free of charge. Waste heat of low temperature quality around 300°C (and even lower) can be utilised through ORC technology to produce valuable electric power, with fuel costs equalling almost zero. ORC units typically have capacities in a range from 300 kW_{el} to several MW_{el}, but smaller capacities are also available, the smallest starting from about 3.5 kW_{el}.

For detailed information on different technologies and the general principle of ORC as well as suppliers, the link list presented in Fehler! Verweisquelle konnte nicht gefunden werden. *ANNEX 5* *[→ see ANNEX 5 References]* may provide further insights.

35) © Siemens, 2014

2.7 Fuel Cells

Key Facts: Fuel Cells	
Typical capacity range	0.5 kW_{el} – 10 kW_{el}
Electric efficiency	Dependent on fuel cell technology ~ 40 – 65%
Application focus	High tech; industry, households

Fuel cell technologies have been developed and indeed used for many years, but they have not reached the large-scale production stage due to their high initial investment costs per kW. They can be differentiated into three broad areas of application, each with typical power ranges: portable fuel cells of 5 W_{el} to 20 kW_{el}, stationary fuel cells of 0.5 kW_{el} to 400 kW_{el}, and fuel cells in the automobile transport section of 1 kW_{el} to 100 kW_{el}. Fuel cells are usually operated with natural gas (all fuel cell types except PEM), although specific types are also suitable for biogas (MCFC fuel cells) and others are operated with hydrogen (PEM fuel cells)[36] *[→ see also ANNEX 5 Link Lists Cogen Technologies].*

Fuel cells chemically combine fuel and oxygen to produce electricity, with useful heat as a byproduct. Due to their functional characteristics they are ideally suited to a power-driven cogen layout. Because there is no combustion, fuel cells are quiet, have no moving parts and can achieve electric efficiencies up to two times greater than internal combustion engines. Depending on the fuel cell technology, the power/heat ratio is just the reverse of the small- to medium-scale cogen technologies (e.g. gas engines) as roughly 2/3 of their energy output is electricity and approximately 1/3 is heat.

Typical applications for fuel cells are for instance airports and hospitals, which are dependent on uninterruptable power supply. Due to their functional design and the absence of moving mechanical parts, this is clearly one of the strongest arguments in favour of fuel cells. Fuel cells for residential application units are typically sized between 0.5 kW_{el} and 10 kW_{el}, but fuel cell capacities for stationary applications can also reach up to several hundred kW_{el} or even several MW_{el} capacity.

However, due to the high initial capital expenditures (capex) widespread application is still limited and would require specific promotion for any future deployment in emerging and developing economies. Generally speaking, fuel cells are typically restricted to special applications where their specific advantages may justify the higher upfront capex.

The link list presented in Fehler! Verweisquelle konnte nicht gefunden werden. *[→ see ANNEX 5 References]* provides further information on available technologies, the general principle as well as suppliers of fuel cells.

36) FuelCell Energy, Inc., 2015

2.8 Bio Sources and Co-/Trigeneration Applications

Key Facts: Biofuels	
Typical capacity range	*See 2.4 Gas Engines*
Aggregate efficiency	*See 2.4 Gas Engines*
Application focus	(Agro-)industry, municipalities, waste-water treatment

As pointed out at the beginning *[→ see Chapter 1 Introduction]*, wherever renewable energy sources are used consideration should also be given to making use of cogen/trigen technology to cover heat and cold demands, for example by utilizing waste heat from processes. Bio sources and zero emission fuels, in particular, appear predestined for various cogen/trigen applications.

The term 'biofuel' encompasses various types of fuel such as biomass, biogas, bioethanol or bio-diesel. Application options for biomass-based cogeneration vary, depending on the type of fuel source and technology. There are numerous applications and various cogen plant sizes for each type of technology and biomass fuel. Biofuel-based cogen applications do not involve entirely new technology, nor any cogen technology different from that described in the previous sections. However, in most cases the combustion process and technology components need to be modified to suit the specific requirements of biofuels. Biofuels can generally be differentiated into solid, liquid and gaseous biofuels and correspondingly into appropriate cogen technologies.

2.9 Solid Biomass

Key Facts: Solid Biomass	
Typical capacity range	*See 2.4* Steam Turbines
Aggregate efficiency	*See 2.4* Steam Turbines
Application focus	(Agro-)industry, municipalities, district heating

Solid biomass, which includes (waste) wood, agricultural (waste) products, e.g. sugarcane, crop residues, husks etc., is utilised for combustion processes and is thus suitable for cogen applications using steam turbine or ORC technology *[→ see also 2.5 and 2.6, Steam Turbines and ORC]*. Since biomass plants are often implemented as large power stations to generate electricity, the waste heat of power generation is frequently utilised for district heating (and/or cooling) purposes *[→ see also 2.12 Networks and Storage Heating and Cooling]*.

2.10 Bioethanol and Biodiesel (Liquid Biomass)

Both fuel types, bioethanol and biodiesel, can be utilised to fire cogen engines. Depending on domestic resources, the fermentation of solid biomass, e.g. the conversion of sugarcane to bioethanol, is utilised for ethanol production. Cassava and sugarcane are among the most commonly used sources of biomass for bioethanol production.

In addition to these, liquid biomass sources such as vegetable oils and fats are utilised for biofuel production, for example through the chemical process of converting palm oil to biodiesel. Apart from palm oil, jatropha oil is another vegetable oil frequently used as a source of biomass for biodiesel production. Other liquid biomass sources such as manure can also be subjected to anaerobic digestion processes and thus utilised to produce biogas (and after a purification process: biomethane), which is described in the following section in further detail.

2.11 Biogas

Biogas-based cogen technology represents an important cogen option, especially in developing and emerging economies, as there are various potential sources of biogas in all sectors, such as industry and service companies as well as agro-industry and farming, which are able to supply waste and wastewater for anaerobic digestion and thus biogas production. A further advantage of biogas for cogen applications is its suitability as a fuel for widely used gas engines as well as its climate-friendliness.

Biogas can be generated from a variety of biomass sources. These include suitable feedstock or substrates *[→ see also Table 4: Biogas Yield from different Types of Feedstock]* such as energy crops, agricultural residues or manure on livestock farms, while various municipal and industrial wastes (e.g. from wastewater treatment processes) and by-products are also widely available sources for biogas production.

Biogas consists primarily of methane (CH_4) and carbon dioxide (CO_2) and may include small amounts of hydrogen sulfide (H_2S), moisture and siloxanes. Biogas is traditionally utilised in modified cogen gas engines *[→ see also 2.4 Gas Engines]*. Since the methane concentrations as well as other gas components vary depending on the biogas source, the gas may require further treatment such as scrubbing. As the composition of biogas deviates from that of natural gas, gas engines need to be adapted for biogas combustion. All major engine manufacturers offer such adapted biogas engines. Biogas is especially attractive as a co-/trigeneration option when natural gas is not available or more costly. This is even more the case if there are schemes to promote electricity production from biogas, for example through feed-in tariffs.

Case study: Ruhrenergie biogas cogen plant

[→ see also ANNEX 1 Case Study Projects]

- Food residues and pig manure are digested in a biogas plant in Essen in the Ruhr valley
- Three biogas engines provide 333 kW_{el} each
- The excess heat is piped over a distance of 600 m to a hotel complex.

If biogas is made available as a fuel, the use of both power and heat should be exploited in order to gain the greatest economic advantage as well as the largest savings of primary energy and CO_2 from the biogas. Consequently the following options are available at the production location when biogas is used for cogen applications:

→ biogas is usually used in cogen units (gas engines) directly at a heat sink, e.g. in agro-industry where there is a simultaneous requirement for both hot water and cooling energy

→ alternatively the biogas can also be piped from the digester to a remote cogen unit located at the heat sink

→ a third option may be the transport of heat or cold to a remote heat sink (or sinks) linked via a (district) heating network *[→ see also 2.12 Networks and storage heating and cooling]*

→ a fourth option is the feeding-in or wheeling of biogas to the gas grid or to other directly connected sites, where the combustion of biogas takes place in satellite cogen plants.

Biogas plants and feedstock quality

Digester technologies as well as pre- and post-treatments of the feedstock vary according to biogas plant size. In most cases the biomass feedstock mix in the farming industry consists of two main components, namely manure and co-ferments. Organic biomass such as energy crops (maize and grass silage, turnips), leftovers, biological waste, food production/kitchen waste or vegetable fat are referred to as co-ferments.[38]

The theoretical yield of biogas produced from different types of feedstock varies depending on:

- dry matter content
- energy left in the feedstock (if it has undergone prolonged storage it may already have begun to break down)
- length of time spent in the digester
- type of digester plant and process and the conditions in the digester
- purity of the feedstock.[39]

There are different scales of biogas production and utilisation plants available, varying from simple small-scale technology to large and complex industrial plant designs incorporating various processing units of 10 MW_{el} and more. Biogas applications and the corresponding technology may thus be differentiated as follows:

→ small household digesters

→ agricultural biogas plants: farm-scale, farm cooperatives

→ centralised biogas plants.[37]

Table 4 below provides an overview of the most common types of feedstock for producing biogas. Biogas yield values may vary due to the characteristics outlined above.

Table 4 Biogas Yield from Different Types of Feedstock [40]

Feedstock	Dry Matter %	Biogas Yield m^3/ton	Feedstock	Dry Matter %	Biogas Yield m^3/ton
Cattle slurry	10	15-25	Potatoes	-	276-400
Pig slurry	8	15-25	Rye grain	-	283-492
Poultry manure	20	30-100	Clover grass	-	290-390
Grass silage	28	160-200	Sorghum	-	295-372
Whole wheat crop	33	185	Grass	-	298-467
Maize silage	33	200-220	Red clover	-	300-350
Maize grain	80	560	Jerusalem artichoke	-	300-370
Crude glycerine	80	580-1000	Turnip	-	314
Wheat grain	85	610	Rhubarb	-	320-490
Rape meal	90	620	Triticale	-	337-555
Fats	up to 100	up to 1200	Oilseed rape	-	340-340

37 Baltic manure, 2011

38 Reference as above.

39 NNFCC Biocentre, York, UK, 2014

40 Own table based on data from “NNFCC Biocentre, York, UK, 2014”

Feedstock	Dry Matter %	Biogas Yield m^3/ton	Feedstock	Dry Matter %	Biogas Yield m^3/ton
Nettle	-	120-420	Reed canary grass	-	340-430
Sunflower	-	154-400	Alfalfa	-	340-500
Miscanthus	-	179-218	Clover	-	345-350
Whole maize crop	-	205-450	Barley	-	353-658
Flax	-	212	Hemp	-	355-409
Sudan grass	-	213-303	Wheat grain	-	384-426
Sugar beet	-	236-381	Peas	-	390
Kale	-	240-334	Ryegrass	-	390-410
Straw	-	242-324	Leaves	-	417-453
Oats grain	-	250-295	Fodder beet	-	160-180
Chaff	-	270-316			

For further information on the biogas production scheme and corresponding cogen technology, refer to the additional biogas links given in Fehler! Verweisquelle konnte nicht gefunden werden. ANNEX 5 *[→ see ANNEX 5].*

2.12 Networks and Thermal Storage Systems for Heating and Cooling

Large power plants and some industries emit huge amounts of waste heat during the electricity generation process. This heat is a (nearly) free byproduct that remains unused at the production location. In such cases, district heating/cooling supply networks become economically attractive to both providers and consumers. Heating and cooling networks allow the implementation of cogen technology in large power plants and thus the utilisation of waste heat which is required elsewhere for heating or cooling applications.

Thermal storage is important because electricity generation and heating/cooling demand often do not coincide; storage systems are further elaborated below.

Networks for Heating and Cooling

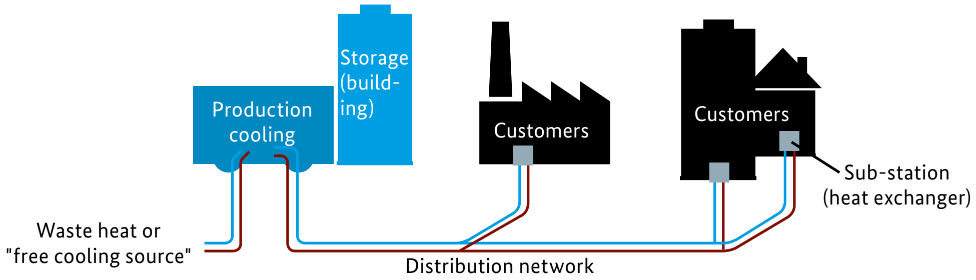
In most cases district heating networks supply heat for the purpose of space heating and hot water in households. Heat in the form of hot water or steam is transported directly through insulated pipes to the heat sink(s). Heat for cooling energy networks, on the other hand, is used to run absorption or adsorption chillers to produce cooling energy as an intermediate step *[→ see also Trigeneration 2.3.1 Absorption Technology and 2.3.2 Adsorption Technology].* Depending on needs and the network design, the same infrastructure may be used for the supply of heat as well as cooling energy.

'District cooling can be a network serving several customers; it can also refer to the local production and distribution of cooling to supply the needs of an institution – business centers, airports, hospitals, universities and public buildings.'
[(Euroheat & Power, 2006)]

Critical criteria for the design of district heating/cooling networks are the distance between the feed-in and extraction points and the thermal quality, profile and pressure requirements of the heat sink(s) for heating/cooling energy, as the heat/cooling load density decreases with the size of the network.

Heating/cooling networks are typically implemented in areas either with large individual heat sinks or with large numbers of relatively small heat demands, such as industrial parks or other high load density (e.g. urban) areas. *Figure 15* below illustrates the principle of district cooling (or heating as applicable) networks, including storage systems to match cooling supply and demand.

Figure 15 **Principle of a District Cooling (or Heating) Network System** [41]



Large district heating networks are historically widespread, especially in the eastern and northern parts of Europe where centralised thermal power production and climatic conditions determine significant heating demands. The same is true for some Asian countries such as Mongolia. District cooling networks in the Gulf area are also developing, based on waste heat from nearby power plants.

District heating and cooling networks enable other technologies such as cogen/trigen to realise their potential by making use of waste heat. Incorporating this energy-efficient technology not only yields fuel savings, it also leads to a significant reduction in greenhouse gas emissions. Furthermore, large district heating and cooling networks may also be combined with large storage systems to further increase energy availability and efficiency of supply *[→ see also ANNEX 1 Case Study projects – Case Study UTES - Oostelijke Handelskade Amsterdam].*

41) © Euroheat & Power, 2006

Thermal Storage Systems and Co-/Trigeneration
Wherever the supply and demand of thermal energy deviates in time, thermal storage systems may provide efficient solutions to close the gaps. This means that in a situation where electricity demand is higher than the corresponding heat demand, excess heat is stored and thereby the overall amount of electricity produced (which does not have to be purchased from the grid) can be maximised.

This applies particularly to cogen/trigen technology, since cogen applications are ideally suited to constant energy supply *[→ see also Chapter 4 Determinants for the Application of Cogeneration]* and are characterised by fixed ratios of heat and power generation. As the specific demand is often characterised by volatile load curves and individual peaks, thermal energy storage (TES) systems are frequently added in order to bridge these gaps. Thus TESs are also a means of smoothing peaks and troughs of demand and allow cogen units to be kept in constant operation.

Case study of a combination of large storage systems and heating/cooling networks.

[→ see ANNEX 1 for further information]

Sustainable heating and cooling by UTES – Oostelijke Handelskade Amsterdam
- Challenge to supply various energy demand patterns in numerous buildings
- Aquifer thermal energy storage system with seasonal storage of surplus heat and cold from the generation system
- Aggregate heating and cooling energy demand of 8.2 MW and 8.3 MW respectively.

TESs encompasses various technology types and scales, but essentially they can be broken down into the following three major segments as illustrated in *Table 5*.

Table 5 Types of Thermal Energy Storage System [42]

Thermal Energy Storage	Sensible TES (heating/cooling storage medium)	Latent TES (phase-change materials)	Thermochemical reactions (e.g. sorption storage systems)
Capacities	approx. 100 MJ/m³	300–500 MJ/m³	approx. 1,000 MJ/m³
Storage volume per GJ	10 m³	2.5 m³	1 m³

The term 'seasonal TESs' usually refers to large, cost-intensive storage systems for relatively large-scale infrastructure supply installed below ground. The cogen guide focuses on residential and industrial hot water storage systems, also referred to as hot water or thermal storage tanks. These tanks are used for storing hot water for space heating or domestic use and are characterised by strong insulation layers to reduce heat losses to the environment. The *Figure 16 next page* shows two thermal storage tanks, on the left a domestic hot water tank with a capacity of 300–500 l and on the right an industrial tank with more than 100,000 l hot water capacity.

42) Own table based on "International Energy Agency - IEA, 2012"

Figure 16 **Thermal Storage Tanks** [43, 44]

Hot water tank for domestic application

Large-scale thermal storage tank

The combination of cogen plants with thermal storage facilitates a power-driven/oriented design of plant as the heat produced is fed into the storage tank when electricity but no heat is needed *[→ see also 4.2.4 Design Philosophies for Cogeneration Projects]*. Depending on the individual characteristics and requirements of a heat sink, adapted thermal storage tanks also allow a combination of cogen and other heating and/or cooling systems, e.g. solar thermal systems. Waste heat from both systems can be stored for up to several days in hot water tanks and supply heat but also cooling energy on demand in trigen applications.

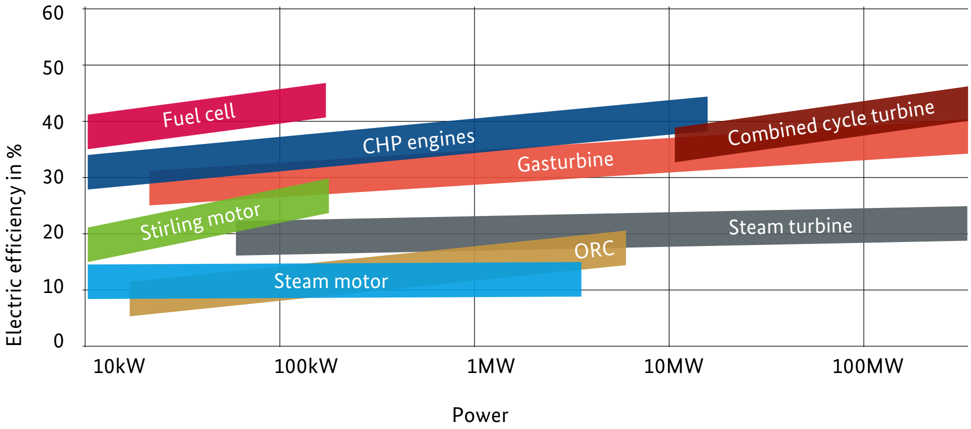
2.13 Overview and Evaluation of Co- and Trigeneration Technologies

Figure 17 on the next page illustrates the electric efficiencies of different cogen technologies. It provides a brief overview of the cogen technologies presented above as well as the specific electric efficiency and capacity range per technology. Fuel cell, large cogen engine and combined-cycle (cc) turbine technologies (summarizing different types and combinations of both gas and steam turbines using back pressure or extraction technology) achieve the highest electric efficiencies. In terms of power capacity, turbine technology covers a wide range but is especially suitable for large-scale application in industry or the power sector, whereas fuel cells and Stirling motors are typically well suited for smaller cogen applications *[→ see also Figure 5: Cogen Capacity Ranges per Technology]*. Due to their low – compared with other cogen technologies – electric (5–15%) and overall (max. 80%) efficiency, steam motors are not described in further detail.

43) © Vaillant, 2014

44) © Hanson Tank, 2014

Figure 17 Capacity and Electric Efficiency of Industrial Cogen Technologies [45]



2.14 Areas of Application for Co- and Trigeneration Technologies

Co-/trigen technology and applications vary significantly between countries and regions. This is partly due to differences in climatic conditions and economic frameworks, as well as local cogen market conditions *[→ see also Chapter 4 for further details]*. Environmental influences such as temperature levels may have a significant impact on the energy demand of defined processes. As climate zones often vary tremendously within countries, classification by country is not helpful in this regard. This also applies to developing and emerging countries. *Chapter 4*, Determinants, examines the above-mentioned factors in detail.

Cogen technologies achieve very high aggregate (electric and thermal) efficiencies:

- well beyond 80%
- extending up to 95%

(depending on the cogen technology used).

Cogen technology applications are not limited to industrial applications but are also increasingly used in the service sector and in the residential sector. Especially the residential sector and buildings offer huge potential for both cogen and trigen applications; they are characterised by high heat and/or cooling demand as rising incomes lead to rising demand for thermal comfort. The International Energy Agency (IEA) characterises and differentiates typical cogen applications as follows.

45) © "B.KWK - Federal Cogen Association of Germany, 2011" with own remarks

Table 6 Overview of Cogeneration Features per Application Segment [46]

Application Segment/ Cogen Feature	Industry (Power Utilities)	Service / Institutional	Space Heating and Cooling
Typical customers	Chemical, pulp and paper, metallurgy, heavy processing (food, textile, timber, minerals), brewing, coke ovens, glass furnaces, (palm) oil refining, agro-sector, incl. dairies, sugar industry *[→ see Chapter 4 for further details]*	Light manufacturing, hotels, hospitals, large urban office buildings, agricultural operations	All buildings within reach of heat network, including office buildings, hotels, individual houses, campuses, airports, industry
Ease of integration with renewables and waste energy	Moderate – high (particularly industrial energy waste streams)	Low – moderate	High
Temperature level	High	Low to medium	Low to medium
Typical system size	300 kW_{el} – 50 MW_{el}	1 kW_{el} – 10 MW_{el}	Depending on conditions and size of building/cluster to be supplied
Typical prime mover	Steam turbine, gas turbine, reciprocating engine (compression ignition), combined cycle (larger systems)	Reciprocating engine (spark ignition), Stirling engines, fuel cells, micro-turbines	Small and medium-sized gas engines Networks: steam turbine, gas turbine, waste incineration, combined-cycle gas turbine (CCGT)
Energy/fuel source	Any liquid, gaseous or solid fuels; industrial process waste gases (e.g. blast furnace gases, coke oven waste gases)	Liquid or gaseous fuels	Any fuel
Main payers	Industry (power utilities)	End users and utilities	Include local community energy service companies (ESCos), local and national utilities, industry
Ownership	Joint ventures/ third party	Joint ventures/ third party	From full private to full public and partly public/ private, including utilities, industry and municipalities
Heat/electricity load patterns	User- and process-specific	User-specific	Standardised, daily and seasonal fluctuations mitigated by load management and heat storage

It is clear from this that cogeneration and trigeneration are highly versatile regarding their application, the sizes of plants and the fuels that can be used. This is why the design of co-/trigen systems is complex and planning needs to consider various parameters.

The *Chapter 3* explains the relevance of cogen/trigen technology for development cooperation.

46) Own table adapted from “International Energy Agency - IEA, 2014” data.


MASS
psi
kg/cm2
THERMOMETER
°C
MASS

3

Relevance of Co- and Trigeneration for Development Cooperation

3.1 Overview

In this module of the co-/trigeneration guide we would like to highlight the relevance of cogeneration technologies in the context of emerging and developing economies. There are many reasons for considering investments in co- and trigeneration solutions in emerging and developing economies. The main reasons are:

- This well-established energy-efficient technology promises significant energy savings and lower CO_2 impacts.
- The production of cogen technology, installation, maintenance and decentralised electricity generation are economically profitable. Overall there is a significant impact on market development and job creation.
- Cogeneration can replace fossil-based energy production by using biomass or biogas and supporting decarbonisation strategies.
- Important for state budgets: less expense on subsidies (in many emerging economies), new tax revenues.

However, if large energy savings are to be generated, strict standards must be applied in line with ISO, and administrative and financial adjustments are needed in order to promote the technology. The macro level and policy-maker perspective will be addressed in the following, including hints for advisors' lobby groups who are interested in promoting co-/trigeneration cooperation agreements. Obstacles must be addressed as well: in many countries politicians do not yet fully appreciate the win-win opportunities including climate mitigation strategies and the macro-economic benefits of co-/trigeneration technologies.

In addition, it will be essential to assess the economic and technological environment for investment market developments, and the ways that individual co-/trigeneration solutions are applied vary from country to country. Assessments should consider the following aspects:

- the type of fuel used for central electricity generation, the availability and cost of gas and other fuels for cogeneration, etc.
- potential for cogeneration from renewable energies (biogas/biomass, geothermal energy, even solar thermal energy)
- market potential for space heating and cooling, particularly in production facilities, industrial and commercial buildings, which account for more than 50 per cent of global energy use
- availability of technologies in the market, after-sale services and seller's warranties.

3.2 Effects of Co- and Trigeneration

It is obvious that the effects of co-/trigeneration are multiple. One sensitive question is how employment can be stimulated without forcing up costs, for example by choosing certain technologies and fuels.

In regions where biomass is a major factor, generating biogas might improve local production and labour markets, depending on the opportunities for promoting bio-feedstock. This relates for example to the harvesting of biomass, which is very labour-intensive. A country's balance of payments might also be improved through primary energy savings (reducing imports), and the competitiveness of small and medium-sized enterprises can be enhanced if energy and production costs are lowered.

Furthermore, the following positive effects arise for the energy sector:

- → potential to enhance capital flows to energy efficiency investments
- → increased energy efficiency and additional decentralised electricity generation lead to in-creased security of supply through additional generation capacity and decreased transmission and distribution losses
- → lower subsidies in those cases where fuel and/or electricity are subsidised.

3.3 Contribution to International Policy Goals

3.3.1 International Energy and Climate Efficiency Policy Goals

Energy efficiency plays a key role in international energy policy as part of the efforts to achieve the 2-degree climate target. The 20 leading economies of the world (G20) recently launched an Energy Efficiency Action Plan. The objective is to encourage greater uptake of efficiencies in the housing and industrial sector, with participating G20 countries promoting energy management best practices. The G20 Energy Efficiency Action Plan (G20-EEAP) establishes a plan to strengthen energy efficiency collaboration between its members and partners on a voluntary basis. The International Partnership for Energy Efficiency Cooperation (IPEEC) has been established to perform an implementing function and supports collaboration under the G20 EEAP.

One of the G20's priority areas for energy efficiency is the use of high-efficient equipment such as combined heat and power systems. IPEEC's efforts to improve energy efficiency in the industrial sector, contributing to a lowering of greenhouse gas emissions, are coordinated through GSEP (Global Superior Energy Performance Partnership) and EMAK (Energy Management Action Network for Industrial Efficiency). This demonstrates that the importance of promoting cogen technology for a wide range of applications with demand for both heat and electricity has already been recognised and is at the top of the international energy efficiency agenda *[→ see also Chapter 5 Recommendations for Technology Cooperation].*

3.3.2 International Development Goals

Co- and trigeneration technology is perfectly suited to contributing to international development goals, in particular the Sustainable Development Goals (SDGs). One objective of the SDGs is to 'double the global rate of improvement in energy efficiency by 2030' relative to the reference year 2010 (SDG 7.3).

Cogeneration serves this objective perfectly, also in relation to the overall 'energy-related SDG' (SDG 7) to 'ensure access to affordable, reliable, sustainable and modern energy for all'. Examples of how contributions can be made include:

- → The use of cogeneration instead of conventional boilers, for instance in factories. Excess electricity can be used to supply households and small and medium-sized enterprises.
- → Trigeneration can be used to refrigerate food and temperature-sensitive goods, in cold stores in rural areas based on biomass, e.g. agro-waste.
- → Trigeneration can also be used as a substitute for diesel generators in the education and health sectors in particular, providing heat, steam and cooling energy for operations, hygiene and medication.
- → An example of the contribution to climate mitigation is the case of the South African telecommunications company Mobile Telephone Networks (MTN), which installed a trigeneration plant with gas-fired engines to serve the cooling loads of its server farms at its headquarters, replacing electricity bought to operate its chillers. As the CO_2 emissions from electricity production by the energy provider's (ESKOM) coal-fired power plants are relatively high (990 g/kWh)[47], MTN calculated the CO_2 savings of the trigen plant to be more than 60% *[→ see ANNEX 1 for further details].*

In all such cases co- and trigeneration generates added value by providing economic and financial benefits. They contribute to the reduction of CO_2 emissions in several ways:

- → Decreased use of (mainly fossil) primary energy by 30 to 40% compared to separate electricity and heating/cooling generation.
- → Reduced transmission and distribution (T&D) losses *[→ see also 3.5.1]* thanks to combined electricity and heat (or cooling) generation without conversion processes that typically cause energy losses; moreover, co-/trigen is decentralised, so supply is generally located close to where demand occurs. This also helps to avoid energy losses caused by long transmission distances.
- → Switching fuel from coal to gas or even to biomass/biogas contributes to emission reduction effects, while lowering the energy bill.

Recent initiatives at the international energy policy level and their related processes also offer promising avenues when it comes to promoting and implementing co- and trigeneration.

47) ESKOM, 2011

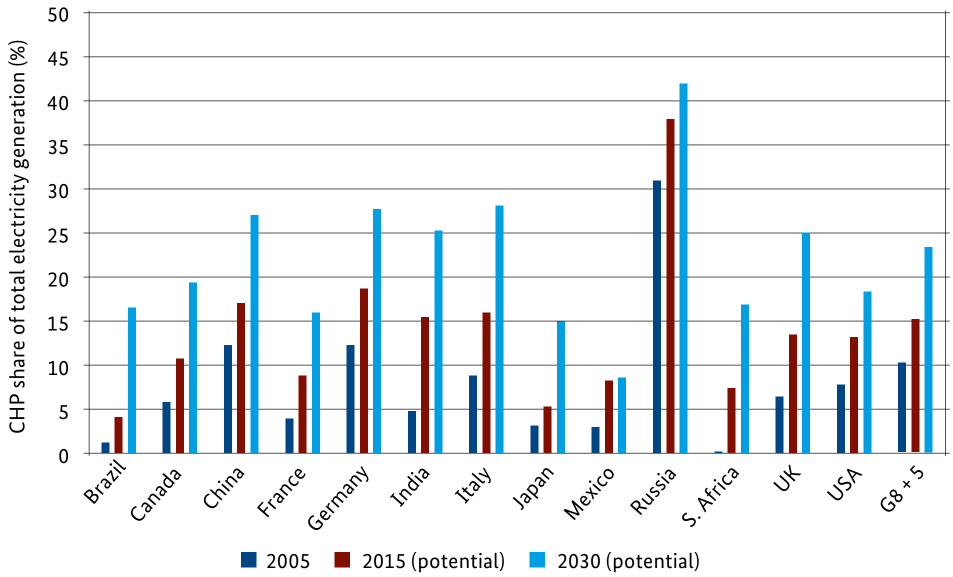
One important example is the Sustainable Energy for All Initiative (SE4ALL) put forward by UN Secretary-General Ban Ki-moon. It was set up by the United Nations to introduce precise goals into the SDG process, and had been successful in doing so. The Copenhagen Centre on Energy Efficiency (C2E2) is the thematic hub for energy efficiency of the initiative (SE4ALL EE Hub) and is dedicated to accelerating the uptake of energy efficiency policies and programmes at a global scale. This is an interesting global platform for public and private cogeneration networks between institutions, businesses and NGOs to provide tools, expertise, technical capabilities and financial capacity. Support for such structures to accelerate improvements is highly relevant, particularly in the district energy systems and industry sectors. [48]

The UN umbrella could be used for further, also national policy initiatives in order to convince decision-makers of the benefits.

In 2008 the IEA analysed the potential of cogeneration in five emerging countries.[49] Here, the IEA assumes, the framework conditions for investment in cogeneration have improved.

While in 2008 the share of cogen in electricity production in the G8 countries was about 11%, by 2030 the share will more than double to reach 24%.

Figure 18 G8 + G5 Countries: CHP Potentials under an Accelerated CHP Scenario, 2015 and 2030 [50]

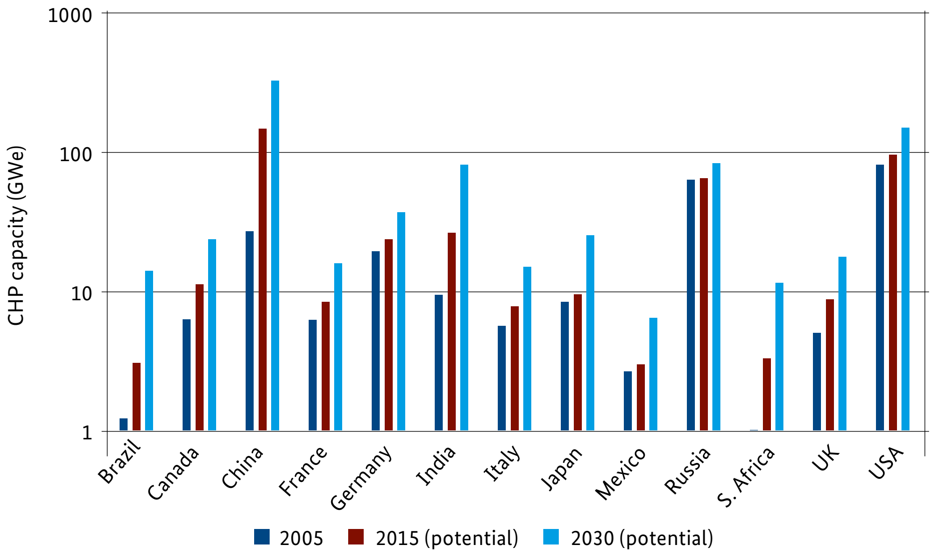


48) Further information on the SE4ALL EE Hub and C2E2 is available from *www.energyefficiencycentre.org*, located in Copenhagen.

49) International Energy Agency (IEA), 2008

50) OECD/IEA, 2008

Figure 19 Current and Projected CHP Capacities under an Accelerated CHP Scenario, 2015 and 2030 [51]



The accelerated scenario also leads to reduced CO_2 emissions. According to the Accelerated CHP Scenario (ACS) scenario, CO_2 emissions are reduced by more than 4% (170 Mt/year) by 2015. In 2030 savings might increase to more than 10% (950 Mt/year). In order to evaluate this data, these reduction objectives can be compared with:

→ the annual emissions arising from 140 GW_{el} of coal-fired power plants operating at a load factor of 80%

→ one and a half times India's total annual emissions of CO_2 from power generation.

3.4 Contribution of Co- and Trigeneration to German International and Development Cooperation Goals

3.4.1 Climate Protection

The German Government has always attached great importance to climate policy. Chancellor Merkel was instrumental in preparing the Kyoto Protocol when she was Minister for the Environment. Given the growth in emerging and developing countries, defining and supporting policies and technologies that mitigate climate change is important to the German Government. The Coalition Agreement of autumn 2013[52] reconfirms that Germany wants to address the global challenges of climate change. German commitment to the MDGs, the subsequent SDGs and climate protection is well manifested in Germany's development cooperation policies, where climate and energy policy and programmes play an important role.

The German strategy for promoting sustainable energy in development cooperation states certain requirements for energy technologies that reduce CO_2 emissions, including decentralised supply and energy efficiency efforts[53], all of which are well applicable to cogen/trigen.

51) Ibid.

52) CDU, 2013

53) BMZ, 2007

The significance of energy efficiency in German development cooperation is also illustrated by the fact that there are more than 30 countries with cooperation activities in the field of energy efficiency. Climate and energy also play a role in the cooperation with most of the emerging economies, such as China, Brazil, India, South Africa, Chile, Mexico and Indonesia. In some of these countries cogeneration shows considerable potential because of the level of industrialisation and/or the thermal comfort (cooling) demand of the service sector and in high- and middle-income housing.

In addition, Germany has set up the German International Climate Initiative (internationale Klimaschutzinitiative, IKI by BMUB) and the German Climate and Technology Initiative (Deutsche Klima- und Technologieinitiative, DKTI by BMZ and BMUB) as programmes which also support energy efficiency projects relating to cogeneration in developing and emerging countries. The National Appropriate Mitigation Action (NAMA) facility, financed by international donors inculding Germany, is also applicable to energ efficiency and thus cogeneration programmes.

Economic and Other Benefits through German Development Cooperation
One of the benefits of decentralised electricity production through co-/trigeneration is that it relieves the strain on central electricity supply systems and allows the use of additional resources for electrification. Promoting sustainable energy access and supply in partner countries is also part of the German sustainable energy cooperation strategy, and cogeneration is contributing to this goal.

Using cogeneration also enables developing countries to benefit from a reduction in costs for fuel imports *[see also next section of this guide]*. In addition to the usual energy-related and climate mitigation benefits, employing cogeneration as part of an energy efficiency strategy is instrumental in developing and strengthening the local economy. Increasing energy efficiency means decreasing costs and thus increasing competitiveness and creating jobs.

Cogeneration is also a highly suitable field for direct cooperation with the private sector, either through industrial associations or with individual local or international firms. German Development Cooperation also involves technology transfer or demonstration projects as well as capacity development and training. International companies benefit from access to developing and emerging markets and related business opportunities. Furthermore, cogeneration is suited to cooperation with German and international industry in order to obtain their engagement in energy efficiency projects and thus leverage the government's official development assistance (ODA) contribution by mobilizing additional resources from the private sector.

3.4.2 Energy Security

Cogeneration not only improves energy efficiency by at least 30% in terms of primary energy, but also increases security of supply, in particular in developing countries, thanks to fuel switching (whether primary or additional fuel), for example from diesel to reduced demand and lower use of primary fossil energy helps keep fossil fuels available for the future when scarcity will lead to rising prices. It also plays a part in reducing these countries' dependence on fossil fuel imports *[→ see also 3.5.2 Balance of Payment and Budget]*. Oil-related security issues (piracy etc.) will thus become less critical.

One other effect is that fossil fuel imports to Europe are secured for a longer period. At the same time cogeneration is associated with greater use of renewable energy. Utilizing both heat and electricity increases the level of fossil fuel replacement. This leads to CO_2 reductions and economic effects (e.g. employment generation) resulting from the harnessing of greater benefit from biogas and biomass.

3.5 Contribution of Co- and Trigeneration to National Goals in Developing Countries

3.5.1National Energy Systems

Cogeneration helps to increase electricity generation and capacity. Most developing and emerging countries suffer bottlenecks in electricity supply. Many countries face brown-outs or black-outs. Industrial production and the development of industry are hampered by a lack of generating capacity. Energy consumers need to invest heavily in standby diesel generators.

The effect of cogeneration on capacity depends of course on the respective load pattern of the electricity system and the energy consumer operating the cogeneration equipment. Cogeneration units are increasingly made dispatchable, a feature that greatly depends on the flexibility of the electricity system and market.

The bottleneck in generation (as well as transmission and distribution) capacity is partially due to the fact that politicians do not want to agree to unpopular tariff increases which are in many cases necessary in order to undertake the investments needed. Cogeneration can alleviate these bottlenecks, as the investments are primarily undertaken by the private sector – be it the final energy consumer or a (private) Energy Services Company (ESCo) *[→ see 4.2.7 ESCos and Contracting]*.

Decentralised electricity (co)generation also increases energy efficiency in the transmission and distribution system. This is due to the fact that co-/trigen plants are usually operated very close to the site where the power and heat/cooling demand occurs, or they can feed into a nearby distribution system; thus energy transmission and distribution over long distances and implied energy losses can be significantly reduced or even be fully avoided. This effect is quite significant and amounts to more than 10% in many developing countries (e.g. 23% in India[54] and 15–16% in Mexico and Brazil[55]).

3.5.2 Balance of Payments and Economic Development

Most electricity generation is based on fossil fuels, in which only few countries are self-sufficient. Most countries thus have to import fuels, which places a significant burden on their balance of payments. Savings of 30% in fuel for electricity generation reduce this burden on the balance of payments and strengthen the national currency. Even those countries which export fuel such as Indonesia or Mexico benefit from the cogen-induced balance of payment effect as they can export more accordingly.

Many developing countries subsidise fuel and (accordingly or additionally) electricity.

54) McKinsey, 2014

55) Worldbank, 2014

56) McKinsey, 2014

Fossil fuel subsidies are estimated to cost between US$ 455 and US$ 485 billion.[56] Accordingly, the saving on fuel subsidies induced by the energy efficiency from cogeneration reduces expenditure, enabling it to be diverted and used much more efficiently for poverty alleviation.

Economic Development
The economic effects of cogeneration are multiple and often not fully appreciated; they can be summarised as follows:

→ development of the economy
  - increased local content and value added, leading to economic development and job creation
  - decentralised electricity generation in smaller units leading to local and regional value added (other than jobs: taxes and other secondary effects) by decentralised production, installation and operation; another perspective to be added in some larger countries may also be local manufacturing, e.g. converting gas engines to cogen equipment

→ balance of payments and currency *[→ see section above]*

→ avoided cost of back-up power

→ employment generation *[→ see 3.4.1 and section above]*

→ decreasing cost of energy to cogen users *[see section below]*.

Energy cost reductions lead to improvements in the following areas:

→ Competitiveness of industry
Many countries are increasingly developing their service industry, which equally benefits from lower energy costs. Tourism, shopping malls or data centres can benefit from energy efficiency by cogen/trigen induced cost reduction. This is also the case for those parts of the commerce/buildings sector that have a significant thermal load or demand.

→ Resilience of industry and the service economy to energy price increases
  - directly – by reduced energy consumption/costs
  - indirectly – increased competitiveness and economic development.

Given these economic effects, in most cases a cost-benefit analysis will easily justify an active cogen policy and even initial subsidies.

3.6 Prerequisites to Harnessing Co- and Trigeneration Benefits

As the benefits of cogeneration are multiple and often very attractive, the question arises: why is so little cogen potential exploited? What prerequisites need to be in place, or what obstacles often impede the harnessing of cogeneration potential?

Table 7 Obstacles and their Mitigation

Issue	Stakeholder	Mitigation remark
Adequate regulatory framework conditions required (e.g. export from cogen unit to willing buyer)	Government (utility)	Liberalisation of generation
Fuel availability	Government Gas companies	Integrated with promotion of biogas and biomass
Poor economics due to low electricity price & high fuel prices	Government	Improves as subsidies diminish, compensated through subsidies for cogen
Low awareness Missing skills (esp. planning)	Industry/energy users Engineering consultants, ESCos, suppliers	

Chapter 4 further elaborates on these framework conditions *[→ see Chapter 4]*.

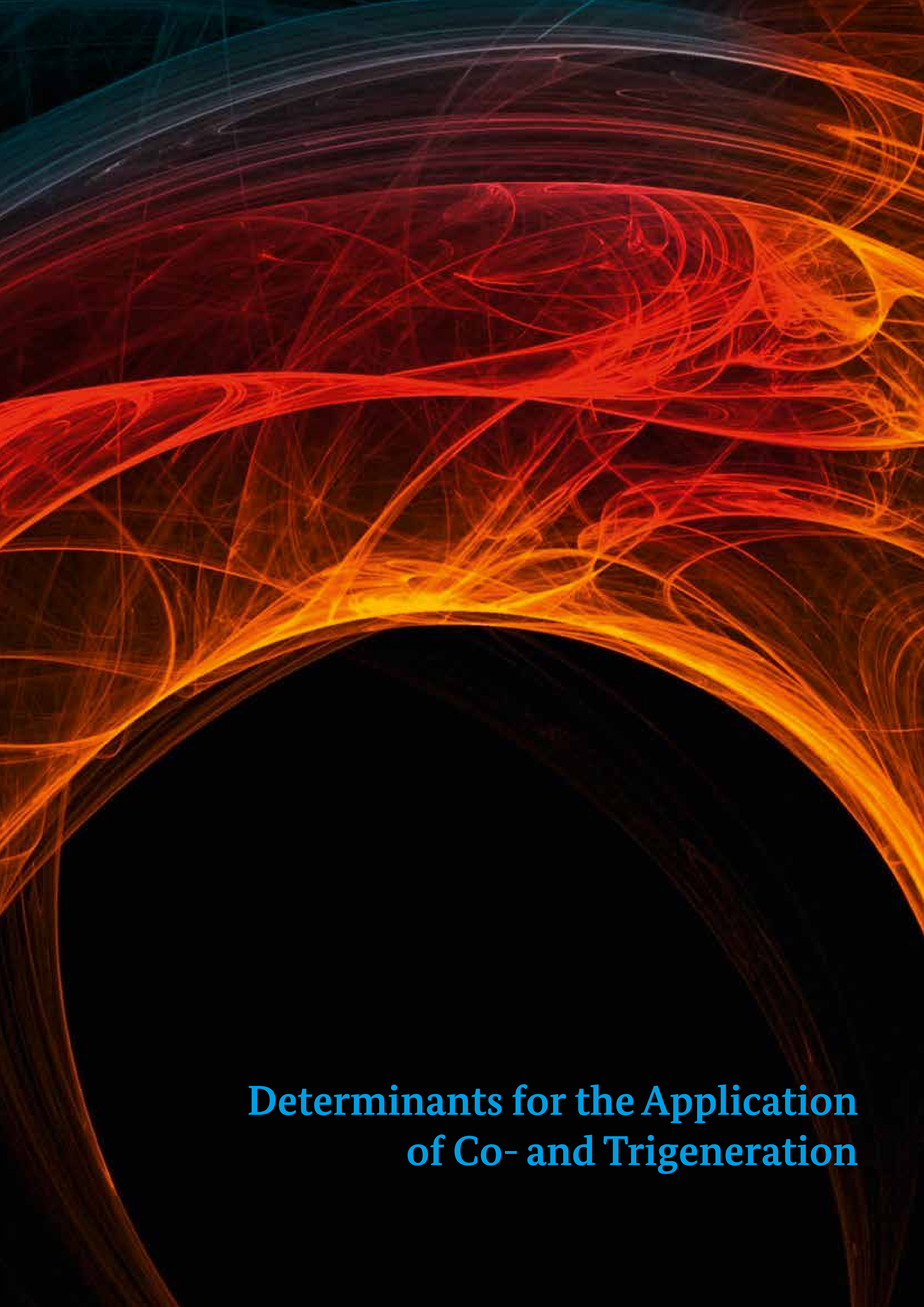
3.7 Conclusions

In many countries cogeneration is still seen as embedded generation which poses a threat to the (national) utility. The benefits for the security of energy supply are still not appreciated by many policy-makers. This is even more so as cogen projects are smaller than conventional power plants and have lesser financing challenges and shorter lead times to be implemented.

The economic and employment effects are seldom assessed and weighed up against each other in a cost-benefit analysis by energy policy-makers. This is true for the direct employment effects as well as for indirect effects resulting from increased competiveness.


Warm Water
Heat Recovery
(LT Ckt)
49%
37%
giz

4



Determinants for the Application of Co- and Trigeneration

4 DETERMINANTS FOR THE APPLICATION OF CO- AND TRIGENERATION

This part of the cogen guide looks into the conditions under which cogeneration and trigeneration can succeed. The first section looks at the macro level of the energy economy, whereas the second section looks at the project level.

The identified conditions help to determine the chances that the technical and economic co-/trigen potential can be successfully transferred into projects. On the other hand, the obstacles suggest potential areas of intervention for development cooperation. How such intervention could be undertaken is discussed in *Chapter 5* *[→ see Chapter 5 Recommendations on the Promotion of Cogeneration]* *of this guide.]*

In order to produce an overall picture and roughly indicate which cogen application is suitable and which is not under the given framework, this chapter includes a determinant mapping on the macro and project level as well as checklists *[→ see also 4.2.8]* to identify risks and cost estimates at an early stage of project planning.

The following part of the guide assumes that the reader is familiar with the co-/trigeneration technologies as outlined in *Chapter 2* *[→ see Chapter 2* Cogen/Trigen *Technologies and their Application]* of the guide.

4.1 Determinants of Co- and Trigeneration at the National Level

4.1.1 Potential

In order to put the contribution of cogeneration to the various policy objectives in perspective, as a starting point it is necessary to examine the potential for co- and trigeneration. This potential and the various associated benefits need to be estimated in order to decide if it is worthwhile actively promoting cogeneration, or to choose the segments in which this may be especially worthwhile. Potential should be investigated for industry, the buildings sector and in particular the tertiary sector (shopping malls, airports, hospitals, hotels, etc.), and for heating as well as cooling demand depending on the availability of fuels, as explained in the following.

Industry

In many countries industry presents the largest market segment for co-/ trigeneration. An analysis of the strategic significance of cogen therefore has also to take into account the expected growth of industry in the respective country. Process heat and cold requirements vary from one industrial sector to the other according to the structure of production.

An overview on the specific process-dependent cogen potential per industry sector is presented in *Table 8* and *Table 9* for technology characteristics such as required temperature levels and suitable applications *[→ see Chapter 2 Cogen/Trigen Technologies and their Application]*. *Table 8* illustrates typical heat demands per branch of industry and corresponding temperature levels.

Table 8 Industry-Specific Heat Demand and Energy Indicators[57]

Branch of industry	Share of heat demand			Cogen technology	Share of energy costs in gross production value %	Ratio of electricity to fuel consumption
	up to 100°C	100–500°C	over 500°C			
Coal mining, peat extraction, extraction of oil/natural gas, etc.	10%	40%	50%	GE / GT / ST / HT	3.7	0.17
Ore mining, mining stone & earth, other mining	5%	2%	93%	GE / GT / HT	9.0	0.50
Food, beverage and tobacco processing	58%	42%	0%	GE / GT	1.9	0.30
Textiles and clothing sector	100%	0%	0%	GE	2.0	0.55
Wood and wood products (excluding furniture manufacturing)	50%	50%	0%	GE / GT / ORC	3.1	1.09
Paper, publishing, printing	34%	66%	0%	GE / GT	3.5	0.54
Coke, refined petroleum products	5%	2%	93%	GE / GT / HT	0.7	0.19
Chemical industry	21%	22%	57%	GE / GT / ST / HT	3.4	0.31
Manufacture of rubber and plastic products	42%	58%	0%	GE / GT	2.2	1.46
Glass, ceramics, stone processing and quarrying	5%	2%	93%	GE / GT / ST / HT	6.7	0.20
Metal production and processing, manufacture of metal products	65%	13%	22%	GE / GT / ST / HT	3.6	0.27
Mechanical engineering	65%	13%	22%	GE / GT / HT	0.9	0.87
Automobile industry	65%	12%	23%	GE / GT / HT	0.7	1.24

GE = Gas Engine, GT = Gas Turbine, ST = Steam Turbine, ORC = Organic Rankine Cycle, HT = High Temperature Waste Heat

These indicators are also important on the micro or project level. The impact of available technology and further determinants on successful cogen project development is therefore elaborated below *[→ see 4.2]*.

57) Own illustration based on German Federal Environment Agency, 2014

In addition to heat requirements, the analysis of cogen potentials has to consider industry cooling demands. Regarding process heat requirements, cooling demands vary from one branch of industry to another. *Table 9* below presents an overview of typical process cooling demands per industry segment and temperature level required.

Table 9 **Industry-Specific Cooling Demand**[58]

Branch of industry	< -15 °C	-15 – 0 °C	0 – 15 °C
Basic chemical industry	38.0%	12.0%	50.0%
Food, beverage and tobacco processing	56.0%	14.0%	30.0%
Glass, ceramics	0.0%	0.0%	100.0%
Manufacture of rubber and plastic products	0.0%	0.0%	100.0%
Mechanical engineering	2.5%	2.5%	95.0%
Metal processing	0.0%	0.0%	100.0%
Metal production	0.0%	0.0%	100.0%
Mining and quarrying	0.0%	0.0%	100.0%
Non-ferrous metals	0.0%	0.0%	100.0%
Other chemical industry	45.5%	4.5%	50.0%
Paper, publishing, printing	0.0%	0.0%	100.0%
Stone processing	0.0%	0.0%	100.0%
Vehicle construction	0.0%	0.0%	100.0%
Other industries	4.5%	0.5%	95.0%

Buildings
The second area of application potential for cogeneration is in larger buildings, where demand can be differentiated between heating and/or cooling energy for thermal comfort and hot water. In developing and emerging economies the demand for cooling is growing more than that for heating purposes.

In any consideration of thermal comfort, it should be borne in mind that several major developments will lead to significant increases in heating and cooling demand in most countries:

→ rising standards of living leading to:
  • more (living) room size per capita
  • increasing demand for thermal comfort (air-conditioning)
  • higher demand for services (hotels, hospitals, etc.)

→ demographic development/population growth

→ climate change and resulting higher temperatures and cooling needs.

58) German Federal Ministry of Economic Affairs and Energy, 2014

This will lead to additional demand for heating and cooling in residential areas and from services such as hotels and hospitals. Any analysis of co-/ trigeneration potential should thus carefully take such future developments into account. The importance of this potential is even greater in light of the fact that in many cases heating and cooling for buildings in particular is based on electricity, which is not only inefficient and expensive but often also scarce as capacities are barely able to satisfy growing demand in many countries.

In such countries it is especially important to excess self-generated electricity to be fed back into the grid. In those cases where no export is possible, the cogeneration units need to be sized accordingly in order to cater for the electricity base load *[→ see also 4.2]*. In many possible applications where no 24 hours base load is needed, this constitutes a key obstacle that reduces the potential for cogeneration in the short term. Load profiles are crucial, therefore they often depend on the make or buy decisions that the establishment has to take, for example for laundry in hotels or hospitals.

Availability of Fuels

As this guide focuses on small to medium-sized cogen applications, gas – or specifically natural gas – is the predominant fuel source, while biomass still plays a minor role in fuel supply. The availability of gas is thus a key determinant for cogeneration.

Given the fact that gas is a clean fuel with long lasting resources, many countries give high priority to development of their gas systems. As cogeneration requires about 8-10% more gas than when used for the provision of heat only, gas sales are about 10% higher, yet still there is a 30% to 40% gain in total primary energy efficiency compared with the separate generation of heat and power.

The availability and provision of gas often depends on the distance to the grid and thus on the cost of connection to be negotiated between the potential client and the utility company. In some cases attractive projects cannot be connected to the gas network because they are located in remote areas.

Without access to the gas grid, use of Liquefied Natural Gas (LNG) or Liquefied Petroleum Gas (LPG), biomass as waste wood/fuelwood or feedstock to generate biogas could be an attractive alternative, in particular for many developing and emerging countries *[→ see also 4.2.1 and 4.2.2]*. The economics depend on the often regulated and subsidised relative prices.

Methods of Information Gathering for the Analysis of Cogen Potential
The indirect methods of information gathering for co-/trigen potential are through intermediaries such as consultants, industrial associations, project developers and vendors who study their markets. Electricity companies normally know their larger consumers of electricity for heating and cooling, but sometimes need to be convinced to make that data available.

Direct information gathering could be carried out by means of quantitative surveys and studies at end-user level, which would look at factors such as:

→ number of establishments in certain key segments, according to:
  • gas availability
  • demand for thermal/air-conditioning comfort (as a function of climate zones)

→ fuel prices relative to electricity prices and transaction costs (costs of getting equipment supplied and connected)

→ users' investment potential.

Cogen Policy in Germany.

[→ see ANNEX 3]

Feed-in bonus system
for electricity from cogeneration (on top of stock exchange revenues). This covers installed capacities from 50 kW up to 2 MW and more and a duration of 10 years or 30,000 hours of full utilisation (hfu), as follows:

Capacity	Bonus	Duration
≤ 50 kW	5.41 ct/kWh	10 years or 30,000 hfu
> 50 – 250 kW	4.0 ct/kWh	30,000 hfu
> 0.25 – 2 MW	2.4 ct/kWh	30,000 hfu
> 2 MW	1.8 ct/kWh	30,000 hfu

Investment incentives
for small CHP plants < 20 kW are limited to 3,325 EUR and distributed as follows (5% degression p.a. from 2014):

- [<1 kW] : 1,425 EUR/kW_{el}
- [1 - 4 kW_{el}]: 285 EUR/kW_{el}
- [4 - 10 kW_{el}]: 95 EUR/kW_{el}
- [10 - 20 kW_{el}]: 47.5 EUR/kW_{el}

Further capital incentives are available on the state level, e.g. in North Rhine-Westphalia (NRW), where the same incentive structure is applied and allows the accumulation of incentives on the federal and state level, yielding a doubling of capital subsidies for small cogen installations in NRW.

In any analysis of cogeneration potential it is essential to take account of the prerequisites for cogen projects such as the supply of fuel, the availability of and access to infrastructure, the demand profile and so forth. It is also useful to differentiate between short- and long-term perspectives, taking into account the existing regulatory framework as well as potential future technical and economic developments that could produce an improved enabling framework.

The assessment of cogeneration potential could start from two different perspectives:

→ heating/cooling demand as above

→ supply of electricity from biogas/biomass.

In many biomass and biogas applications the cogeneration potential is not fully exploited. This applies to sugar mills, for example, and to large installations forming part of wastewater treatment plants.

4.1.2 Policy Environment

As far as the policy environment for cogeneration is concerned, the first level of analysis is the energy efficiency (EE) policy framework.

Issues to be addressed are:

→ existence and objectives of a national EE policy

→ consideration of EE in industry, the buildings sector and/or other segments relevant to cogeneration

→ consideration of cogen within that framework

→ reduction of transmission and distribution losses as an objective.

A second area of policy environment to be analysed is regulation of the electricity sector in connection with the generation of electricity by an independent party or consumer. Liberalisation or even decentralisation of electricity generation should ideally be part of the policy framework in order to promote cogeneration.

More specific features in relation to cogeneration are:

→ unbundling and liberalisation of electricity generation, free access to the grid

→ wheeling to a willing buyer (with regulated and thus reasonable wheeling charges).

If a policy framework for renewable energies already exists in the country, cogeneration could be added to it with similar arguments.

The strain on an electricity system with a permanent lack of capacity would be greatly alleviated by a policy framework that allows decentralised generation and the feeding in of electricity.

Analysis of the economic mechanism of a promotional policy framework requires differentiation between the following:

→ feed-in tariffs/bonus payments

→ tendering

→ certificates

→ capital subsidies per kW installed

→ tax incentive schemes.

This is further elaborated in *Chapter 4.1.7.* Examples include the German Cogeneration Act *[→ see markup box Cogen Policy in Germany]*, which combines incentives for cogen plants with feed-in tariffs for cogen-based electricity generation. Another example is the system adopted by the Government of India *[→ see markup box India]*, which explicitly supports cogeneration in its bagasse industry with capital subsidies and fiscal incentives for privately owned cogen plants. Another approach to cogen promotion is the bonus system developed by the Tunisian Government based on the natural gas price *[→ see markup box Cogen Policy in Tunisia]*.

India – Policy for Support of Bagasse-based Cogen

[→ see ANNEX 3]

India provides various tax incentives, capital subsidies and feed-in tariffs for CHP which often differ from state to state. The focus is thereby clearly set on biomass and bagasse -based cogen applications:

- Grants: INR 1.5 to 1.8 m for 65% of the capacity *[INR 1.8 m * (capacity in MW)^0.646]* for private sugar mills
- Also for existing cooperative or public sugar mills, up to max. INR 80 m per project, including INR 4–6 m per MW of surplus power exported to the grid for new public or cooperative sugar mills.
- Fiscal incentives: 80% accelerated depreciation and concessional import and excise duties.

(International Energy Agency - IEA, 2014); 1 EUR = 77.52 INR (EZB: 2014/10/24)

Cogen Policy in Tunisia

[→ see ANNEX 3]

To promote the application of cogeneration schemes, the Tunisian Government has developed a bonus system for surplus electricity from cogeneration sold to the Tunisian Company for Electricity and Gas (Société Tunisienne de l'Electricité et du Gaz), based on the price of natural gas, the main commodity for CHP units in Tunisia, taking into account four different tariff slots:

- Daytime: 0.8 x gas price (c/kWh) + 16
- Peak time: 1.03 x gas price (c/kWh) + 100
- Evening: 1.0 x gas price (c/kWh) + 38
- Night: 0.72 x gas price (c/kWh).

To assist industry in setting up CHP projects, the following action plan was launched in 2005:

- Support for all technical and financial issues concerning cogeneration
- Organisation of technical workshops for each sector
- Setting up of credit lines on favourable terms to finance cogeneration projects
- Setting up a service unit covering all aspects of cogeneration to improve acceptance of this new technology by industrial decision-makers.

4.1.3 Regulatory Environment

The regulatory environment mainly concerns regulation of the possibility of energy consumers producing their own electricity and feeding their surplus back into the grid.

In many countries, electricity generation is still organised as a monopoly with strict regulations regarding grid stability, excluding any competition. Transmission and distribution systems are regional monopolies, and access needs to be regulated.

The main regulatory determinants for cogeneration that need to be analysed are:

- → Licensing for self-generation and export of electricity from the installed capacity to the grid.
- → Grid code, technical requirements for the connection of generators: the adequateness of the grid code is one issue. More important in many cases is practical handling in terms of delays until a connection is granted or the connection fees charged.
- → Payment for the reinforcement of grids can be an issue if the installation of cogeneration is a green field installation.

Tariff regimes may also become determinants if a cogeneration unit is connected to the grid, for example with regard to reactive power, contracted power/back-up power, etc. The utility company should not be allowed to change or interpret contract and tariff conditions to the disadvantage of the cogenerator.

4.1.4 Institutional Framework

Cogeneration is a technology that has not yet been introduced on a wide scale, especially among smaller consumers in most countries; it requires an enabling framework involving various stakeholders.

The initial stakeholder map outlined below gives an idea of the stakeholders who may have a role to play in most cases, including in developing countries, depending on the specific conditions in each country.

The roles of the stakeholders listed in the table need to be clarified and/or strengthened.

Table 10 Types of Fuel per Cogeneration Technology, Application and Sector

Stakeholder	Possible role
Ministry responsible for electricity/ regulator	Enhancement of framework conditions
Ministries for economic or industrial development	Promotion of and subsidies for cogen
Development or local banks (with support from development banks)	Financing of cogen/trigen by adequate credit lines, inclusion in clean/green financing schemes
Electricity utility(ies)	Understanding and promotion of cogen/trigen in the framework of national policies, possibly acting as ESCo
Energy (promotion) agency	Promotion vis-à-vis users, training, framework conditions
Consulting engineers	Awareness, training, clarification of ESCo role
Industry associations	Advocacy and promotion
Partly: individual investors from industry/ residential sector	Investment (debt/equity) in cogen/trigen projects

4.1.5 Availability of Skills

For most developing countries, cogeneration and trigeneration are new technologies and no skilled labour force is available for cogen. This can be a serious bottleneck for the rapid and large-scale dissemination of co-/trigeneration. The following steps are recommended in order to establish a sound value chain:

→ Planning
During the planning phase, experience in South Africa shows for example that the technical capacity to design and plan cogeneration units is available, but skills to prepare bankable projects still need to be reinforced. Large project developers such as refineries can always rely on international consultants, but for smaller projects the availability of local capacity is crucial. The most challenging fields in the cogen/ trigen sector for which planning skills have to be developed are:

- trigeneration
- waste heat recovery
- biogas and biomass utilisation.

→ Engineering, Procurement and Construction (EPC)
In order to implement a project at reasonable cost and to high quality standards the critical issues are:

- local and regional availability of skilled manpower
- transparency and competition among suppliers.

→ Operation & Maintenance (O&M)
Even if training and online support can be assured by the supplier, O&M know-how needs to be available on site on a broad enough level. The specific requirements for O&M skills need to be compared to the level of technical competence and skills in related areas.

In order to create an enabling environment for the development of co-/trigeneration, capacity-building for decision-makers through the provision of appropriate information and training is also a crucial prerequisite for the successful implementation of projects in this field. Some of the typical skills which are required and should be developed if gaps are identified are presented in the table below.

Table 11 Skills Needs of Stakeholder Groups

Stakeholder group	Skills and competencies required
Decision-makers in government departments	Awareness/understanding of cogen/trigen in principle and its multiple benefits on the macro level
Energy economists working in EE policy and electricity sector reform	Knowledge of the economic and environmental benefits of cogeneration, the economic mechanisms and drivers of cogeneration and its potential contribution to national energy supply capacity
Agents in cogen/trigen promotion units (energy agencies or similar)	Understanding of cogen and trigen technology in detail
Commercial and development bankers	Understanding of the costs and benefits of cogen and trigen Understanding of ESCo/IPP/ models
Energy users in government and private sector	Understanding of the rationale and the financial benefits on the micro level
Staff of (local) banks/financial institutions	Basic cogen/trigen know-how for evaluating bankability of projects

4.1.6 Value of Capacity to the Electricity System

One determinant of positioning cogeneration on the national agenda is the value of its contribution to the national electricity system, especially in those countries where capacity is scarce. The value of the contribution that can be provided by cogen units to the national electricity system depends on the relative stability of the system, for instance the frequency of load shedding required or even of blackouts. The question is: how flexible and thus dispatchable cogeneration units can be operated in order to respond to the needs of the electricity system by providing additional capacity to cover these bottlenecks.

In general, cogeneration follows the demand for heat or electricity from the consumer. However, it can be designed and operated in a more flexible way to cover the needs of the system, too. One possible option is to provide economic incentives to encourage the installation of additional generation or storage capacities suitable for covering peak demands or other bottlenecks of the system. For example, additional heat storage can give the flexibility to run the cogen unit even if there is no immediate heat demand in order to provide the electricity needed by the system and to use the heat later.

Two different types of dispatchability can be differentiated:

- → Adaptation to time of day/load by differentiating the price to be paid for electricity fed back into the system according to contractually arranged dispatchability, e.g. for 15-minute intervals, or for participation in secondary reserve for larger cogeneration units.
- → Participation in short-term energy markets as they emerge, e.g. day-ahead market.

From a technology point of view the following conditions must be met:

- → Communication technology for remote control of the engine is available.
- → Forecasting and control software is installed and functional.
- → Weather forecast must be improved to provide information on the future load demand at consumer level.
- → The operation of cogeneration engines must be as flexible as possible.
- → Gas engines, for example, can in most cases be operated at 50–60% of their rated capacity, and in case of emergency their full capacity can easily and rapidly be activated.
- → If the system/market requires the cogen unit to produce electricity, the waste heat can be stored using appropriate storage technology such as large hot water tanks.

In order to allow for the maximum amount of additional generation and/or storage capacity, the price signals should be as clear and stable as possible.

Appropriate regulations can be established between market operators and the cogenerating enterprises concerning the provision of dispatchable power at peak load times or upon demand or in response to market conditions. This requires features such as:

- → the fixing of a minimum/maximum load to participate
- → the prearrangement/lead time in the timing when power is required (1 day ahead)
- → an appropriate price-fixing mechanism (e.g. by auction).

4.1.7 Incentive Schemes

The analysis of financial incentive schemes and instruments for cogen project invetsmenst and operation in partner countries should differentiate between cogen-specific schemes and the applicability of certain energy-related incentive schemes to cogeneration. *[→see also Chapter 5]*

In principle there are two types of direct financial support schemes, the first related to the kWh produced and/or provided to the grid (feed-in tariff, bonus payments), the second related to the capital expenditure (CAPEX) per kW installed.

The following table shows the main types of incentive systems whilst at the same time pointing out their pros and cons.

Table 12 **Incentive Schemes for Co-/ Trigeneration**

Scheme	Advantage	Disadvantage
Capital subsidies (per kW installed)	Schemes exist in many countries Easy to handle	No relation to energy output No incentive to generate electricity in the peak hours Difficult to differentiate according to technologies and fuels
Subsidised interest loans	As above	As above
Tax incentive schemes including exemption from customs duties	No additional expenses for government, just foregone revenues for government and also municipalities	Tax incentives only valuable if sufficient profits to pay taxes (not suited for IPP/ESCo)
Feed-in tariffs	Geared to national benefit of efficient electricity production Greater uplift of the cogen industry	Locking in long-term subsidies Resistance from utilities
Bonus schemes (remuneration per kWh provided)	Can be handled outside tariff scheme Independent of fluctuations on electricity market	New administrative system in many countries, measurement & verification effort
Net metering	Can easily limit the financial impact on the utility	Mainly geared to smaller (PV) systems Biasing as a function of load duration curves
CO_2 tax rebates	Directly aiming at climate objectives	Applicable only in a few countries

In some countries important financial and fiscal support for cogen projects may additionally be offered on state or municipal level; this partly depends on the level of centralisation in electricity sector regulation.

Some countries limit the duration of the cogen support scheme *[e.g. Tunisia and Germany → see ANNEX 3]* in terms of calendar years, hours of operation or the percentage of production to be remunerated when fed back into the system. This leads to differentiation between electricity generated for your own use and electricity provided to the system. From the electricity system point of view, the most important aspect is decentralised self-generation, which takes load off the system and also reduces the strain on the distribution system.

In South Africa, for example, the government is planning a tendering scheme for cogenerated electricity. Such schemes can only be applied when the market is at a certain degree of maturity and are only suitable for relatively large projects (e.g. above 5 or 10 MW).

For systems which are under capacity strain it may be wise to provide an incentive scheme for feeding electricity back into the grid, especially at peak times. Governments have to analyse and take into account the overall macroeconomic benefits of cogen and create exceptions from the monopoly for generation if necessary.

The promotion of local content often comes up as an issue when investments are promoted. Capital subsidies and tax incentive schemes could be bound to a minimum of local content. As energy-producing equipment such as generators or turbines is produced in only a very limited number of countries, the local content mainly comprises the required infrastructure and the integration of cogen equipment into existing heating and cooling systems. Domestic content requirements are quite valuable for generating local benefits in most cases, especially in developing and emerging countries.

4.1.8 Capital Subsidies

In some countries such as Germany or Italy, financial subsidies for investment in co-/trigeneration are granted as investment subsidies or tax incentives. In other cases cogeneration investment may benefit from Small and Medium Sized Enterprises (SME) facilities aimed at enhancing productivity and competitiveness.

Information and guidelines on financing and financial subsidy schemes are available at international and national level in many countries, for example through national development banks or investment promotion agencies.

The development of co- or trigeneration projects is particularly challenging due to the complexity of the technology and of the regulatory framework and needs thorough planning. Project development is even more challenging for:

- → technologies that are new to the country or associated with higher risks, e.g. volatile biogas/biomass fuel supply and purchase conditions
- → ESCo/IPP business models.

In light of these risks it is recommended that support schemes be provided for the funding of bankable feasibility studies. This is an area where development cooperation projects have been active (e.g. in Chile, where GIZ financed feasibility studies) and can give further support.

4.1.9 Financing Co-/Trigeneration Investments

Commercial financing for investments including cogeneration are available in most countries as long as the size and thus investment is not too demanding. However, the availability and costs of financing investments in cogen technology vary significantly per country or region.

If financing is scarcely available in a market, investments in cogen technology compete against other investment opportunities, including those associated with lower risks from a banking perspective. This holds true in particular for the majority of smaller and medium-sized cogen projects which depend mostly on debt financing.

Local banks and financial institutions are not always familiar with financing cogen technologies.

Third parties such as ESCos provide alternative financing opportunities *[→ see 4.2.7 ESCos and Contracting]*.

If insufficient financing sources are available on the market, **ESCos or** the contracting approach might be a very attractive balance sheet financing option for cogen projects *[→ see 4.2.7 ESCos and Contracting]*. The term contracting is used here in a similar context to Independent Power Producer (IPP) and Build Own Operate (BOO) schemes, which tend to be used for larger power generation plants.

Depending on investment volume and associated transaction costs *[→ see 4.2.5]*, project finance might also constitute a reasonable option, more probably for very large cogen projects and financing volumes exceeding EUR 20–25 million.

Table 13 Different Approaches to Funding Co-/Trigeneration Incentive Schemes [60]

Scheme	Funded by governmental budget	Funded by electricity consumers (ECs)
Capital subsidies (per kW installed)	E.g. in Germany (ex-post) for cogen installations or in Tunisia	
Subsidised interest loans	E.g. in Tunisia	-
Tax incentive schemes including exemption from customs duties	E.g. in India or Brazil for biomass-based cogen, South Africa for cogen as part of energy efficiency	-
Feed-in tariffs	E.g. subsidies for utilities for paying feed-in-tariffs as applied in Tunisia	
Bonus schemes (remuneration per kWh provided)	E.g. in Slovenia	As applied e.g. in Germany, a bonus is paid by ECs through a special cogen charge as part of the electricity bill

4.2 Determinants of Successful Co- and Trigeneration Projects

As elaborated in *Chapter 4.1*, the decision whether cogen applications are applicable and/or economically viable depends on various framework conditions, and decision-making is not a linear process and in most cases subject to an individual project assessment. *Chapter 4.2* therefore takes the project level perspective into account to identify the most important determinants that influence the implementation of cogen applications. Barriers to specific cogen projects are also investigated, however the identification of such barriers could also be interpreted as an opportunity to leverage hidden cogen potentials.

4.2.1 Infrastructure

As described on the macro level in *Chapter 4.1*, the existing energy infrastructure is one of the key determinants for the proper design of a cogen application. Thus, an analysis of the infrastructure is the starting point for examining energy supply solutions. Gas and electricity grids are frequently the most important energy supply options and define the baseline as well as cogen opportunity costs (in terms of reliability, environmental safety and costs of energy supply). However, energy infrastructure and related costs vary significantly from one country/region to another, as do the corresponding legal framework conditions and the allocation of costs between consumers and grid/network operators.

Access to the electricity grid and – as natural gas-fired cogen applications are a core technology in this guide – to the gas grid is a crucial project determinant. If no direct access to the grid is available, the feasibility of expanding the grid needs to be investigated and evaluated further. Depending on the project size, expansion of or connection to the grid may have a significant impact on the cost-effectiveness of cogen applications.

60) *See also ANNEX 3* International Cogen policy Practice

In summary again, external infrastructure infrastructure determinants to be taken into account are:

→ access to the electricity grid and gas grid

→ feasibility of expansion/connection to the grid
- costs *[→ see also 4.2.5]* and
- timing of expansion/connection to the grid

→ availability of sustainable biomass resources
- waste wood and fuelwood availability from industry or forestry within 50 km
- biogas plants nearby to purchase (e.g. piping) biogas; treatment/processing (capacities) to natural gas quality

→ availability of Liquefied Natural Gas or Liquefied Petroleum Gas
- retail market for LNG or LPG
- constraints from limited transport capacity of trucks to supply liquefied gas may affect cogen plant capacity (→ LNG/LPG thus more likely to be suitable for smaller cogen plants).

Internal infrastructure determinants to be taken into account are:

→ availability of sufficient space for the
- installation of co-/trigen technology
- handling of required (fuel) resources (e.g. biomass: drying, chipping, storage etc.)
- further treatment processes for the fuel source, e.g. certain types of biomass

→ logistical requirements and restrictions *[e.g. fuel supply → see Chapter 4.2.2 below]*.

4.2.2 Availability of Fuel and Technology

An analysis of the existing infrastructure and fuel availability for cogen projects also incorporates other, non-grid bound energy sources, such as coal, oil, agricultural, municipal or industrial wastes and other renewable energy sources such as biofuels, biomass and biogas or waste heat. Especially in developing and emerging countries where the natural gas grid rarely covers relevant areas, alternative cogen fuels such as those mentioned above *[→ see 4.2.1]* constitute promising options that should be analysed.

Biomass and feedstock resources for biogas production are particularly likely to be associated with fuel supply risks. These risks may take the form of extremely volatile supply or shortages of supply due to:

→ decreasing (volatile) industrial production levels and thus generation of waste

→ crop or harvest failures

→ increasing demand for scarce biomass resources

→ rising prices as suppliers see the value of biomass.

The risk of rising prices for the supply of biomass and feedstock for biofuel/biogas production should therefore be taken into account. Some projects suffer from a lack of contract compliance. This may occur when an alternative usage becomes economically extremely attractive, for example if there is a significant increase in world market prices for crops.

Depending on the country's specific project framework there might be restrictions on accessing the described cogen technology *[→ see Chapter 2]*. The availability of cogen technology, including the necessary expertise, may differ for both equipment and services depending on the stage of the value chain:

→ planning

→ engineering, procurement and construction (EPC)

→ operation & maintenance (O&M).

The segments are examined in more detail above *[→ see 4.1.5]*. Cogen supply and service level/quality and related pricing at all of these stages depend on the presence of corresponding local expertise and the given competition level of the local market. As cogeneration is a rather new technology in emerging and developing economies, cogen equipment and related services are likely to be purchased from industrialised markets and thus may be associated with additional charges.

4.2.3 Own Use and Export of Electricity (Willing Buyer)

Due to the characteristics of the technology, cogen projects require high runtime and the longest possible operation hours in order to scale applications properly, so the operator's own demand and the available energy export options are important determinants for the design of the cogen system. Depending on the design approach *[→ see also 4.2.4 Design Philosophies for Cogeneration Projects]* the surplus of heat (in cases of power-driven design) or electricity (heat-driven design) that is usually produced must be utilised according to local opportunities and in order to maximise project benefits. This may include the following options:

→ feed-in to the grid (with or without remuneration)

→ net metering

→ wheeling through the grid to willing buyers.

Options such as wheeling to willing third-party buyers may also contribute to the overall economic benefit of cogen projects, as the additional revenues (depending on the specific energy demand required) allow the utilisation of economies of scale by larger cogen engines/plants.

Related restrictions that lower cogen profits may accrue from:

→ (prohibitive) wheeling charges in case of willing buyers

→ bottlenecks in the grid

→ licensing obligations *[→ see also 4.1.3 Regulatory Environment]*.

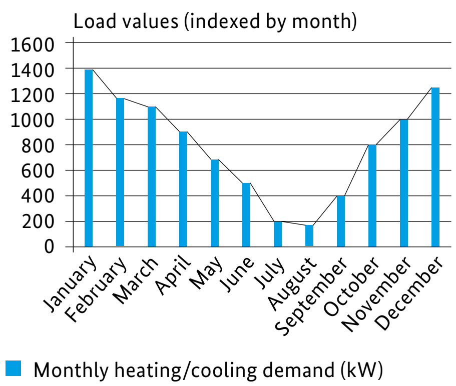
4.2.4 Design Philosophies for Projects

As pointed out, cogen design is often complex and requires careful planning and expertise to be implemented successfully and realised as a cost-efficient solution.

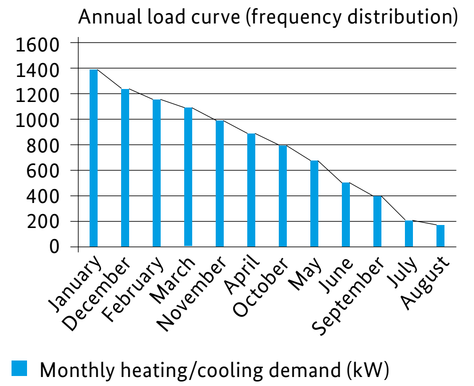
> **Heat-driven cogen design**
>
> 'Depending on climate zone, object type and power/gas prices, a profitable [cogen] operation can be reached if the thermal power of the CHP unit (QCHP) is ca. 10–30% of Qmax.'
>
> *(Sokratherm, 2014)*

Depending on the specific framework conditions, on energy purchase prices and other above-mentioned determinants, two main design philosophies for cogen applications are common: heat-driven or power-driven design. Both concepts imply – depending on the specific needs and project background – the incorporation of heat or electric power storage facilities. A heat-driven cogen design maximises utilisation of the heat production, while the power-driven design maximises the electric power output of the cogen plant. The starting point for each cogen design approach is a detailed analysis of the individual (power, heating, cooling) energy demand and load profile as well as the expected prospective development. *Figure 20* below illustrates typical process steps for a heat-driven cogen design.

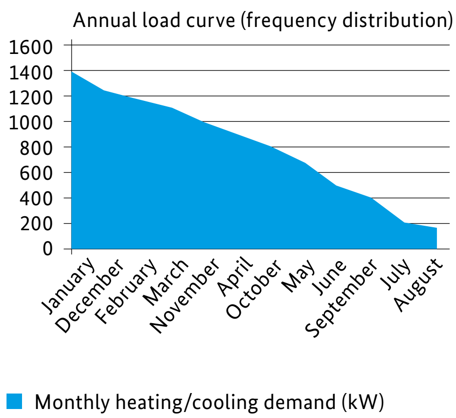
Figure 20 **Process Steps of a Heat-Driven Cogen Design**



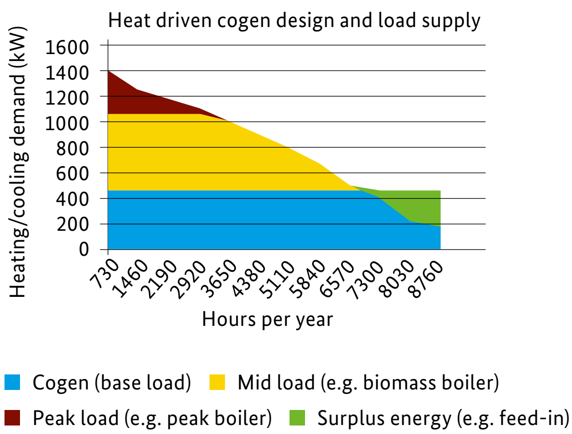
1. Analysis of observed/monitored values →



2. Demand ordered by load (frequency distribution) →



3. Surface beyond load curve defines required load supply →



4. Cogen heat-driven design; focus on maximizing cogen full load hours and thus supply of heat base load (blue surface)

The electricity-driven design approach involves the equivalent process steps, but focused on electricity consumption and load curves.

Adequate and plain (not temperature-dependent) load profiles, for example through process heating/cooling/electricity demands, facilitate the cogen design whereas highly volatile profiles require measures to reduce peaks, for instance through the implementation of storage concepts.

Cogen design philosophies are usually base-load oriented in order to maximise the cogen plant's full load hours during its lifetime and thus minimise specific cost per kWh of energy (electric or heating energy) produced.

Case study: multi-unit cogen design

Phoenix Contact, Germany *[→ see Figure 21 and detailed in ANNEX 1]*

Trigeneration project

- cogen: 7,000–8,000 full load hours
- ∑ 2.8 MWel, 3.0 MWth
- payback < 3 years.

A further aspect of cogen design is the system layout, namely single- or multi-unit systems. Single-unit systems are common practice and allow greater economies of scale compared to multi-unit systems as prices usually decrease significantly with higher capacities. Also O&M expenses as well as the complexity of system control are reduced compared with multi-unit systems.

On the other hand, cascading multi-unit systems allow more precise adaptation to energy demand at the site. This includes cogen-based energy supply with compact cogen units achieving capacities in the MW range. The systems' redundancy also increases the reliability of supply, for example through the optional operation of a unit or units while one or more of the others is undergoing maintenance. *Figure 21* below shows a multi-unit cogen design.

Figure 21 **Example of a Multi-Unit Cogen Design** [61]

61) © Sokratherm, 2014

4.2.5 Costs

Cogeneration costs not only vary according to the type of cogen unit and equipment [*→ see 4.2.5.1*] or project costs [*→ see 4.2.5.2*], but also according to country/region, and thus need to incorporate different baselines. Consequently there is greater difficulty comparing project costs and related cost components such as:

- → capital expenditures (CAOEX)
- → financing costs
- → operation & maintenance (O&M) costs.

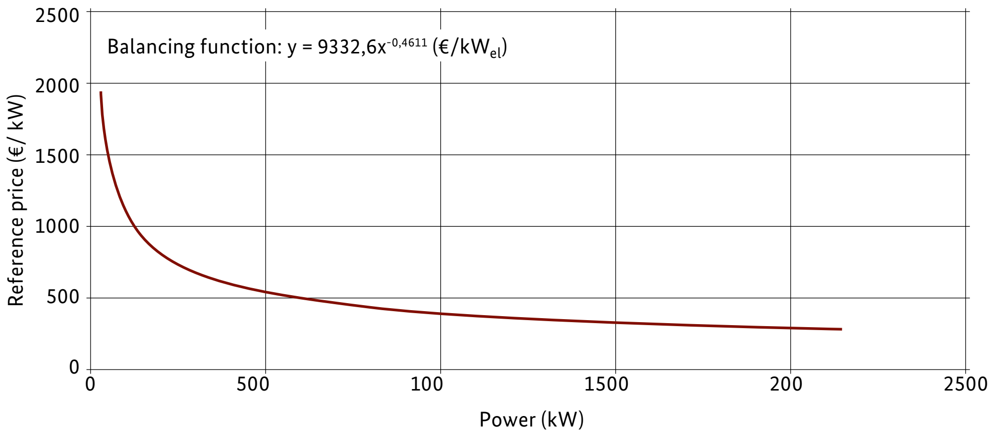
Moreover additional cost elements need to be incorporated into project planning:

- → (up-front) transaction costs of projects
- → costs for backup power and outages
- → storage.

4.2.5.1 Costs of Cogen Units

The cost of cogen units relate to equipment costs and services required for the installation and commissioning of cogen units. The total amount of cogen unit costs varies significantly between the various cogen technologies [*→ see Chapter 2*]. However, the underlying logic of economies of scale is valid for all cogen technologies in terms of volume production, but especially for cogen engines as presented below. *Figure 22* illustrates the cost degression curve for the example of gas-fired cogen engines.

Figure 22 Cost Degression of Natural Gas-fired CHP Engines [62]



62) © ASUE, 2006, own remarks

The reference prices include cost elements directly related to the cogen unit such as the engine itself (major cost share with 73–87%) as well as cogen equipment, working materials and implementing services. *Table 14* illustrates the relative cost components of six common gas engine capacity.

Table 14 Distribution of Cost Components of Gas Engines per Capacity [63]

Power [kW_{el}]	≤ 50	≤ 100	≤ 250	≤ 500	≤ 1,000	≤ 2,500
Engine	80.0%	73.0%	75.0%	76.0%	87.0%	84.0%
Sound absorption	2.8%	3.5%	2.6%	3.0%	2.3%	3.3%
Catalytic converter	1.0%	1.4%	0.8%	0.9%	0.8%	1.2%
Lubricating oil cycle	1.7%	2.7%	2.4%	2.5%	1.2%	1.2%
Control box	6.0%	10.9%	11.2%	10.4%	3.4%	3.1%
Ventilation	2.7%	3.3%	4.1%	3.4%	3.6%	5.0%
Transport and assembly	3.2%	2.3%	1.9%	1.6%	0.7%	0.7%
Implementation	3.5%	2.3%	2.4%	2.0%	0.9%	0.7%

These shares may vary significantly depending on cogen technology and plant size. The data presented above does however offer an indication of cost drivers for cogen equipment and plant implementation as per cogen capacity.

4.2.5.2 Costs of Cogen Projects

In addition to the costs of cogen equipment/units, the costs of cogen projects incorporate all project-related activities along the entire value chain and thus include costs for planning, engineering, construction, operation and maintenance (O&M) as well as costs for specific system-related design elements, such as storage facilities, and costs for grid connection or any required back-up power facilities.

Due to the wide range of available technologies and areas of application for cogen projects, costs may easily vary from several thousand euros for small-scale applications to millions of euros for complex industrial plants or large power stations.

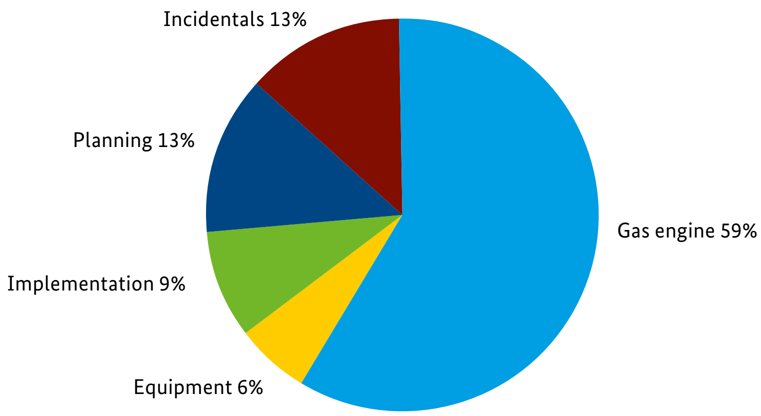
Costs can be broken down according to type of costs as follows:

- capital-related (e.g. planning and equipment)
- consumption-related (e.g. fuel costs)
- operation-related (e.g. maintenance) expenses.

The structure of capital-related project expenses required for the installation of a cogen gas engine, (typical investment of approx. EUR 300,000 for 225 kW_{el}) for example, can be divided up as follows.

63) Own table based on ASUE, 2006

Figure 23 **Typical Cost Structure for Investment in a Cogen Project** [64]



This does not include costs of financing and costs for specific system-related design elements such as storage or back-up power. These costs are investigated in the following sections.

Fuel Costs and Energy Prices

Fuel costs have a major impact on the cost-effectiveness of cogen projects. Depending on the specific (energy quality) demands and energy infrastructure (fuel availability), different types of fuel may offer specific benefits. However, fuel availability and related costs vary significantly according to country and source. In cases where waste energy is utilised in cogen applications, costs may be (close to) zero or even negative in cases where disposal is associated with waste management costs.

Since the opportunity costs for investments in small- and medium-scale cogen applications are usually defined by local grid tariffs for electricity and gas, comparing these two prices is often crucial for determining the cost-effectiveness of cogeneration.

As this guide focuses on smaller cogen applications, gas is the predominant fuel. Thus fuel costs for a gas-fired cogen application are analysed as an example. However, the underlying logic holds also true for other types of fuel.

In particular, the spread of the electricity and fuel price may indicate the economic feasibility of cogen projects. For large power stations this spread is referred to as 'spark spread' and is typically calculated using spot prices for natural gas and electricity at various (regional) trading points. The spread (difference between the price received for the electricity produced and the cost of natural gas needed to produce that electricity) indicates the profitability of natural gas-fired power plants[65].

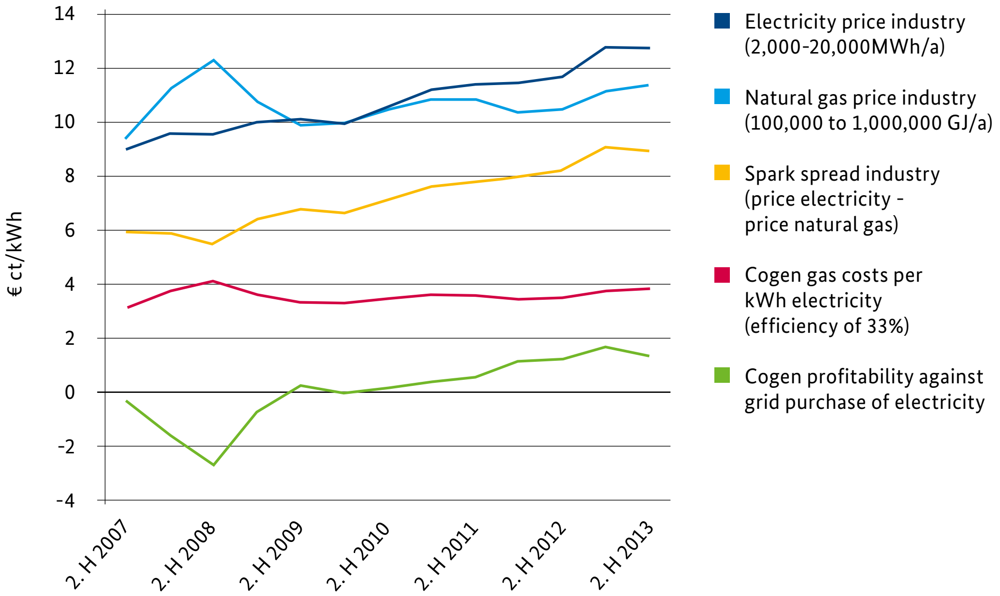
64) Own illustration based on ASUE, 2012

65) EIA - U.S. Energy Information Administration, 2013

As both electricity and gas tariffs for households and especially for companies and industrial consumers are country/region-specific and dependent on consumption and the consumers' load profile, the cost-effectiveness of cogen applications must be evaluated case by case.

For many industrial consumers in Germany, for example, the following prices are relevant to an evaluation of gas-fired cogen applications.

Figure 23 **Industrial Electricity and Natural Gas Prices in Germany** [66]



The prices of electricity and natural gas for industrial consumers in Germany shown in *Figure 24* include excise taxes, without VAT. The figure is intended to demonstrate the logic of cogen profitability for the majority of smaller cogen applications, where cost-effectiveness derives from the avoided costs of purchasing electricity from the grid. This is due to the comparatively high cost of electricity while fuel costs (here: natural gas) are significantly lower. This correlation is exemplified as follows.

The spark spread level (electricity price - fuel price) is an important indicator for cogen profitability.

Figure 24 illustrates the relevance of the price spread between cogen fuel (here: price of natural gas, light blue line) and the grid tariff of purchased electricity (dark blue line). It becomes clear that the larger this spark spread (yellow line) is, the better is the cost efficiency of cogeneration. Low fuel prices induce low generation costs for electricity produced through cogeneration (dotted blue line).

In this example a fuel input of 3 kWh of natural gas leads to roughly 1 kWh of electricity and nearly (losses not considered) 2 kWh of heating energy. The spread between cogeneration gas costs per kWh of electricity and grid purchase indicates the cogen profitability for electricity generation (dotted green line). As *Figure 24* indicates, a spark spread of less than 2/3 of the grid power tariff results in negative cogen profitability. This is due to the fixed electric efficiency (here: 1/3) of cogeneration.

66) Own illustration based on Federal German Statistical Office (destatis - Statistisches Bundesamt), 2014

Further utilisation of the 2 kWh of heating energy from the cogeneration process improves overall cogen profitability as the natural gas purchase required for heating purposes is (partly) avoided. However, the achieved savings during the project lifetime need to be high enough to pay back the capital expenses for cogen project implementation in a reasonable period of time. Nevertheless, the spread of electricity and cogen fuel prices (spark spread level) may be an important indicator of cogen profitability in the majority of energy markets, as it is a relative measure and not dependent on absolute values.

Costs for O&M

Operation and maintenance efforts are significant cost drivers for cogen projects. Gas engines in particular (in engine-driven cogen applications, not including Stirling technology) are subject to high maintenance costs on account of their frequent service and maintenance intervals. Major overhauls for gas engines usually become due after approximately 60,000 hours of operation, but depending on the technology this may range from as low as 40,000 to as high as 80,000 hours of operation. Smaller gas engines tend to be more maintenance-intensive than larger gas engines.

O&M costs represent a large share of total cogen costs and are usually defined per hour of operation. As O&M expenses also greatly depend on the availability of qualified personnel and the local presence of cogen manufacturers and corresponding services, these costs may vary significantly between countries and regions.

The share of O&M costs is typically in a range of 1.5% – 3.0% p.a. of total capex. These costs are often covered by full service/maintenance contracts that account for the cost of rectifying faults, including spare parts, and include personnel and travel costs during the agreed period. As part of a full maintenance contract, regular maintenance is normally carried out by the service provider.

As O&M costs are fixed factors, whether the cogen unit runs at full load and for 8,000 hours or for 1,500 hours per year only, the cost-effectiveness of cogen technology (especially of gas engines) increases with the runtime (full load hours) of cogeneration.

Cost of Back-up Power and Outages

Cogen technology provides on-site electricity generation that is resilient in the face of power outages. Especially in cases where grid outages occur frequently and thus seriously restrict the reliability of production processes, cogen technology improves the security of energy supply and reduces the risk of interruption of production, while negating the need for additional investments in back-up power capacity. Back-up systems are rarely in operation but are associated with high investments costs (high-capacity back-up systems), as well as continuous costs for infrastructure and maintenance, including expenditure on fuel for regular test runs. Cogen applications can reduce these costs significantly. Depending on the cogen plant design, for example if redundancy is built into a multi-engine cogen layout *[→ see also 4.2.4]*, such costs may be saved completely. Cogeneration technology thus contributes to the overall cost-effectiveness of the energy supply system.

However, many cogeneration systems maintain their connection to the utility grid for supplementary power needs beyond their self-generation capacity and/or for standby and back-up service during routine maintenance or unplanned outages. Utility charges for these services (standby rates) can significantly reduce the cost-saving potential of cogeneration[67].

67) Center for Climate and Energy Solutions, 2014

4.2.5.3 Transaction Costs and Project Implementation Costs

To ensure successful implementation of cogen projects, it is not only essential to have engineering expertise with profound understanding of the technical design but specific know-how in the field of licensing and legal obligations is required, too.

Cogen design and the technical implementation of cogen technology within a given energy infrastructure is a complex matter. This causes significant transaction costs, as the complex planning and engineering process and especially the technical design and cogen plant layout requires external support from capable engineers and from consulting companies specializing in this field. Cogen licensing and compliance with specific legal obligations are also crucial, so an allowance must be made for a project budget for lawyers or corresponding surveys. Project-specific planning efforts and related transaction costs may be as high as 10–20% of the total capex.

The transaction costs vary substantially depending on the complexity of the operation, determined by various factors:

→ Financing: transaction costs related to financing are determined by issues such as:
  • self-finance or debt finance
  • availability of subsidies
  • applicability of ESCo/PPP models

→ Licensing: transaction costs related to licensing mainly depend on fuel, size, location and technology. Electricity generation licensing is an issue in many countries and needs to be investigated early as it may depend on the size of the generator *[→ see also 4.1.3. Regulatory Environment]*. Besides licensing (generation allowance), the registration of power plants might be an obligation, e.g. usually in liberalised markets.

Relevant sources for cogen financing, subsidies and promotion schemes at the national level were summarised in a previous section *[→ 4.1.7 Cogen Incentive Schemes]*. Also, Cogen financing, subsidies and support schemes are presented in *Chapter 4.2.7 ESCos and Contracting*.

4.2.6 Financing and Promotion Schemes on Project Level

Additional promotion for cogen on the project level may accrue from institutional support such as energy agencies and (cogen) related associations of both local/national and international agents. Promotion of cogen can thereby be implemented through:

→ support related to research and development (R&D) and international collaboration

→ promotion of pilot model projects

→ integration of lessons learned from pilot projects and models into infrastructure development plans.[68]

These instruments help to widen cogen financing opportunities and contribute to improving the profitability of cogen projects, for instance by shortening payback periods etc. Within the international context, capacity-building as well as market creation and development for cogen and trigen technologies can be fostered by bilateral and multilateral development and cooperation agents such as GIZ.

68) Center for Climate and Energy Solutions, 2014

4.2.7 ESCos and Contracting

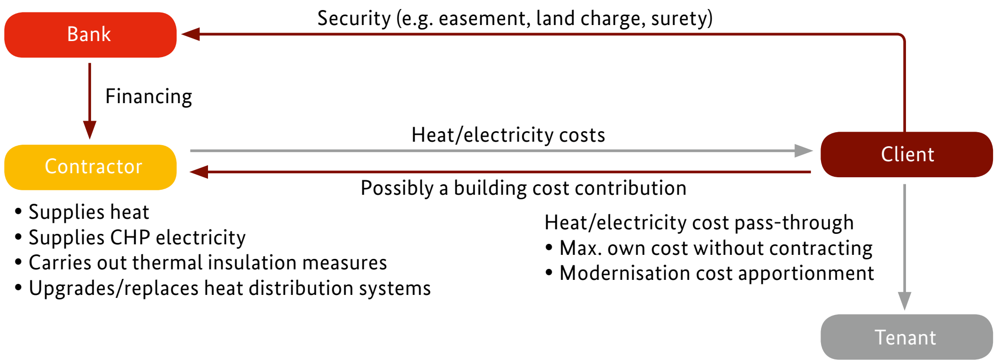
The term 'ESCo' is widely used as shorthand for all companies offering energy-related services. In a broader sense this implies three groups of energy service providers, namely:

- consultancy (service) providers such as energy auditors, planning engineers, certified measurement and verification experts, accountants, lawyers and others who basically provide advice
- technology suppliers of energy efficiency hardware (e.g. efficiency technologies like lighting, cogen and solar components or systems) or software (e.g. for energy accounting or management) and their related operation and maintenance services (e.g. servicing of burners, technology maintenance services or software updates)
- ESCos which provide performance-based energy contracting (also labelled as ESCo or Energy Efficiency Services).[69]

→ For a detailed overview and further information on ESCos and their related services, see GIZ ESCo guide 'Assessing Framework Conditions for Energy Service Companies'.[72]

A rather narrow definition of ESCos used within the cogen context refers to the third ESCo group, who offer specific energy service ('contracting') models. In this guide the term 'contracting' hence refers to energy service models as defined in the GIZ ESCo guide 'Assessing Framework Conditions for Energy Service Companies'.[70] These contracting (energy service) models can be broken down into various segments, but the most important for cogen applications is energy supply contracting (ESC). *Figure 25* below shows a typical structure for this contracting model.

Figure 25 **Schematic Overview of an Energy Supply ESC Model** [71]



Case Study: ESC

Heideblume Dairy, Elsdorf, Germany
[→ see ANNEX 1 Case Study Projects]

- Trigeneration project
- cogen capacity: 1.1 MW_{el}
- investment: EUR 600,000
- return on equity after first year: 83%.

69) Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2013

70) Ibid.

71) Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2013

72) Ibid.

The availability of contracting services mainly depends on the size of local energy and cogen markets and thus the presence of specialised ESCos offering these services. The contracting approach is one of the major risk mitigation instruments for cogen applications, as capital investments are (usually) performed by the contractor. Each type of risk may be considered under the contracting approach and then outsourced to an ESCo willing to take these risks.

Under the ESC approach, most of the above-mentioned *[→ see 4.2.9 Investment Risks]* technical and economic risks of cogen planning, installation, operation and maintenance as well as the uncertainty over the development of fuel and electricity prices are usually borne by the contractor (ESCo) for a certain contracting period, typically 10 to 15 years, when the contractor conducts all cogen-related investments. In order to finance these installations, the contractor raises funds on the capital market, which is normally much easier for him than for the small or medium-sized enterprise subsequently using the cogen equipment. On the other hand the client is therefore obliged to purchase the amount of energy, which has been agreed by contract at fixed prices (usually below or at the same pricing level as before contracting) during the contract period. The contractor usually operates the cogen plant and supplies the contracted amount of energy to the client, who is the owner (at the latest after the ESC contract comes to an end) under this scheme. The benefit (risk premium) for the ESCo is gained through the energy cost saving potential of cogen implementation and system design over the contracting period, when it still receives full payment of the energy costs from the client *[→ see markup box Case Study ESC: Heideblume Dairy]*.

4.2.8 Economic Analysis of Projects

Although this greatly depends on energy framework conditions, cogen projects generally benefit from high (unadjusted) electricity tariffs as self-generated power is normally cheaper than grid power. A large spread of fuel and electricity prices significantly improves the economic attractiveness of cogen solutions.

> As the planning and engineering of cogen is complex, this guide additionally provides a decision matrix *[→ ANNEX 2]* to give a sense of the adequacy of cogen applications within specific project backgrounds.

The first instrument for an economic assessment of projects pesented in this guide is a decision matrix (consisting of determinant mapping and checklist) on both national and project level in order to decide whether or not a project scenario is adequate for the utilisation of cogen technology. Determinants reflecting the guide's chapter structure quickly indicate critical aspects as well as feasibility by setting markers for each aspect of cogen applications [→ *ANNEX 2]*

On the project level, cogen/trigen potential is often characterised by beneficial conditions regarding

- → fuel availability
- → alternative fuels
- → project size.

However, co- and trigeneration investments are also confronted with technical and economic risks, which need to be assessed in order to perform an economic evaluation and carry out proper implementation of cogen projects. The following section sets out the most important risks for cogen project investments.

4.2.9 Investment Risks

The risk of investments can be divided into technical (cogen plant-related) and economic (changing purchase conditions, etc.) risks.

Technical risks relate to:

→ construction/installation of the cogen plant

→ operation & maintenance

→ volatility in fuel quality

→ peripheral equipment.

Economic risks relate to:

→ fuel availability, e.g. volatile supply or production of biomass

→ development of fuel prices, e.g. increasing gas prices

→ development of electricity prices, e.g. decreasing prices (reduced spark spread of cogen fuel), or, after implementation of cogen technology, increasing prices (for the consumer) when a decline in power purchase is associated with higher fees or a less advantageous tariff structure

→ Off-taking and remuneration risks (due to legal changes, e.g. feed-in tariffs, wheeling; uncertain PPAs, insolvency of private off-takers, etc.).

Potentially suitable risk mitigation instruments and strategies include:

→ outsourcing of risks (technical, operational, economic), e.g. ESCo/contracting such as energy supply contracting (ESC)

→ hedging of risks, e.g. fuel hedging, currency swaps, etc.

The ESCo/contracting model, one of the major risk mitigation instruments for cogen applications, is explained in detail above *[→ see 4.2.7]*.

5

Recommendations on the Promotion of Co- and Trigeneration

5 RECOMMENDATIONS ON THE PROMOTION OF CO- AND TRIGENERATION

5.1 Introduction

Chapter 5 looks at development cooperation and addresses advisors and all stakeholders who are active in the promotion of cogeneration or are considering supporting co-/trigen promotion and project implementation.

This chapter first elaborates the policy framework that should be developed to promote cogeneration. Human capacity development is then discussed in the following section. Thereafter the various financial subsidy schemes are summarised. A wide range of other activities to promote cogeneration technologies is finally presented.

5.2 Energy Policy and Sector Framework Conditions

Cogeneration should be integrated into the national energy policies of the relevant countries and be promoted by establishing appropriate framework conditions as suggested below.

→ Energy efficiency policies
EU policies, e.g. National Energy Efficiency Action Plans (NEEAPs), provide a useful format for energy efficiency and cogen policies as they quantify the savings objectives and specify the measures to be taken. For cogeneration this means:
- an analysis of the cogen potential is required
- specific objectives for cogen shall be spelled out (e.g. on the sectorial level). Measures to increase the use of cogeneration are specified (e.g. obligatory cost-benefit analysis, priority for dispatching of cogen plants, subsidies etc.). Also the importance of ESCos for implementing cogen can and should be considered. In other words cogen policies can and should be included in the NEEAP in as detailed a form as possible.

→ Renewable energy policies
The use of biogas and biomass will benefit from the application of cogeneration. On the one hand the economics of projects are improved by revenues from the production of both electricity and heat/cold generation. On the other hand if biogas and biomass are promoted governments should insist on or specially promote cogeneration in order to harness the full benefits of this primary energy source including energy efficiency and the respective CO_2 savings.

→ Climate mitigation policies
Co-/trigeneration is highly beneficial for climate mitigation by achieving reductions in CO_2 emissions of 40% or more, depending on the fuel use pattern and efficiencies of the central thermal power plants. Depending on what climate policy instruments are used, cogeneration should be explicitly promoted, for example by an exemption from CO_2 taxes.

- Electricity sector policies
  In many cases cogeneration projects are only viable if some electricity can be exported to or through the grid. The general endeavour to liberalise electricity generation and to promote decentralised generation is an important framework condition for the successful establishment of a national cogeneration policy. It appears to be useful to define explicit targets for cogeneration and/or embedded or captive generation of electricity in MW or percentage of electricity, as generation planning and licensing is centrally regulated in many countries.
- Tariff policies and regulation oversight must ensure that private co-/trigen operators are not discriminated. The contribution of cogeneration to peak power and dispatchability should be taken into consideration, for example.

Furthermore, the departments of industry or economic development in each country should also be involved in the development of cogen promotion policies, as smaller-scale decentralised generation is more labour-intensive and thus promotes employment. These departments may also operate or adapt incentive schemes to encourage modernisation, efficiency and competitiveness. Ideally, cogeneration should become part of those programmes.

In some countries municipalities or municipal utilities play an important role in electricity generation. In this case they should also become an important stakeholder in the promotion of cogeneration.

5.3 Incentive Schemes

Why and to what extent would financial incentives be necessary for cogeneration?

- In many countries electricity tariffs are subsidised or do not reflect the true cost to the economy including all external costs (such as environmental impacts).
- There are benefits of cogeneration which do not apply to the investor but to the country at large in the form of external effects. Increase in the reliability of supply, reduction of transmission and distribution losses, positive balance of payment effects and environmental effects are important examples.

The various incentive schemes were discussed as ‘determinants’ for the success of cogeneration in *Chapter 4*. In order to promote cogeneration, in many cases it is necessary to improve these instruments or indeed create them.

In order to better understand and justify the need for financial support of the initial co-/trigen investment, as a first step the economics of cogeneration projects should be illustrated by means of an economic analysis. This analysis should clearly indicate the economic and financial benefit of cogeneration depending on size, load profile and fuel used, with special emphasis on the segments where the potential for cogeneration is most important, for example food processing industries, hotels, etc. The remuneration of excess electricity to be exported to the grid is an important factor to be considered. The financial subsidies required in relation to a minimum payback period and internal rate of return can then be calculated accordingly. In a second step, avoided subsidies included in the electricity tariffs and other effects as well as avoided external costs such as reduced fuel imports and postponed investment in power plants should be considered in the economic analysis on the national level.

The different types of financial incentives are laid out in *4.1.7*.

The following considerations should be taken into account for the design of any cogeneration promotion scheme:

- Facilitating the export of surplus electricity to the grid, e.g. by means of an attractive feed-in tariff, tends to be much more beneficial than capital subsidies.
- Financial incentives should be differentiated by fuel and size, and can be developed with all schemes even though the practicalities may vary.
- Any scheme that is subject to electricity sector regulation may face resistance from existing large generation companies which want to defend their market share and monopoly in generation; consideration should be given to specific arguments such as the reduced need for reserve capacities due to the introduction of dispatchability of decentralised generation.
- Any incentive scheme should be tailored in such a way that it is also applicable to third-party investors and operators such as ESCos/IPPs and to energy supply contracting.
- Especially for biomass and biogas projects, but also for larger and more complex cogen/trigen projects, the development phase is long and burdened with many risks of failure. Project development facilities should be made available for the project development/feasibility phase to cover these risks. This type of funding does not necessarily have to take the form of subsidies; it can also be a type of insurance through which the promotor receives some co-funding for the development phase, which must be paid back if the project succeeds.

5.4 Human Capacity Development

Human capacity development (HCD) is important as it not only contributes to the development of cogeneration in terms of debottlenecking development but also helps to increase local value added and employment. In most countries cogeneration projects will very much rely on engineers to promote, plan, implement and operate cogen projects. Technicians and skilled workers are needed during construction and to a limited extend for operation and maintenance.

A systematic approach to capacity-building should thus be chosen along the following lines:

→ analysis of needs and skill gaps:
  - differentiate according to stakeholder/target groups and required steps in the value chain *[→ see differentiation in Chapter 4]*
  - involve industry (engineering firms, etc.) and explicitly address short term bottlenecks

→ focus on further education, as complex technologies cannot be designed and implemented by young graduates

→ involve suppliers in training (materials, delivery)

→ include planners and architects (for the commercial and residential sector) who have a role in early phases of new projects

→ develop training markets in order to achieve sustainability by means of incentives or setting of compulsory requirements for training-based certification when related to subsidies and other government support

→ take into consideration interfaces with existing capacity-development programmes by development cooperation institutions/donors in the respective country (e.g. energy efficiency as a whole but also biogas/biomass)

→ include cogen in higher education curricula, mechanical engineering courses at technical universities, etc.

Human capacity development contributes to developing the cogen market in several important ways:

→ engineers and advisors are enabled to develop the market by selling their services

→ cogen training could be made obligatory for certain groups (e.g. energy managers or energy auditors)

→ potential cogen clients should be made aware of the potential and application possibilities

→ staff of local (development or commercial) banks could be considered for capacity development to accelerate financial support mechanisms for co-/trigen.

Whereas skills gaps and training needs are country-specific, the following pattern will apply in most countries.

Table 15 Target Groups and HCD Issues

Target group	Issues			
	Basics of cogeneration	Application and determinants	Economic modelling	Design of cogen systems
Policy-makers	X	X		
Energy agencies and promotors	X	X		
Final clients	X	X		
Banks	X		X	
Consulting engineers			X	X
ESCos	X	X	X	X
Trainers in energy	X	X		X

The HCD issues will be quite similar for a number of partner countries. Training should therefore be offered on a regional or global basis, especially for individuals from ministries and/or energy agencies where the number of potential participants per country is limited.

Sample issues for 'Basics of Cogeneration' are suggested as follows:

Overview, benefits and determinants of cogeneration

- Cogeneration technologies (features)
- gas engines
- trigeneration (adsorption chillers)
- regulatory framework conditions (export of electricity and licensing)
- financial incentives
- economics and life cycle costing
- other benefits of cogeneration.

Optional

- Cogeneration from biogas
- introduction to cogeneration design
- steam turbines
- district heating and cooling
- thermal storage.

5.5 Awareness-Raising and Demonstration

5.5.1 Awareness-Raising

To enable technologies that are not yet very well established – such as cogeneration in developing and emerging countries – to be properly promoted, it is vital to raise the general level of awareness of final clients as well as energy and engineering consultants.

According to international experience, the main issues in raising awareness of cogen are:

- → general understanding of the concept
- → range of applications (fuels, generation of cold, etc.)
- → good practice projects on national and international level.

Ministries and energy agencies should work on a cogen promotion package. The details of cogen promotion campaigns have to be well planned and target-group oriented. Promotion campaigns should be designed on the basis of a balanced mix of instruments and be properly funded. Typical activities include:

- → Establish advisory services on cogen issues including the recommendation of consultants and suppliers.
- → Set up a round table with suppliers and engineering firms. Suppliers and engineering firms should be involved in designing and implementing the campaign so that it can benefit from their knowledge of the markets. These commercial stakeholders also need to benefit from the campaign in order to increase their sales. Its tasks are to:
  - identify obstacles and need for action
  - develop joint promotion activities.
- → Promote the idea of cogen vis-à-vis policy-makers responsible for the development of financial incentive schemes and financing:
  - ensure that cogen is part of any new EE or RE promotion regulation
  - promote cogeneration among financing institutions and especially development financing institutions.
- → Engage in advocacy for cogen in electricity market regulations.
- → Identify possible pilot projects and develop support for pilot projects *[→ see 5.5.2]*.

Awareness-raising among energy users

- → Identify target groups (main market segments such as hotels, hospitals, chemical industry, etc.)
- → identify intermediaries (industrial associations, chambers of commerce, engineering associations, etc.)
- → use annual assemblies, working groups and other existing structures
- → develop specific cogen promotion events, include site visits and involve suppliers
- → write articles in industries' newsletters and journals
- → develop a promotion brochure and other material in association with intermediaries.

5.5.2 Development of Demonstration Projects

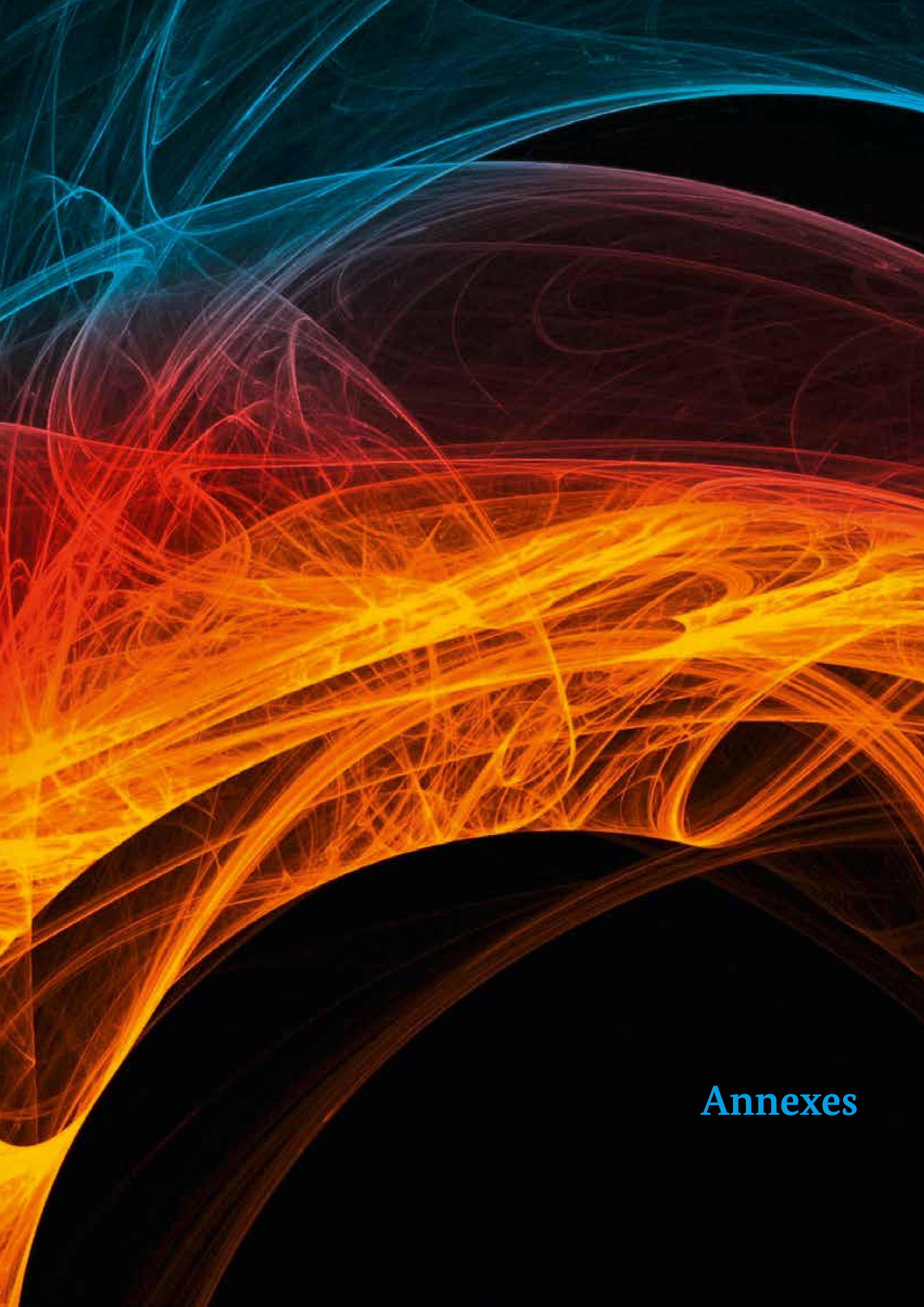
Decision-makers and especially engineers like to see proof that the technology will work in their country's conditions. Demonstration projects in the respective target countries are thus valuable and important.

So far inChile, South Africa and India GIZ has facilitated the development of pilot projects in various ways. One established example is the Trigen India Portal *[→ see ANNEX 1]*.

Development cooperation can work with local partners and decision-makers to support demonstration projects in a series of steps, typically:

- → initial assessment and motivation
- → prefeasibility check
- → feasibility phase: direct funding of consultants by development cooperation or facilitation of funding for feasibility studies or review of studies
- → facilitation of licensing and other regulatory issues
- → facilitation of funding, in some cases (co)funding of investment projects and/or monitoring.

Documentation and dissemination of the projects need to be well planned and resources must be allocated as appropriate. National road shows and exhibitions related to demonstration projects could also be initiated to ensure that experience with the technology and awareness of its benefits are spread across the country. If possible, provision should be made to hold seminars at the premises of the demonstration project.



Annexes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ANNEX 1: CASE STUDY PROJECTS

Overview of Case Studies

No.	Technology	Country	Plant capacity	Fuel	Case Study
1	Trigen (Absorption chiller)	South Africa	2,000 kW_{el}	Natural gas	MTN
2	Trigen (Absorption chiller)	India	1,000 kW_{el}	Natural gas	JPNATC Hospital
3	Gas Engine	Mexico	400 kW_{el}	Natural gas	Lagunero Alimentos
4	Gas Engine	Chile	140 kW_{el}	Natural gas	Hospital HUAP
5	Bio-Source	Germany	1,000 kW_{el}	Biogas	Im Brahm
6	Bio-Source	Honduras	1,200 kW_{el}	Biogas	HonduPalma
7	Network and Storages	Netherlands	> 6,000 kW_{el}	Various	UTES - Oostelijke Handelskade
8	Trigen (Absorption chiller)	Germany	1,100 kW_{el}	Natural gas	Heideblume Elsdorfer
9	Trigen (Absorption chiller)	Germany	694 kW_{el}	Natural gas	LVR Clinic
10	Trigen (Absorption chiller)	Germany	2,827 kW_{el}	Natural gas	Phoenix Contact

Off-grid gas-fired Trigeneration at MTN Communication, Johannesburg, S.A.

Background

In the West Rand of Johannesburg, the multinational communications company MTN runs an off-grid trigeneration plant together with City of Johannesburg. It is located at MTN´s head-office and produces electricity, heat and chilled water at the same time to partially meet MTN´s energy requirements. Construction of the plant started in October 2008 and in 2012 the trigeneration plant was registered as a carbon credit project under the United Nations Clean Development Mechanism (CDM) Programme. The French energy company EDF bought all carbon credits the plant will earn over ten years.

MTN´s building complex consists of offices, data centres and telecommunication switch facilities. Before the installation of the on-site trigeneration plant, the commercial site was provided with electricity from City of Johannesburg through the national grid; heat from conventional electric heaters and cooling were provided through conventional electric vapour compression chillers.

The 2 MW trigeneration plant will be supplemented by the already existing cooling and heating systems and the national electricity grid to fully meet the energy demand of MTN. The fuel used by the plant is methane-rich natural gas from the Temane gas field in Mozambique and is supplied via Sasol´s pipeline to Egoli Gas in Johannesburg.

Key facts		
Capacity	electrical thermal	$1{,}063\ kW_{el}$ $2 \times 1{,}200\ kW_{th}$
η (el)		≈ 35% (Absorption chiller)
Fuel		Natural gas
Consumption		$4{,}945\ m^3/a$
Electricity generation		18,623 MWh/a
Three absorption chillers		Lithium bromide as refrigerant
Cooling capacity		$2 \times 550\ kW_{th}$ $1 \times 450\ kW_{th}$
Heat exchanger		$100\ kW_{th}$

Achieved savings	
CO_2	2,000 t/a
Energy total	≈ 26 GWh/a
Grid electricity displaced	18.6 GWh/a
Replaced electricity cooling	5.4 GWh/a
Replaced electricity heating	0.876 GWh/a

Economics	
Investment	3.5 M EUR
Payback	< 5 years

Gas-fired Trigeneration – JPNATC Hospital, New Delhi, India

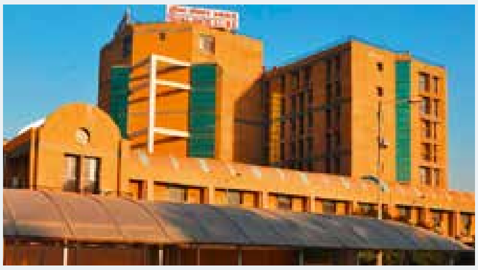
Background

The trigen pilot project “Jai Prakash Narayan Apex Trauma Center” (JPNATC) in New Delhi, was implemented through a co-operation initiative of the Government of India represented by the Bureau of Energy Efficiency (BEE) under the Ministry of Power (MoP) and the German government represented by GIZ to realize one of the first trigeneration projects in India in 2010.

Project impressions and key parameters are summarized hereby as follows.

The demonstration plant has three major components: gas engine, Vapour Absorption Machine (VAM) and an electrical chiller (Vapour Compression (VC)) for meeting balance cooling demand. The gas engine generates electrical power (347 kW) by utilizing 96 standard cubic meter (scm) gas per hour and the gases from the exhaust are passed through a VAM. The VAM through absorption refrigeration cycle produces chilled water at 7°C by utilizing heat from the exhaust gases and from High Temperature (HT) circuit; this further increases the efficiency.

Further information on the project might be retrieved from *www.trigenindia.com*. This includes amongst other information also video and image galleries.



Key facts	
Gas engine capacity	347 kW_{el}
η_{el} gas engine	≈ 40% (Absorption chiller)
COP VAM / VC	0.7 / 4.0
Chilled water temp. required	7 °C
Fuel	Natural Gas

Achieved savings	
Energy total p.a.	660,000 kWh
Energy costs p.a.	220,000 EUR
CO_2	1,700 t/a

Economics	
Investment	690,000 EUR
Payback	3.2 years

2

Natural gas-fired Cogeneration – Animal Food Industry, Torreon, Mexico

Background

The animal food manufacturer Lagunero Alimentos Balanceados Simón Bolivar in Torreon Mexico implemented a natural gas-fired cogen plant for this industrial application.

The plant features a 400 kW_{el} gas engine supplying 484 kW of thermal energy. The system provides a total efficiency of almost 90% with an electrical efficiency of close to 40%. The cogeneration module was supplied "all in one" container option. This layout minimizes CHP system floor space and allows for easy access and operability. Installation time was reduced to only three days followed by a very quick start-up.

The CHP module was integrated into the existing food processing & manufacturing and factory infrastructure.

Further information is provided by 2G Cenergy.
http://www.2g-energy.com/projects/intelimeter

Key facts	
Gas engine capacity	400 kW_{el} 484 kW_{th}
Fuel	Natural gas
Operational altitude	~ 1,200 m
Configuration	Container module
Electricity generation p.a.	3,320 MWh/a
Heat generation p.a.	4,017 MWh/a
Full load hours p.a.	8,300

Gas-fired Cogeneration – Hospital de Magallanes, Punta Arenas, Chile

Background

As part of the GIZ initiative Energía 4E, a German-Chilean co-operation project under participation of the Agencia Chilena de Eficiencia Energética (AChEE) implemented combined heat and power (CHP) and energy efficiency measures in public hospitals in Chile. In this regard experts from BEA conducted a feasibility study for the regional hospital in Punta Arenas, in the Region of Magallanes in the extreme south of Chile in 2012.

Part of the project was the installation of a natural gas-fired cogeneration plant (CHP) in order to save electricity consumption from the grid and increase at the same time the security of power supply. The gas engine provides an electrical output of 300 kW and a thermal power of 380 kW. The Magallanes region has in comparison to other regions very low natural gas prices, thanks to governmental subsidies.

Further information may be retrieved from GIZ or Berlin Energy Agency (BEA), e.g. *www.berliner-e-agentur.de/news*

Key facts	
Gas engine capacity	300 kW_{el} 360 kW_{th}

Achieved savings		
Thermal energy p.a.		30%
Electricity p.a.		74%
CO_2	Absolute p.a. Relative p.a.	1,000 t/a 35%

Economics	
Pay back	6 years

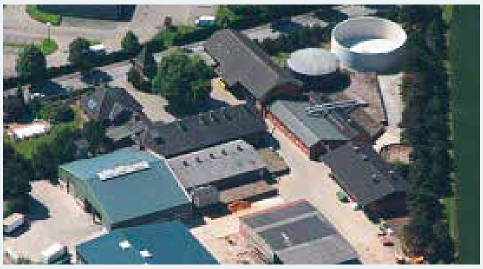
Biogas-fired Cogen and District Heating-Agro Sector, Im Brahm, Essen,Germany

Background

Due to European regulation requirements the working farm and recycling company Im Brahm in Essen-Kettwig, Germany, was bounded to reorganize their pig manure treatment and kitchen waste recycling business, as e.g. pigs were not allowed to be fed by kitchen waste anymore. As several biomass sources are available at low costs, they decided to utilize these sources for their own biogas production and cogen based energy supply in 2005.

The utilized feed stock for biogas production consists of co-ferments, such as kitchen wastes, fats and grains which are gathered from surrounding restaurants and canteen kitchens, as well as pig manure from the farm. The co-ferments are pretreated (hygienized) and mixed with manure. After pretreatment the organics are digested in two fermenters and the produced biogas is combusted in three 333 kW_{el} gas engines.

The produced electricity is fed to the public grid and remunerated according to the German Renewable Energy Act. The excess heat from cogeneration process is fed into a private heating grid to supply surrounding neighbors. Largest heat sink is a hotel complex, for which the heat is piped over a distance of 600 m.



Key facts	
Co-fermentation biogas plant	
Capacity gas engines	3 x 333 kW_{el}
Fuel	Biogas
Feed stock	Pig manure, kitchen waste, fats, grains
Fermenter capacity (concrete tank)	2 x 1,205 m^3
Construction	Krieg & Fischer Ingenieure GmbH
Plant operator	Im Brahm

Economics	
Investment (without enlargement in 2007/2011: 2nd digester and 3rd gas engine)	≈ 1 M EUR

Organic Waste gas-fired Cogeneration – Palm Oil Industry, El Negrito, Honduras

Background

HonduPalma, one of the leading palm oil manufacturers in Central America ordered a complete and highly efficient 1.2 MW 2G® biogas CHP cogeneration system. The fully integrated prime mover of the CHP System is a 2G® avus® 1200 with an MWM® core engine and a capacity of 1,200 kW_{el} or 9,960 MWh p.a. electrical power and 1,225 kW_{th} of thermal power. In addition to the CHP cogeneration unit, 2G CENERGY also supplied the complete gas treatment, including cooler, dryer / dehumidification, and the H_2S removal system.

The biogas energy conversion plant provides electricity to HonduPalma's factory and oil processing facility, as well as feeding surplus electricity into the utility grid. The thermal energy is fully utilized in the palm oil processing facility.

Further information is provided by 2G Cenergy.
www.2g-cenergy.com/biogas-project.html

Key facts	
Gas engine capacity	1,200 kW_{el} 1,225 kW_{th}
Fuel	Biogas
Fuel source	Anaerobic digestion of organic waste
Configuration	Container module
Heat utilization	Thermal distribution to oil processing facility
Electricity generation p.a.	9,960 MWh/a
Heat generation p.a.	10,167 MW/a
Full load hours p.a.	8,300

Sustainable Heating and Cooling by UTES - Oostelijke Handelskade Amsterdam

Challenge

Sustainable heating and cooling for the Oostelijke Handelskade project:

→ passenger terminal, office buildings, hotel, arts centre and apartments

→ various energy demand patterns

→ heat and cold demand 8.2 MW and 8.3 MW respectively

→ initiators: City of Amsterdam, Nuon, Novem.

Solution

Centralized aquifer thermal energy storage system in combination with decentralized heat pumps.

→ Balancing supply and demand of thermal energy:
1. within each building
2. between the buildings
3. using aquifer storage

→ seasonal storage of surplus heat and cold

→ heat pump capacity 6.5 MW, two warm and two cold wells (total flow rate 500 m³/h)

→ use of surface water to balance the system thermally.

Key data Aquifer Thermal Energy Storage (ATES) System (project fully operational):	
Heating capacity ATES	4.060 kW
Heat delivered by storage	2.760 MWh
Cooling capacity ATES	4.060 KW
Cold delivered by cold storage	2.290 MWh
Maximum flow rate groundwater winter	500 m³/h
Maximum flow rate groundwater summer	500 m³/h
Pumped quantity winter	400.000 m³
Pumped quantity summer	330.000 m³
Number of warm wells	2
Number of cold wells	2
Aquifer depth	90 – 180 m b.s.

Results

→ Energy saving 50% as compared to conventional heating and cooling system

→ reduction of energy losses due to low temperature heating and high temperature cooling

→ investment and operation by utility company (Nuon)

→ energy rates in conformity with conventional system

→ temporary surplus of cold:
- passenger terminal: occupancy different from prognosis, thermal insulation sub-optimal
- project still under construction (status 2002).

Gas-fired Trigeneration - Conracting Approach for Elsdorf Dairy, Germany

Background

The Heideblume dairy and Elsdorfer Feinkost AG (aggregate turnover of EUR 190 million and 340 employees) decided to redesign the energy supply infrastructure at their shared production site in order to increase energy efficiency and thus reduce energy related costs and CO_2 emissions. Besides a comprehensive energy saving program, the new cogen plant in combination with cooling chillers (tri-generation plant) was the core measure to achieve these goals. The project was implemented under an innovative, longterm Energy Supply Contracting (ESC) scheme with Hochtief Energy Management.

Further benefits of the implemented trigen plant:

→ complete use of the heat

→ supplies base load for the cold storage

→ use of tax benefits

→ reduction of CO_2-emissions

→ collaboration with an ESCo allows focusing on the core business.

Key facts	
Capacity cogen plant	1.125 MWel
Project duration	2006 - 2015

Achieved savings	
Energy savings (total)	12.6 GWh/a
Reduced costs of energy in % of total energy costs	501,000 EUR/a 12%
CO_2 reduction through trigen plant	4,700 t/a
CO_2 reduction incl. further energy saving measures	8,350 t/a

Economics	
Investment	600,000 EUR
Return on equity in first year	83%

Trigeneration and ESC & EPC Contracting LVR Hospital, Bonn, Germany

Background

The LVR-Clinic Bonn, Germany, has facilities for more than 800 patients in 27 buildings.

Driven by high energy costs, a contracting approach for electricity, steam, heating and cooling energy with ESCo Imtech Deutschland GmbH & Co. KG was implemented in 1998.

Heat was supplied former by an inefficient 21 MW high-pressure-steam boiler and electricity over the public grid. The annual primary energy consumption summed up to 45 GWh. To reduce both energy costs and related CO_2 emissions, a couple of measures were conducted within the energy supply (ESC) as well as performance and service (EPC) contracting:

- → conversion from the inefficient high-pressure-steam boiler to hot water supply
- → actual demand orientated design of the new high efficient tri-generation process
- → building a management system for energy controlling.

The contracting cooperation between LVR and Imtech was extended in 2010.

Key facts		
Cogen plant: 2 gas engines, power driven design		
Capacity	electrical thermal	2 x 347 kW_{el} 2 x 520 kW_{th}
Fuel		Natural gas
Temperature	inflow backflow	90-95°C 75-80°C
Absorption chiller capacity		1,000 kW_{th}
Steam boiler capacity		2 x 2,000 kW_{th}

Achieved savings	
CO_2 % total	> 50% 4,600 t/a
Operation cost reduction	≈ 40 %
Total energy cost reduction	≈ 25%
Downsizing of steam production capacity	11 MW (from 21 MW to 10 MW)
Energy consumption reduced by	1/3
Aggregated efficiency through cogen plant increased to	88%

Economics	
Investment	4.5 M EUR

Gas-fired Trigeneration, Automation Industry, Phoenix Contact, Germany

Background

Phoenix Contact AG is one of the leading industrial automation, interconnection and interface solutions manufacturer with more than 12,000 employees.

To increase energy efficiency and reduce energy costs Phoenix decided to redesign their energy supply and implement a new cogeneration plant in 2008. The companies' constant power, heating as well as cooling energy demand made new investments for cogen application attractive. In order to further increase full load hours of cogen operation and thus efficiency this approach incorporates an absorption chiller to produce cooling energy from cogen waste heat.

Before incorporation of cogen technology the companies' oil consumption summed up to 950,000 liters per year and its power consumption purchased from the grid to 40,000 MWh.

Key facts		
Cogen Plant consists of 2 x MTU gas engines as well as 1 x Jenbacher gas engine		
Capacity	electrical	$\sum$ 2.8 MW_{el} (1,166 kW_{el}, 772kW_{el}, 889 kW_{el})
	thermal	$\sum$ 3 MW_{th} (1. 272 kW_{th}, 861kW_{th}, 896 kW_{th}
η (el)		41% – 42.8%
η (th)		43.1% – 46.3%
Fuel		Natural gas
Full load hours (flh)		7,000 - 8,000 h/a
Cooling demand (flh)		> 2,000 h/a
Heating demand (flh)		> 4,000 h/a
Calculated operation lifetime		12 years

Achieved savings	
Oil	950,000 l/a
Energy savings	significant (n.a .)

Economics	
Payback	< 3 years

ANNEX 2: CO- AND TRIGENERATION DETERMINANT MAPPING AND CHECKLIST

As the planning and engineering of co- and trigeneration is complex, the following determinant mapping and checklist has been developed as an addition to the co- and trigeneration practical guide of the GIZ sector project 'Technology Cooperation in the Energy Sector' (funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)). It is aimed to serve as a decision matrix if and how these technologies can be introduced in a market and particularly which relevant aspects should be considered. The target group are experts working on national cogeneration promotion or cogeneration projects, especially in emerging and developing economies.

The matrix is intended to be instrumental in assessing the framework conditions for co-gen/trigen on both national macro level (enabling environment) and project micro level, and in that way finally helping to decide whether or not a project scenario is adequate for application of the technology. The determinants listed in the matrix are closely related to the structure of the guide's *Chapter 4* and quickly indicate critical aspects as well as feasibility by setting markers for each aspect of co-/trigeneration applications.

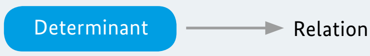
Annex 2 should be used to analyse and identify necessary market conditions to support the use of cogen/trigen application. Based on the results of the analysis, an advisory approach for developing cooperation projects can be developed. Further support for such an assessment will be provided by the GIZ sector project 'Technology Cooperation in the Energy Sector'.

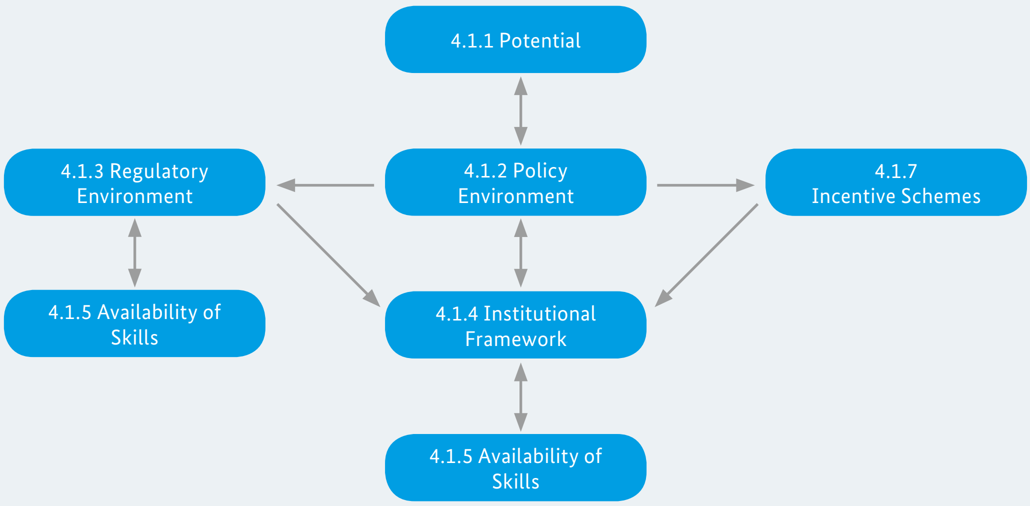
This decision matrix comprises two sections *(4.1 und 4.2)*, which reflect the above mentioned distinction between the macro and micro level as presented in *Chapter 4*. Also, each section consists of two elements, a determinant mapping and a checklist for determinants.

4.1 Mapping of determinants on the national macro level (enabling framework)

Relation model: Illustrating interdependencies between determinants

How to read the mapping





4.1 Checklist for determinants on the national macro level (enabling framework)

Overview of the enabling framework

Determinant and section	Segment
4.1.1 Potential	
Industry *Potential can be found in the following industries*	Coal mining, peat extraction, extraction of oil/natural gas etc.
	Ore mining, mining stone & earth, other mining
	Food, beverage and tobacco processing
	Textiles and clothing sector
	Wood and wood products (excluding furniture manufacturing)
	Paper, publishing, printing
	Coke, refined petroleum products, manufacture of nuclear fuel
	Chemical industry
	Manufacture of rubber and plastic products
	Glass, ceramics, stone processing and quarrying
	Metal production and processing, manufacture of metal products
	Mechanical engineering
	Vehicle construction
Buildings *Rising standards of living leading to*	More living room per capita
	Increased thermal comfort
	Greater demand for services (hotels, hospitals etc.)
	Demographic development/population growth
	Climate change and resulting higher temperatures
Cooling demand *Potential can be found in the following segments*	Agroindustry
	Cold houses in supply chain
	Dairy industry
	Slaughterhouses
	Data centres
	Pharmaceutical industry
	Hospitals
	Hotels
4.1.2 Policy Environment	
Energy efficiency (EE)	Existence and ambition of national EE policy framework
	Consideration of EE in industry and/or other segments relevant to cogeneration
	Consideration of cogeneration within that framework
	Reduction of Transmission & Distribution losses as an objective
Electricity sector development	Unbundling and liberalisation of electricity generation with free access to grid
	Wheeling to willing buyer (with regulated and thus reasonable wheeling charges)
Promotional policy	Feed-in tariff/bonus per kwh
	Tendering
	Capital subsidy

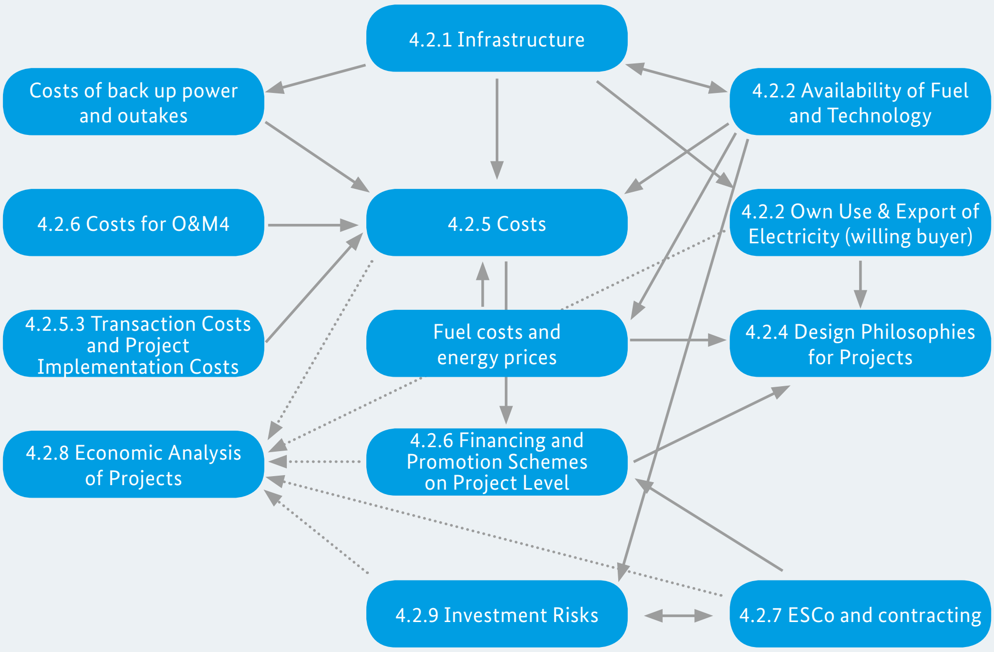
Determinant and section	Segment
4.1.3 Regulatory Environment	
Licensing for electricity generation	Self-generation
	Export above a certain specified installed capacity, how easy or cumbersome, etc.
Grid code	Technical requirements for connection of generator
	Practical handling in terms of delays until a connection is granted or costs charged
Grid connection of cogeneration *Payment for the reinforcement of grids*	If the installation of cogeneration is a greenfield installation
	Levels of costs charged
	Delays
Tariff regimes *Regarding reactive power, contracted power/backup power, etc.*	Ease of changes or interpretation of contract and tariff conditions to the disadvantage of the cogenerator by the utility company
4.1.4 Institutional Framework	
Ministry of electricity/regulator	Enhancement of framework conditions
Ministries of economic or industrial development	Promotion of and subsidies for cogen
Development banks or local banks (with support from development banks)	Financing of cogen by adequate credit lines, inclusion in clean/green financing schemes
Electricity utility(ies)	Understanding cogen, promotion of cogen within the framework of national policies, possibly act as ESCo
Energy (promotion) agency	Promotion towards users, training, framework conditions
Consulting engineers	Awareness, training, clarification of ESCo role
Industry associations	Advocacy and promotion
Partly: individual investors from industry/residential sector	Investment (debt/equity) in cogen projects
4.1.5 Availability of Technologies and Skills	
Challenging planning fields	Trigeneration
	Waste heat recovery
	Biogas and biomass utilisation
Critical issues for engineering, procurement and construction (EPC)	Local and regional availability of skilled manpower
	Transparency and competition among suppliers
Operation & maintenance (O&M)	Even if training and online support can be assured by the supplier, O&M know-how needs to be available on site on a broad enough level
	The specific requirements for O&M skills need to be compared to the level of technical competence and skills in related areas
Decision-makers in government departments	Awareness/understanding of cogen/trigen in principle and its multiple benefits on the macro level
Energy economists working in EE policy and electricity sector reform	Knowledge about the economic and environmental benefits, as well as the economic mechanisms and drivers of cogen/trigen and its potential contribution to national energy supply capacity
Agents in cogen/trigen promotion units (energy agencies or similar)	Understanding of the technology in detail
Commercial and development bankers	Understanding of costs and benefits of cogen/trigen
	Understanding of ESCo/IPP models
Energy users in government and private sector	Understanding of the rationale and financial benefits on the micro level
Staff of (local) banks/financial institutions	Basic cogen/trigen know-how for evaluating bankability of projects

Determinant and section	Segment
4.1.6 Value of Capacity to System	
Two different types of dispatchability can be differentiated	Adaptation to time of day/load by differentiating the price to be paid for electricity fed back into the system according to contractually arranged dispatchability, e.g. for 15 minute intervals, or for participation in secondary reserve for larger cogeneration units
	Participation in short-term energy markets as they are emerging, e.g. day-ahead market
From a technology point of view the following conditions must be met	Communication technology for remote control of engine is available
	Forecasting and control software is installed and functional
	Weather forecast must be improved to provide information on the future load demand at consumer level
	The operation of cogeneration engines must be as flexible as possible
	Gas engines for example can in most cases be operated at 50–60% of their rated capacity, and in case of emergency their full capacity can easily and rapidly be activated
	If the system/market requires the cogen unit to produce electricity, the waste heat can be stored by appropriate storage technology such as large hot water tanks
Appropriate regulations	The fixing of minimum/maximum load to participate
	The prearrangement/lead time in the timing when power is required (1 day ahead)
	An appropriate price fixing mechanism (e.g. by auction)
4.1.7 Incentive Schemes	
Capital subsidies (per kW installed)	Availability of such instruments in the country/ region?
Subsidised interest loans	
Tax incentive schemes including exemption from customs duties	
Feed-in tariffs	
Bonus schemes	
(remuneration per kWh provided)	
Net metering	
CO_2 tax rebates	

4.2 Mapping of determinants of successful cogeneration projects

Relation model: Illustrating interdependencies between determinants

How to read the mapping



4.2 Checklist for determinants of successful cogeneration projects

Overview of projects

Determinant and section	Segment
4.2.1 Infrastructure	
External determinants *Electricity and gas grid*	Access to the electricity grid
	Feasibility of expansion/connection to the electricity grid (<2 km distance)
	Acceptable costs of expansion/connection to the electricity grid
	Acceptable timing of expansion/connection to the electricity grid
	Access to the gas grid
	Feasibility of expansion/connection to the gas grid (< 2 km distance)
	Acceptable costs of expansion/connection to the gas grid
	Acceptable timing of expansion/connection to the gas grid
Internal determinants *Availability of sufficient space for:*	Installation of cogen/trigen technology
	Handling of required (fuel) resources (e.g. biomass storage)
	(If necessary) further treatment processes
	Logistical infrastructure
	Absence of noise prevention requirements
4.2.2 Availability of Fuel and Technology	
Fuel supply risks *Absence of likely threats of:*	Decreasing (volatile) industrial production level and thus waste production
	Crop failures
	Increasing demand for scarce biomass
	Increase in prices as suppliers see value of biomass
Technology risks *According to value chain: availability of cogen/trigen supply and service level/ quality and related pricing*	Sufficient expertise in planning
	Sufficient expertise in engineering, procurement and construction (EPC)
	Sufficient expertise in operation & maintenance (O&M)
	Acceptable pricing for planning
	Acceptable pricing for engineering, procurement and construction (EPC)
	Acceptable pricing for operation & maintenance (O&M) *[→ see 4.2.6]*
4.2.3 Own Use and Export of Electricity (Willing Buyer)	
Cogeneration benefits *Power and heat 'marketing' options:*	Feed-in to the grid (with or without remuneration)
	Net metering
	Wheeling through the grid to willing buyers
Restrictions that lower profits *Absence of barriers:*	No (prohibitive) wheeling charges in case of willing buyers
	No bottlenecks in grid
	No restricting licensing obligations
4.2.4 Costs	*Comparative cost level for:*
CAPEX	Cogen/trigen units
	Cogen/trigen equipment (if not included in unit costs)
	Planning (consulting, engineering)
	Implementation

Determinant and section	Segment
4.2.5 Fuel Costs and Energy Prices	
Fuel costs	Low cogen/trigen fuel (gas) price
Electricity tariff	High electricity price
'Spark spread'	Large difference between fuel and electricity prices
4.2.6 Costs for O&M	
	Availability of cogen/trigen manufacturer's service providers for O&M
	Availability of full service/maintenance contracts
	Costs are in a range of 1.5% – 3.0% p.a. of total capex
4.2.7 Cost of Backup Power and Outages	
	Existence of diesel gensets for backup power
	Frequent utilisation of diesel generators for auxiliary or even regular power generation
	Upcoming rehabilitation of backup power facilities
4.2.8 Transaction Costs and Project Implementation	
Financing	*[→ see 4.2.6]*
Licensing	Allowance obligation for cogen/trigen plant (power generation)
	Registration obligation for the plant
4.2.9 Promotion Schemes and Subsidies	
Incentives *Availability of:*	Low-interest loans
	Capacity grants
	Feed-in tariffs (incl. feed-in premium on top of stock/market prices)
	Fiscal incentives (customs and tax reliefs or exemptions)
Further support schemes *Availability of:*	Support-related research and development (R&D) and international collaboration
	Promotion of pilot models
	Integration of lessons learned from pilot projects and existing models into infrastructure development plans
4.2.10 Financing	
Availability of:	Debt financing sources
	Project finance
	ESCo/PPP models
Competitive pricing of:	Debt financing sources
	Project finance
	ESCo/PPP models (especially energy supply contracting (ESC))
4.2.11 ESCo and Contracting	
Availability of:	Consultancy (service) providers
	Technology suppliers of hardware for increasing energy efficiency
	ESCos who provide energy supply contracting (ESC)
	Long-term contracting periods (approx. > 10 years)
4.2.12 Economic Analysis of Projects	

Determinant and section	Segment
4.2.13 Investment Risks	
Technical risks *Absence of following risks:*	Plant
	Operation & Maintenance
	Volatility in fuel quality
	Peripheral equipment
Economic risks *Absence of following risks:*	Fuel availability, e.g. volatile formation or production of biomass
	Development of fuel prices, e.g. increased gas prices
	Volatile development of electricity prices, especially decreasing electricity prices (reduced spark spread of cogen fuel)
	Strongly rising electricity tariff after cogen/trigen implementation (due to reduced power consumption from the grid)
	Off-taking and remuneration risks (due to legal changes, e.g. feed-in tariffs, wheeling; uncertain PPAs, insolvency of private off-takers etc.)
Risk mitigation strategy *Availability of:*	Outsourcing of risks (technical, operational, economic), e.g. ESCo/contracting such as energy supply contracting (ESC)
	Hedging of risks, e.g. fuel hedging, currency swaps, etc.
4.2.14 Design Philosophies for Projects *[→ see ANNEX 4 Questionnaire for a detailed list]*	
Availability of detailed information such as load profiles for e.g.:	Electricity demand
	Space heating demand
	Process heat demand
	Process cooling demand
	Cooling (building air conditioning) demand
	Production shifts and process(es)
	Temperature requirements
	Storage facilities


MAIN PANEL
BUS BAR CHAMBER

ANNEX 3: INTERNATIONAL COGENERATION POLICY PRACTICE

Overview of Cogen/Trigen Promotion Policies per Country

Country	Brazil	Germany	India/ West Bengal	Tunisia
Liberalization				
Export options for electricity (net metering → wheeling → stock exchange)	Net metering for biomass < 1 MW_{el} in general, incl. biomass based cogen	Fully liberalized market		
Cogen promotion instruments				
Explicit cogen policy	No	Yes		
Tax Incentives	Yes (State Sao Paulo only: biomass based cogen equipment is exempted from the state VAT)	Yes	Yes (for biomass based cogen only, dependent on state)	
Legal Facilitation	No	Yes	Yes (for biomass based cogen only, dependent on state)	
Capital Subsidies	No	Yes	Yes	Yes (amongst others for cogen)
Feed-in tariff	No	Yes (RE based cogen only)	Yes (for biomass based cogen only, dependent on state	Yes (based on gas prices and day/ night times)
Feed-in Bonus	No	Yes (max. 5.41 ct/kWh)		
Others	**Exemption from grid usage fees** for electricity generation with biomass (based cogen)		**Certificates** in West Bengal State; (Cogen is defined as RE source) "The west Bengal Electricity Regulatory Commission (WBERC) has mandated 4% of total procurement of electricity from RE sources as Renewable Purchase obligation (RPO) by 2012-13 for the next 10 years."	

International Cogen Policy Practice

Brazil

Brazil – Key Facts [73, 74]	
Capital	Brasilia
Official language	Portuguese
Currency	Real (BRL)
Population in millions (2012)	198.66
Area in km²	8,459,420
Gross Domestic Product (PPP) in billion US$ (2012)	2,247,745

Brazil's decreasing hydro generation capacities and at the same time significantly increasing peak demand with growth rates of 4–5% p.a. are leading to pressure to modify the energy matrix.

Brazil – Energy Market [75]	
Total electricity production (2014)	531,758 GWh
Total generation capacity installed (2014)	116.8 GWel
Share of electricity generation (2014)	Hydropower: 80.6%; biofuels: 6.1%; natural gas: 4.7%; nuclear: 2.9%; oil: 2.7%; coal and peat: 2.3%; wind: 0.05%; other sources: 0.01%
Electricity market faces capacity concerns	Although hydro-electric power is a very cost-effective source, in 2001 droughts caused power shortages and energy rationing. This situation was attributed to the lack of investment within the sector. Rationing lasted until May 2002. The consumption of electricity was drastically reduced, resulting in major economic consequences. The estimated economic cost of the rationing was close to 3% of GDP.
Development of electricity demand until 2020	Assuming an annual GDP growth rate of 4.7% through to 2020, Brazil's projected electricity consumption will be 730,000 GWh, while installed capacity is expected to grow to 171 GW by 2020. Total investment required under the government's 2011–2020 Power Expansion Plan stands at R$190 billion (approx. EUR 55.7 billion)[76] to bring an additional 62,000 MW of power generation capacity to the grid.
Increasing electricity peak demand until 2020	4–5% p.a.

73) Federal German Statistical Office (destatis - Statistisches Bundesamt), 2014

74) CIA - The World Factbook, 2014

75) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

76) 1 Euro = 3,4107 BRL, retrieved from European Central Bank, *www.ecb.europa.eu* on 03.16.2015

Brazil – Energy Regulation [77]	
Energy regulation	**National Electric Energy Agency (ANEEL):** Regulation of prices and other aspects of the electricity industry, concession granting for the operation of electricity companies, supervision of concession agreements. **National Agency of Petroleum, Natural Gas and Biodiesel (ANP):** Responsible for all matters relating to the regulation of the upstream and downstream oil, natural gas and biodiesel sectors, including an oversight role in the oil and gas bidding rounds.
Ownership of electricity generation capacities	In Brazil, large government-controlled companies dominate the electricity sector. • **Eletrobrás** holds about 40% of the generation capacity. • Currently, about **27% of the generation assets are in the hands of private investors**. • Considering the plants under construction, as well as the concessions and licenses already granted by ANEEL, this figure is **expected to grow up to 31% in the medium term and to reach almost 44% over 5–6 years**.
Private sector access to the energy market **Existence of two parallel markets**	Two-market design launched in 2004 • 'Regulated' pool that buys power from generators and shares the costs between distributors under set prices; • 'Free market' where distributors and generators can negotiate their own contracts. Large consumers can choose between buying directly in the 'free market' and buying indirectly in the 'regulated' pool through a distributor. There are two major energy **trading environments:** • The Regulated Contracting Environment, where distribution companies need to purchase energy from generators through **public auctions under cap prices set by government (reverse bidding scheme)**; • **Free Contracting Environment, where free consumers (non-captive) and generators can freely negotiate their own bilateral contracts.**
Transmission	Until 2007, transmission was almost exclusively under government control. Under the new sector regulatory model, there are **about 40 transmission concessions in Brazil**. Most of them are still controlled by the government, with subsidiaries under federal company **Electrobras holding 69% of total transmission lines.**
Distribution	In 2010, there were **63 utilities with distribution concessions**, all independent of state control. As of 2007, about **64% of Brazilian distribution assets were controlled by private-sector companies.**

Brazil – Energy Efficiency and Cogen Policy [78]	
National Energy Plans	The Brazilian National Energy Plan for 2008–2017, recently published by the Ministry of Mines and Energy, aims to increase energy capacity from 99.7 MW to 154.7 MW. The National Energy Plan for 2030 *(http://www.epe.gov.br/PNE/Forms/Empreendimento.aspx)* sets forth long-term government strategies to meet the country's energy needs in a sustainable way.
Energy Efficiency Policy	In October 2011, the Ministry of Mines and Energy (MME) reported the approval of the 'National Plan for Energy Efficiency - PNEf - Premises and Basic Guidelines' by Ordinance No. 594. Both primary energy intensity and industrial energy intensity are significantly below world averages, and 109 TWh of electricity savings are forecast under the PNEf by 2030.
Explicit Cogen Policy	None

77) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

78) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

Meaning of Renewable Energy for Cogen in Brazil

Apart from Brazil's energy efficiency and currently not intensively pursued cogen policy, the country is already a world-leader in renewable energy and is set to almost double its output from renewables by 2035, maintaining their 43% share of the domestic energy mix. Among the fuels with a rising share in the power mix, onshore wind power, which is already proving to be competitive, **natural gas and electricity generated from bioenergy take the lead.**[79]

This also reveals strategic opportunities for cogen technology and correspondingly the implementation of cogen promotion instruments. Currently cogen benefits from the following promotion scheme, designed for electricity generation from renewable energy sources:

Brazil – Beneficial Cogen Promotion Instruments	
Net metering	For biomass < 1 MWel in general, including biomass-based cogen
Exemption from grid/ system usage fees	Biomass-based electricity generation is exempted from grid usage fees
VAT exemptions for	Hydropower: 80.6%; biofuels: 6.1%; natural gas: 4.7%; nuclear: 2.9%; oil: 2.7%; coal and peat: 2.3%; wind: 0.05%; other sources: 0.01%
Cogen equipment on state level (Sao Paulo)	Equipment required for treatment of and electricity generation from biogas are exempted from the state value added tax, also covering equipment for biomass-based cogen equipment.
Exclusive cogen promotion	None

Cogen Applications in Brazil

The core application for cogen technology in Brazil is found within the sugarcane industry, as 7 out of 10 cogen plants are fired by cane biomass. Natural gas-fired cogen applications account for 11% of the installed cogen plants. The comparatively small numbers of cogen plants (approximately 1,000 cogen plants are installed all over Brazil) indicate the huge potential for cogen technology in Brazil as decentralised electricity production within Brazil's huge sugarcane industry based on waste from ethanol production and bagasse utilisation becomes increasingly attractive when the current capacity concerns within Brazil's electricity sector are taken into account. [80]

79) International Energy Agency (IEA), 2013

80) Data Cogen, 2014

International Cogen Policy Practice

Germany – Key Facts [81, 82]	
Capital	Berlin
Official language	German
Currency	Euro (EUR)
Population in millions (2014)	80.9
Area in km²	357,340
Gross Domestic Product (PPP) in billion EUR (2014)	2,903.4

Germany – Energy Market [83, 84]	
Total electricity production (2014)	610,000 GWh
Electricity production by cogen (2012)	95 GWh
Cogen share of total electricity production (2012)	16% [85]
Share of electricity production (2014)	Lignite (25.6%), hard coal (18%), nuclear (16%), gas (9.6%), oil (0.8%), others (4.4%), renewables (25.8%)
Total generation capacity installed (2014)	192 GW
General information	In May 2011 the German Government decided to close down its 17 nuclear plants by 2022 at the latest in the wake of the nuclear disaster in Fukushima, Japan.

Germany – Energy Regulation [86]	
Energy regulation	**Federal Network Agency (BNetzA):** Promotes effective competition in the energy sector and ensures non-discriminatory access to networks. In addition, the Federal Network Agency is responsible for implementing the Grid Expansion Acceleration Act. Federal Ministry for Economic Affairs and Energy (BMWi): **The Federal Ministry for Economic Affairs and Energy has the lead responsibility for the formulation and implementation of energy policy.**

81) Federal German Statistical Office (destatis - Statistisches Bundesamt), 2014

82) CIA - The World Factbook, 2014

83) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

84) Agora Energiewende, 2015

85) Öko-Institut e.V., 2014

86) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

Germany – Energy Efficiency Policy and Promotion of Renewables [87, 88]	
Renewable Energy Sources Act	The Renewable Energy Sources Act from 2000 has the aim of enabling young technologies such as wind and solar energy to enter the market with support provided by fixed tariffs, a purchase guarantee and priority feeding-in of renewable electricity into the grid.
Energy Efficiency Policy	**National Action Plan on Energy Efficiency (NAPE) 2014:** The aim is to achieve a 20% reduction in primary energy consumption by 2020 and 50% by 2050 compared to 2008.
Private-sector access to the energy market	Since the initial liberalisation and deregulation of the German power markets in 1998, driven by the implementation of the Electricity Directive, diversity within the group of energy producers has continuously increased. Transmission network operators are obliged to grant non-discriminatory network access to all market participants.
Transmission and distribution	The German electrical grid is operated by four separate transmission network operators. Regional or local distribution networks are operated by a large number of vertically integrated utilities.

Cogen Capacity in Germany [89]

As a result of the current cogen law, the share of net electricity generation attributable to cogeneration increased from 13.6% to 16.0% between 2003 and 2012. The net electricity produced from cogeneration has been continuously expanding, and increased by about 17 TWh in the period between 2003 and 2011. The level of electricity production by cogen was 95 TWh in 2012.

Cogen Promotion in Germany

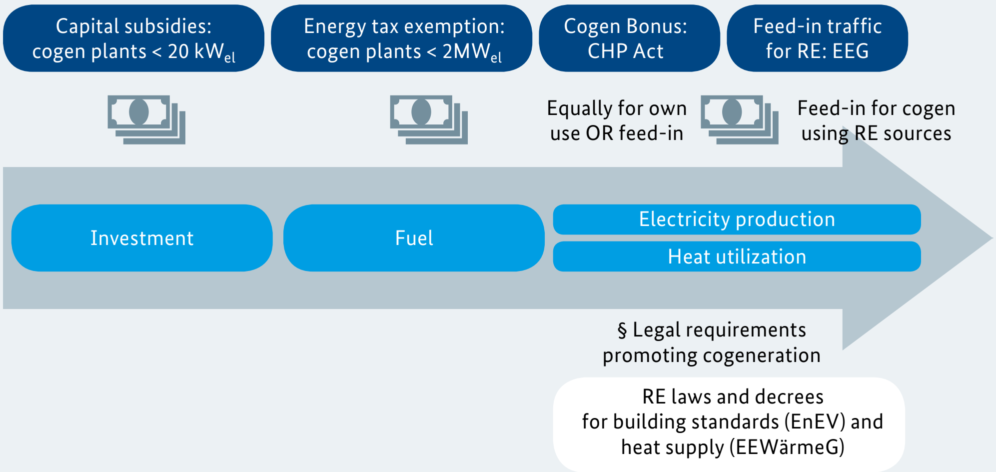
According to the revised CHP Act from 2012, 25% of total electricity production in Germany shall be based on cogeneration by 2020. This shall contribute to the NAPE goal to reduce primary energy consumption by 20% by 2020, and to the national goal to save 40% of CO_2 emissions by 2020 compared to 1990. To achieve this goal, a twofold promotion scheme has been established, comprising a bonus to be paid for every kWh produced (paid as part of the electricity tariff by all electricity consumers) and a capital subsidy for small cogen plants (paid by the Federal Government). In addition to this, operators of cogen plants may benefit from various other instruments, which are outlined in the following. The figure on the next page illustrates the variety of different cogen promotion instruments:

87) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

88) German Fedral Ministry for Economic Affairs and Energy (BMWi), 2015

89) Öko-Institut e.V., 2014

Figure 1A Framework of Cogen Promotion Policy in Germany



Bonus for Cogeneration of Electricity

The bonus system applied in Germany covers installed capacities from 50 kW$_{el}$ to 2 MW$_{el}$ and a duration of 10 years or 30,000 hours of full utilisation (hfu). The bonus is paid on top of the baseload price on the EEX in Leipzig and is also granted if the electricity is used for the operator's own purposes. The bonus structure is shown in the following table.

Bonus Scheme

Capacity	Bonus on stock exchange prices	Duration
≤ 50 kW	5.41 €ct/kWh	10 years or 30,000 hfu*
> 50 - 250 kW	4.0 €ct/kWh	30,000 hfu
> 250 - 2,000 kW	2.4 €ct/kWh	30,000 hfu
> 2 MW	1.8 €ct/kWh	30,000 hfu

** hfu = hours of full utilisation*

Capital Subsidies for Small Cogen Plants

The capital subsidies for small cogen plants < 20 kW$_{el}$ consist of a basic subsidy and efficiency bonuses for particularly efficient plants. The basic subsidy is calculated as follows.[90]

Subsidy Calculation for Small Cogen Plants

Capacity	Incentive per kW$_{el}$
<1 kW$_{el}$	1,900 €/kW$_{el}$
1 - 4 kW$_{el}$	300 €/ kW$_{el}$
4 - 10 kW$_{el}$	100 €/kW$_{el}$
10 - 20 kW$_{el}$	10 €/kW$_{el}$

A **heat efficiency bonus** of 25% of the basic investment subsidy is granted for cogen plants that are equipped with an exhaust gas heat exchanger and that are connected to a hydraulically balanced heating system.

90) German Federal Office for Economic Affairs and Export Control (Bafa), 2015

Cogen plants that comply with certain efficiency factors *[→ see table below]* receive an **electric efficiency bonus** of 60% of the basic subsidy. Both types of efficiency bonus can be combined.

Electric Efficiency Bonus Requirements

Capacity	Electrical efficiency factor
<1 kW_{el}	> 31%
1 - 4 kW_{el}	> 31%
4 - 10 kW_{el}	> 33%
10 - 20 kW_{el}	> 35%

Furthermore, operators of cogen plants with a capacity < 2 MW_{el} (for natural gas: all cogen plants) are allowed to claim a **repayment of energy taxes**. The amount of the repayment depends on the fuel used:

Repayment of Energy Taxes [91]

Fuel	Repayment
Natural gas	0.55 €ct/kWh
Liquid gas	6.06 €ct/kg
Light heating oil	6.135 €ct/lt
Other heating oils	2.5 €ct/kg

Further Promotion of Cogen Technology

Germany – Further Cogen Promotion	
Renewable Energy Sources Act (EEG)	As an alternative to promotion under the CHP Act, the operator of a biomass/biogas cogen plant can choose a **feed-in tariff** under EEG 2014. The feed-in tariffs range between 5.85 €ct/kWh_{el} and 23.73 €ct/kWh_{el}, depending on the capacity of the plant and type of biomass utilised.
Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG)	For new buildings the German Government prescribes the use of renewable energies for heating and cooling purposes. The degree of heating and cooling demand that has to be covered depends on the type of renewable energy utilised (15% for solar thermal energy, 50% for biomass/biogas). Due to its high efficiency and CO_2-saving potential, cogen technology is accepted as an equal substitute under the renewable energy sources obligation of the EEWärmeG if at least 50% of the heating and cooling needs are covered by cogen.
Instruments on State Level	There are **further capital incentives** available on the state level, such as in North-Rhine Westphalia (NRW), where additional capital subsidies are granted for highly efficient cogen plants with a capacity < 50 kW_{el}.[92] The subsidies range from EUR 1,425 (1 kW_{el}) to EUR 16,150 (50 kW_{el}). An accumulation of incentives on federal and state level is possible.

91) German Energy Tax Act (EnergieStG), 2015

92) The EnergyAgency.NRW, 2015

International Cogen Policy Practice

India – Key Facts [93,94]	
Capital	New Delhi
Official language	Hindi, English
Currency	Indian Rupee (INR)
Population in millions (2012)	1,236.34
Area in km^2	3,287,500
Gross Domestic Product (PPP) in billion US$ (2012)	1,880,100

Germany – Energy Market [95,96]	
Total electricity production (2012)	1,054,000 GWh
Total generation capacity installed (2013)	229 GW_{el}
Development of electricity demand	In 2011, India was the world's third largest consumer of energy, and its rapid economic and population growth have driven steady increases in energy demand. This development is expected to continue.
Electricity market faces capacity concerns	The IEA predicts that by 2020, 327 GW of power generation capacity will be needed, which would imply an addition of 16 GW per year.

India – Energy Regulation [97,98]	
Energy regulation	**Central Electricity Regulatory Commission (CERC):** Formulation of National Electricity Policy and Tariff Policy; promotion of competition, efficiency and economy in the activities of the electricity industry; promotion of investment in electricity industry. **State Electricity Regulatory Commissions (SERCs):** Determination of intra-state transmission and retail tariffs. Tariff regulation and promotion of CHP, and electricity generation from renewables.
Ownership of electricity generation capacities	The Indian electricity sector is dominated by governmental facilities at both central and state level. The share of electricity generation is: • 39% governmental at central level • 45% governmental at state level • 16% private sector The private sector contributes only 18.74% of all grid-connected capacity
Private sector access to the energy market	**Electricity Act 2003:** The Act provides for non-discriminatory open access to the transmission network, and the de-licensing of generation, including captive power generation. The Act also recognises trading as a distinct activity. Such provisions provide an enabling environment for development of the bulk power market in India. Phased open access of the distribution network by respective state utilities provides consumer choice, subject to open access regulations, including the cross-subsidy surcharge
Distribution	Geographic distribution of power generation capacity in India is unevenly dispersed with a mismatch in supply and demand in different regions. In India, the transmission and distribution (T&D) system is a three-tier structure comprising distribution networks, state grids and regional grids. The central transmission utility, PowerGrid India, operates transmission lines at 800/765kV, 400kV, 220kV & 132kV, as well as at over 500kV HVDC.

93) Federal German Statistical Office (destatis - Statistisches Bundesamt), 2014

94) CIA - The World Factbook, 2014

95) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

96) Bridge to India Pvt. Ltd. , 2014

97) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

98) Central Electricity Regulatory Commission (CERC), 2014

Explicit Cogen Promotion in India [99]

During the last decade India has introduced several policies and regulations to promote CHP on both federal and state level. The result is a combination of various regulations, feed-in tariffs, tax incentives and capital subsidies for bagasse and non-bagasse CHP which often differ from state to state. The focus is clearly set on biomass and bagasse-based cogen applications.

India – Beneficial Cogen Promotion Instruments	
Cogen based on conventional fuels	Capital subsidies on the federal level ranging from 5% to 25% of the cogen project costs
Cogen based on biomass fuels (federal level)	Capacity grants to bagasse-based cogeneration projects in sugar mills and distilleries, varying per region and ownership structure *(Tables: Grants for private sugar mills (differentiated by region) and Grants for cooperative/public sector sugar mills)*
Cogen based on biomass fuels (state level)	• 5% reimbursement on loans for plant construction and capital cost for bagasse-based CHP is available in Uttar Pradesh State • Tax incentives for investments in bagasse-based cogen technology in Uttar Pradesh State, exemptions from stamp duties and land registration fees for land purchase to be used for cogeneration as well as exemptions from the administrative charge on molasses for cogeneration units on new or existing sugar mills • Feed-in tariffs in many states *(Table: "Biomass based Cogen Promotion Policy per State")*
Certificates in West Bengal state	(Cogen is defined as RE source) 'The West Bengal Electricity Regulatory Commission (WBERC) has mandated 4% of total procurement of electricity from RE sources as a Renewable Purchase Obligation (RPO) by 2012–13 for the next 10 years.'

Grants for private sugar mills (differentiated by region)	
In North East Regions, Sikkim, Jammu & Kashmir, Himachal Pradesh and Uttaranchal	INR 1.8 m x (capacity in MW)^0.646
In all other states	INR 1.5 m x (capacity in MW)^0.646

Grants for cooperative/public sector sugar mills	
40 bar to 60 bar	INR 4 m per MW of surplus power
60 bar to 80 bar	INR 5 m per MW of surplus power
80 bar & above	INR 6 m per MW of surplus power

99) Information and tables based on (International Energy Agency (IEA), 2014

Biomass-based Cogen Promotion Policy per State [100]

State	Feed-in tariffs for biomass cogeneration (INR per kWh)
Andhra Pradesh	3.48 (cogeneration)
Bihar	4.25 (existing cogeneration projects) 4.46 (new cogeneration projects)
Gujarat	4.55 (cogeneration), accelerated depreciation for first 10 years
Haryana	3.74 (cogeneration), 3% escalation, base year 2007-08
Maharashtra	4.79 (cogeneration)
Madhya Pradesh	3.33 to 5.14 3% to 8 % escalation p.a. for 20 years
Odisha	4.87 3% escalation variable cost, base year 2011-12
Punjab	4.80 (cogeneration) 5% escalation, base year 2011-12
Tamil Nadu	4.37 to 4.49 (cogeneration) 2% escalation, base year 2010-11
Uttarakhand	3.12 (for new cogeneration projects)
Uttar Pradesh	4.29 (for existing projects) 4.38 (for new projects) 4% escalation p.a., base year 2006

Cogen Capacity in India [101]

There are no recent studies on or estimates of the current total cogen installed capacity in India. The Indian Government reported a cumulative cogen capacity of 3.0 GW based on bagasse and non-bagasse biomass by the end of 2013. In a 2008 publication, the IEA estimated that the total cogen installed capacity in India in 2005 was 10 GW_{el}. District cooling (DC) in India is limited to a few existing and proposed projects accounting for 69 MW capacity, though there is potentially scope for application on a much wider scale if the necessary framework conditions are established.

100) 1 euro = 66.6332 INR, retrieved from European Central Bank, *www.ecb.europa.eu* on 16 March 2015

101) International Energy Agency (IEA), 2014

International Cogen Policy Practice

Tunisia – Key Facts [102, 103]	
Capital	Tunis
Official language	Arabic
Currency	Tunisian Dinar (TND)
Population in millions (2012)	10.94
Area in km²	163,610
Gross Domestic Product (PPP) in billion US$ (2012)	105.3

Tunisia – Energy Market [104]	
Total electricity production (2011)	15,150 GWh
Total generation capacity installed (2011)	4.03 GW
Development of electricity demand	Demand for energy in Tunisia is rising as a result of the growing economy. Compared to its neighbouring countries, domestic fossil energy sources in Tunisia are limited. In 2009, the peak load in public supply was 2,660 MW, representing an increase of 193 MW or 7.8% compared to 2008.

Tunisia – Energy Regulation [105]	
Energy Regulation	**TMIE: The Ministry of Industry and Energy** is the main governmental actor in the energy sector. The Directorate General for Energy of the Ministry of Industry and Energy is responsible for energy infrastructure planning and the implementation of national energy policy. **National Agency for Energy Management (ANME):** Accountable to the Ministry of Industry and Energy. Its tasks comprise translating ministerial policy directives into practice, including safeguarding Tunisian energy supplies in the long term.
Ownership of electricity generation capacities	Until 1996, the monopoly on electricity generation and marketing was held by the Société Tunisienne d'Electricité et du Gaz (STEG). Since then, liberalisation of the energy market has taken place, and the market was opened for independent power producers (IPPs). However, with a market share of 88%, STEG is still the largest player in the power market.
Private sector access to the energy market	In 1996 the government withdrew STEG's monopoly for power generation in a move to allow private power generation projects. STEG is still the sole organisation responsible for transmission and distribution (and retains control of the existing power generation facilities).

Explicit Cogen promotion in Tunisia

The overall technical and economic potential for cogeneration in the industrial sector in Tunisia is estimated to be approximately 250 MW_{el}. To mobilise this potential, a short- and medium-term development programme was launched by the government and a task force was established, comprising all stakeholders from the energy sector, namely the Ministry of Industry and Energy, the national utility STEG and the national energy agency ANME, working on the following lines:

102) Federal German Statistical Office (destatis - Statistisches Bundesamt), 2014

103) CIA - The World Factbook, 2014

104) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

105) reegle Information Gateway for Renewable Energy and Energy Efficiency, 2014

- improvement of the regulatory and administrative framework for cogeneration
- sensitisation and information of all stakeholders
- identification of cogeneration projects in the industrial sector
- support for industries in setting up their cogeneration projects
- capacity-development of all actors such as consultants, technical experts and industrial managers in all aspects of cogeneration.

So far, 50 engineers from industry and 40 consultants have been trained. The task force has identified about 40 industrial enterprises suitable for cogeneration with a capacity of 110 MW and a saving potential of about 90,000 toe/year, which could reduce CO_2 emissions by 200,000 t/year. The overall investment has been estimated at EUR 80 million with a payback period of about 4 years.

Tunisia – Cogen Promotion Instruments [106]	
Feed-in tariffs	Bonus system for surplus electricity from cogeneration sold to STEG, based on the price of natural gas (as electricity tariffs are quickly changing), taking into account four different tariff slots: • Daytime: 0.8 x gas price (€ct/kWh) + 16 • Peak time: 1.03 x gas price (€ct/kWh) + 100 • Evening: 1.0 x gas price (€ct/kWh) + 38 • Night: 0.72 x gas price (€ct/kWh)
Action plan launched in 2005	• Support in all technical and financial issues concerning cogeneration • Organisation of technical workshops for each sector • Set-up of credit lines on favourable terms to finance cogeneration projects • Set-up of a service unit covering all aspects of cogeneration to improve acceptance of this new technology among industrial decision-makers.

Cogen Capacity in Tunisia

Fifteen cogeneration units had been installed by 2013, with a total capacity of 56.6 MW_{el}, saving 40,244 toe of primary energy per year. The total investment was about EUR 30 million, with the payback periods varying between 3 and 5 years.

Selected realised CHP projects in Tunisia in 2013 [107]

Company	Industry	Capacity [MW_{el}]	Produced electricity [MWh/a]	Saving CO_2 [ton/a]	Technology
Carthago Ceramic	Building materials, ceramic and glass industry	5	40,062	10,115	Gas turbine
Sotipapier	Paper	10	52,852	15,530	Gas turbine
Maklada MPS	Mechanical and electrical industry	4	20,077	6,334	Gas engine
Briqueterie Bir 'Chergua	Building materials, ceramic and glass industry	5	29,117	10,624	Gas turbine
Complexe El Mazraa	Agroindustrial industry	5	31,624	3,634	Gas turbine

106) Société Tunisienne d'Electricité et du Gaz (STEG), 2015

107) DFIC, 2014


П.17
П.18

ANNEX 4: QUESTIONNAIRE

The following questionnaire is part of the GIZ practical guide 'Cogeneration & Trigeneration – How to produce energy efficiently'. It serves as an initial assessment of the preconditions and potential for applying co- or trigeneration projects at a certain production site or other facility.

The target group which can make use of this data collection form are experts working on national cogeneration promotion or cogeneration projects, especially in emerging and developing economies.

Further support for such an estimation of cogen/trigen project potential is planned to be further developed and provided by the GIZ sector project 'Technology Cooperation in the Energy Sector' (funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)).

The data collection form can also be made available as a basic Excel tool.

1. General Information

1. General and Contact Information		Date:	
Company Name:			
Business sector:			
Main Products:			
Staff, ca.:			
Revenues [in M]:			
Notes:			
Address:			
Contact Person:		Tel:	
Position:		Mobil:	
		Fax:	
		Email:	

2. Operational Information					
Operating hours per day					
Operating days per week					
Operating weeks per year					
Operating hours per year					
Operation time regular extra	Monday	time time	until	Friday	time time

3.	General Questions	yes	no	to clarify until (date)
3.1	Do you have an energy management system?	☐	☐	☐
	If yes, which one?			
3.2	Does documentation exist about energystems/-components?	☐	☐	☐
3.3	Are single consumer measured?	☐	☐	☐
	If yes, how many?			
3.4	Are monthly values available for electric consumption?	☐	☐	☐
3.5	Are hourly values / load curves available for electric consumption?	☐	☐	☐
3.6	Are monthly values available for heat consumption?	☐	☐	☐
3.7	Are hourly values / load curves available for heat consumption?	☐	☐	☐
3.8	Are monthly values available for chill consumption?	☐	☐	☐
3.9	Are hourly values / load curves available for chill consumption?	☐	☐	☐
3.10	Is a chill storage installed?	☐	☐	☐
3.12	Were efficiency activities conducted in the last years?	☐	☐	☐
	If yes, which?			
3.13	Which different energy consuming processes are established?			
3.13.1	Process 1			
	Which hot water temperature is needed?	°C		
	Which cold water temperature is needed?	°C		
	Which process steam conditions (pressure/temperature) are needed?	bar °C		
3.13.2	Process 2			
	Which hot water temperature is needed?	°C		
	Which cold water temperature is needed?	°C		
	Which process steam conditions (pressure/temperature) are needed?	bar °C		
3.13.3	Process 3			
	Which hot water temperature is needed?	°C		
	Which cold water temperature is needed?	°C		
	Which process steam conditions (pressure/temperature) are needed?	bar °C		

4. Planed investments (changes) in energy efficiency and energy supply system:	
Existing connection to the gas grid?	yes ☐ no ☐
If not, what is the approx. distance to the gas grid [in km]?	

2. Energy-related information

5. Energy Import					Date:		
Energy Source		**Amount**	**Energy content *)**	**Energy MWh/a**	**Peak demand kW; t/h; l/h; Nm³/h**	**Energy Costs _______ /a**	**Notes**
1	Electricity	MWh/a	-				
2	Natural Gas	MWh(HHV)/a					
3	LPG	l/a					
4	Light fuel oil	l/a					
5	Heavy fuel oil	t/a					
6	Hard coal	t/a					
7	Lignite	t/a					
8	Process steam	t/a					
9	District heating	MWh/a	-				
10	Hot water	MWh/a	-				
11	Cold water	MWh/a	-				
12							
13							
14							

6. Energy Production						
Energy Source		**Amount**	**Energy content *)**	**Energy MWh/a**	**Peak demand kW; t/h; l/h; Nm³/h**	**Notes**
1	Electricity	MWh/a	-			
2	Process steam	t/a				
3	Hot water	MWh/a	-			
4	Cold water	MWh/a	-			
5	Process chill	MWh/a	-			
6						
7						
8						

7. Comments, additional information

*) Lower heating value (LHV), specific heat-/energy content (e.g.: kWh/kg; kWh/l; kWh/Nm³; kWh/t)

LINK LISTS – COGEN TECHNOLOGIES

The following link lists provide additional information on *Chapter 2*, CO- AND TRIGENERATION TECHNOLOGIES AND THEIR APPLICATION.

Waste Heat Recovery by Organic Rankine Cycle (ORC)

For detailed information on different technologies and the general principle of ORC as well as suppliers, the following link list may provide further insights.

ORC Link Collection		
Information	**Link comment**	**Hyperlink**
Technology, business cases, manufacturers, market reports videos	The U.S. Waste Heat to Power (WHP) industry association offers information on waste heat utilisation, including ORC, systems and technologies as well as case studies and reports.	*www.heatispower.org*
ORC market potential in India	The Indo-German Energy Forum (IGEF) recently (29 Aug. 2014) provided a detailed Market Potential Study for Organic Rankine Cycle Technology in India.	*www.energyforum.in/publications.html*
Video on ORC technology	The Energy Agency of North Rhine-Westphalia provides illustrative animated videos (in German) on biomass power plants utilizing ORC technology.	*http://www.energieagentur.nrw/bioenergie/animationen*
Principle of ORC and applications	Wikipedia shows a wide range of application for ORC engines.	*https://en.wikipedia.org/wiki/Organic_Rankine_cycle*

Fuel Cells

The following links may provide further insights into different technologies and the general principle of fuel cells as well as suppliers.

Fuel Cell Link Collection		
Information	**Link comment**	**Hyperlink**
Technology, business cases, manufacturers, market reports	Fuelcells.org is an information platform operated by the non-profit organisation Breakthrough Technologies Institute and provides detailed information on its platform on fuel cell technology, business cases, fuel cell supplier lists per country, etc.	*www.fuelcells.org*
Technology, history, case studies, industry reviews, glossary	Fuel Cell Today by the Johnson Matthey plc group is an information platform providing information on the basic functional principle of fuel cells and their various technologies.	*www.fuelcelltoday.com*
Technology, applications, products	Nedstack, a PEM fuel cell manufacturer from the Netherlands, provides detailed information on the basic functional principle of fuel cells, their various technologies and applications.	*http://www.nedstack.com/about-us/company-profile*
Principle of ORC and applications	Wikipedia shows a wide range of application for ORC engines.	*https://en.wikipedia.org/wiki/Organic_Rankine_cycle*

Biosources

For further information on the biogas production scheme and corresponding cogen technology, please refer to the following additional biogas links.

Biogas Link Collection		
Information	**Link comment**	**Hyperlink**
Technology, news, market and research, institutions	The private company AB ENERGY SPA provides a comprehensive video collection on biogas-related issues and the services it offers, including its own youtube video channel.	*www.biogaschannel.com*
Technology, market (EU focus), recent developments, EU companies	The European Biogas Association (EBA) provides information on European national organisations, scientific institutes and companies. A comprehensive collection of specialised websites on biogas, bio-methane and statistics incl. e.g. maps of biogas/bio-methane plants.	*www.european-biogas.eu*
Technology, market news, feedstock, outlook for biogas industry, German companies	The German biogas association provides recently published studies and detailed information (also international markets) on biogas technology and different types of feedstock as well as the current status of and outlook for biogas applications and industry, e.g. in Kenya (Biogas Journal October_2014).	*www.biogas.org*
Video on biogas production	The Energy Agency of North Rhine-Westphalia provides animation videos (in German) on biogas production technology (agro-industry).	*http://www.energieagentur.nrw/bioenergie/filme-zum-thema-biomasse*

Networks for Heating and Cooling

Further information on heating and cooling networks is available on the International Energy Agency website *www.iea-dhc.org*, for example.

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